Standing Panel on Impact Assessment

CGIAR

Shining a Brighter Light: Comprehensive Evidence on Adoption and Diffusion of CGIAR-related Innovations in Ethiopia

Frederic Kosmowski, Solomon Alemu, Paola Mallia, James Stevenson, Karen Macours

October 2020

SPIA Synthesis Report

The Standing Panel on Impact Assessment

The Standing Panel on Impact Assessment (SPIA) is an external, impartial panel of experts in impact assessment appointed by the System Council and accountable to it. SPIA is responsible for providing rigorous, evidence-based, and independent strategic advice to the broader CGIAR System on efficient and effective impact assessment methods and practices, including those measuring impacts beyond contributions to science and economic performance, and on innovative ways to improve knowledge and capacity on how research contributes to development outcomes.

https://cas.cgiar.org/spia

Recommended Citation

Kosmowski, F., Alemu, S., Mallia, P., Stevenson, J., Macours, K. (2020). *Shining a Brighter Light: Comprehensive Evidence on Adoption and Diffusion of CGIAR-Related Innovations in Ethiopia*. Rome: Standing Panel on Impact Assessment (SPIA).

Authors

Frederic Kosmowski, Solomon Alemu, Paola Mallia, James Stevenson, Karen Macours

Editor

Heidi Fritschel

Design and layout

Macaroni Brothers/Luca Pierotti

Cover Photo: Farmer works in restored terraced fields
in the Yewol watershed highlands, Ethiopia.
Credit: WLE/M. Ayene

Shining a Brighter Light: Comprehensive Evidence on Adoption and Diffusion of CGIAR-related Innovations in Ethiopia

Frederic Kosmowski, Solomon Alemu, Paola Mallia, James Stevenson, Karen Macours

Contents

Abbreviations

ACGG	African Chicken Genetic Gains
AGP	Agricultural Growth Program
AGSS	Agricultural Sample Survey
AI	artificial insemination
ARC	Agricultural Research Center
AR4D	agricultural research for development
ARARI	Amhara Regional Agricultural Research Institute
ATA	Agricultural Transformation Agency
BBM	broad bed maker
BoA	Ethiopian Bureau of Agriculture
AWM	agricultural water management
CA	conservation agriculture
CAPI	computer-assisted personal interviewing
CASI	conservation agriculture–based sustainable intensification
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
CRP	CGIAR Research Program
CSA	Central Statistical Agency
DSM	Direct Seed Marketing
DTMZ	drought-tolerant maize
EA	enumeration area
ECX	Ethiopian Commodity Exchange
EIAR	Ethiopian Institute of Agricultural Research
ESE	Ethiopian Seed Enterprise
ESIP	Ethiopian Sorghum Improvement Project
ESS	Ethiopian Socioeconomic Survey
ETB	Ethiopian birr
EQUIP	Strengthening Smallholder Livestock Systems for the Future
FAO	Food and Agriculture Organization of the United Nations
FCA	Federal Cooperative Agency

FDRE	Federal Democratic Republic of Ethiopia
FEED	Feed Enhancement for Ethiopian Development
GDP	gross domestic product
GOE	Government of Ethiopia
GTP	Growth and Transformation Plan
HAPP	Holland Africa Poultry Partners
HOPE	Harnessing Opportunities for Productivity Enhancement
ICRAF	International Centre for Research in Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
ILCA	International Livestock Center for Africa
ILRI	International Livestock Research Institute
ILSSI	Innovation Lab for Small-Scale Irrigation
IMF	International Monetary Fund
IPMS	Improving the Productivity and Market Success of Ethiopian Farmers
ISSD	Integrated Seed Sector Development
IWMI	International Water Management Institute
IWUA	irrigation water users association
LFSDP	Livestock and Fisheries Sector Development Project
LIVES	Livestock and Irrigation Value chains for Ethiopian Smallholders
LMP	Livestock Master Plan
LSMS	Living Standards Measurement Study
M&E	monitoring and evaluation
MoA	Ministry of Agriculture
MOE	market-oriented extension
NARS	national agricultural research system
NBE	National Bank of Ethiopia
NBDC	Nile Basin Development Challenge
NGO	nongovernmental organization
NRM	natural resource management
NuME	Nutritious Maize for Ethiopia
OARI	Oromia Agricultural Research Institute
OFSP	orange-fleshed sweet potato

OPV	open-pollinated variety
ORARI	Oromia Regional Agricultural Research Institute
PATSPO	Provision of Adequate Tree Seed Portfolio in Ethiopia
PDC	Planning and Development Commission
PSNP	Productive Safety Net Program
QDBH	Quality Diet for Better Health
QPM	Quality Protein Maize
R4D	research for development
RLLP	Resilient Landscapes and Livelihoods Project
SACCOs	savings and credit cooperatives
SASAHA	Sweet Potato to Action for Security and Health in Africa
SARI	South Agricultural Research Institute
SDG	Sustainable Development Goal
SHARE	Support to the Horn of Africa Resilience
SIMLESA	Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa
SLM	sustainable land management
SLMP	Sustainable Land Management Projects (I, II)
SNNPR	Southern Nations, Nationalities, and Peoples' Region
SPC	seed producer cooperative
SPIA	Standing Panel on Impact Assessment
SWC	soil and water conservation
T4FS	Trees for Food Security
TSC	tree seed center
QDBH	Quality Diet for Better Health
UNDP	United Nations Development Program
USAID	United States Agency for International Development
WB	World Bank
WOCAT	World Overview of Conservation Approaches and Technologies
WUA	water users association

Acknowledgments

This report has relied directly on the cooperation of at least 90 researchers and government officials across multiple institutions in Ethiopia who provided information in interviews, shared data, and checked facts. We thank them all, especially the Ethiopian Central Statistics Agency and the World Bank Living Standards Measurement Study (LSMS) team, for the productive collaboration at every stage in this process. We are deeply grateful for the time and forbearance of the thousands of Ethiopian citizens who patiently responded to the Ethiopian Socioeconomic Surveys in 2016 and 2019. Without those data this report would not be possible.

Executive Summary

In recent decades the agricultural sector in Ethiopia has seen a sustained period of growth, which is believed to have contributed in turn to economic growth and poverty reduction. The country is undergoing a structural transformation and a gradual process of modernization in agriculture, supported by government programs. In this context, this report provides new nationally representative micro-level evidence of the adoption and diffusion of agricultural innovations, focusing in particular on those innovations that can be linked to CGIAR research.

The report presents an unprecedented stocktaking of all CGIAR-related innovations in a given country as well as new estimates of adoption of those innovations from a nationally representative dataset generated through a partnership among the Ethiopian Central Statistics Agency (CSA), the World Bank Living Standards Measurement Study (LSMS) team, and the CGIAR Standing Panel on Impact Assessment (SPIA). Ethiopia was chosen for this exercise because it is a hotspot of CGIAR research, with almost all the CGIAR centers represented in Addis Ababa.

The report documents the reach of CGIAR-related agricultural innovations in a comprehensive manner across the core domains of CGIAR research activity: animal agriculture; crop germplasm improvement; natural resource management; and policy research. In order to identify the right innovations to collect data on, SPIA conducted more than 90 interviews with CGIAR research leaders, scientists, government officials, and colleagues from the Ethiopian Institute for Agricultural Research (EIAR), all the while compiling documented evidence to support claims made by these key informants. The output of that work is a stocktaking of 52 agricultural innovations and 26 claims of policy influence.

Quantitative evidence on the adoption of 18 of these innovations was obtained through the incorporation of measurements of the reach of these innovations in the Ethiopian Socioeconomic Survey (ESS), a regionally and nationally representative panel survey of households. We also document the reach of two government programs on which CGIAR research had an influence. We report some data from the third wave (ESS3, carried out in 2015/16), but our major focus is on ESS4 (2018/19). Guided by the output from the stocktaking exercise, we incorporated a range of novel data collection instruments—new survey questions, data collection protocols featuring visual aids, and collection of samples of plant tissue for subsequent varietal identification by DNA fingerprinting. This exercise necessarily focused on innovations with distinctive features that could be observed through a survey with household and community-level modules and for which accurate measurement was deemed possible.

Through the combination of these two processes, we find that between 4.1 and 11.0 million Ethiopian households have been reached by agricultural innovations linked to CGIAR research. The upper-bound figure of 11 million, representing 78.7 percent of all rural households in Ethiopia, should be interpreted as the "potential reach" of CGIAR in the country. It is based on an estimate of the number of households reporting technologies or practices that have been subject to CGIAR research efforts, even if it does not imply that all these households de facto have benefited from a specific innovation regarding those technologies or practices that can be attributed to CGIAR. The upper bound hence captures the number of households that in theory could benefit from CGIAR research efforts (a notable example being soil and water conservation methods). Restricting the focus to those innovations that exhibit distinguishable markers of CGIAR efforts in the ESS—improved barley, maize, sorghum, sweet potato, and kabuli chickpea type—gives the lower-bound figure of 4.1 million Ethiopian households. This is a lower bound given our inability to incorporate a number of households reached by CGIAR-related innovations that could not be measured in the ESS; bean and wheat varieties were particularly relevant omissions.

In addition to the new evidence on the share and the number of households adopting each of these innovations covering the different CGIAR research domains, the report also presents: (1) data on who the adopters are (using socioeconomic characteristics collected through the detailed modules of the ESS); (2) maps and spatially explicit data highlighting where the adopters are; and (3) evidence of synergies between different innovations (as measured by the share of households jointly adopting different combinations of innovations together).

The strategy of bringing improved measurement of agricultural innovations into the ESS is partly justified by the fact that the rich socioeconomic data allow us to characterize who the adopters are, a key input for understanding whether the innovations can contribute to the various impact areas targeted by CGIAR. The data show there is substantial heterogeneity in the adopting households when comparing across different CGIAR-related innovations. Varieties with CGIAR germplasm, as well as certain natural resource management (NRM) practices, are equally likely to reach smallholders and larger farmers. Large ruminant crossbreeds (as well as other NRM practices) are more likely to be adopted by farmers with larger landholdings. Irrespective of the specific measure of poverty that is used, the data show that poorer households may be equally or even more likely to adopt a number of the NRM practices than wealthier households. The opposite holds true for improved barley varieties. The age of the head of the household does not seem to be a major factor shaping adoption, and only a few innovations have a statistically significant correlation with female management: improved poultry is more likely to be adopted by female managers, whereas improved large ruminants and conservation agriculture are all correlated negatively with female participation in farm activities.

In terms of geographic spread, the main regions of Amhara; Oromia; Southern Nations, Nationalities, and Peoples' Region (SNNPR); and Tigray appear to be relatively well covered, with reach demonstrated in each and some innovations more prominent in some regions than in others. Although there are a large number of *woredas* in which research activities took place, we could find no significant association between the location of research and dissemination activities and adoption in ESS4.

Because the returns to certain innovations can depend on whether the household manages to simultaneously adopt other innovations, the report also analyzes whether it is indeed the same households that are adopting multiple complementary innovations. It is these types of synergies that partly motivate CGIAR's system-level research. Exploiting the unique advantage of having measurements of multiple CGIAR-related innovations in the same dataset, we show, however, that there is no clear consistent evidence of synergies between innovations; if anything, there are quite a few combinations for which it appears that innovations are substitutes rather than complements. This is consistent with different innovations reaching different types of households (farmers) rather than a subset of farmers being reached by many of the innovations.

Finally, the data also allow us to demonstrate the value of obtaining objective data on crop varietal identification by examining the misclassification that would have resulted from using self-reported data for improved maize. Using self-reported data from farmers alone would have underestimated the adoption of improved maize varieties by 15 percentage points and would have led to erroneous conclusions about the characteristics of the adopters. Building on these insights and looking toward the future, we also identify priorities for future data collection efforts.

Overall, the stocktaking and the empirical evidence allow us to demonstrate that many different CGIAR-related innovations are being adopted by different types of households and in different regions of Ethiopia. In some cases, diffusion of new innovations has gone remarkably fast. The empirical evidence further shows there are large differences in the number of households reached by different innovations, with only a few innovations reaching multiple millions of households. This is not surprising, given the inherently uncertain nature of research and adoption pathways. Moreover, the large variation in households' internal and external constraints, and in the context and agroecological conditions they face in different parts of the country, likely make adoption of certain innovations more attractive for some households, while other innovations could be more appealing for others. Considering the different innovations together, as we do in this report, shines new light on the implications of this heterogeneity and notably shows that the reach of the portfolio of innovations can be much larger than the reach of each of them considered separately. The data we report can help explain these patterns and guide future research, development, and scaling efforts.

Selling maize at the market in Addis Ababa, Ethiopia.
Credit: CIMMYT/A. Wangalachi

Introduction

Agriculture is a major source of income and employment in low- and middle-income countries. Policymakers have long sought to reproduce the agricultural productivity gains of the Green Revolution—a technology package centered on new high-yielding varieties that increased agricultural productivity in Asia from the late 1960s—in sub-Saharan Africa. Increased agricultural productivity through the diffusion of innovations has the potential to contribute to economic growth, food security, and poverty alleviation, particularly in sub-Saharan Africa (World Bank, 2020). Furthermore, the goals of social inclusion and women's empowerment, adaptation to climate change, and improved environmental health all need to be addressed simultaneously, as spelled out in the United Nations' Sustainable Development Goals (SDGs). CGIAR, a global agricultural innovation network of 15 research centers employing more than 8,000 scientists, researchers, technicians, and staff, seeks to use agricultural research for development (AR4D) to help reduce poverty, enhance food and nutrition security, and improve natural resources and ecosystem services.

Within CGIAR, the Standing Panel on Impact Assessment (SPIA) has a mandate to expand and deepen evidence on the impact of CGIAR research investments and their potential to contribute to these goals. Documenting the reach of the innovations resulting from CGIAR research investments is one of the pillars of SPIA's strategy for impact assessment (SPIA, 2020). However, the process of collecting evidence on the reach of CGIAR-related innovations is a necessary but far from sufficient step. The evidence collected must be accurate, be at the relevant scale, and be available at a reasonable cost (Stevenson et al., 2019). To document the adoption and diffusion of agricultural innovations related to CGIAR research, SPIA has developed a comprehensive, country-level framework (Kosmowski et al., 2019b).

There are several good reasons why the country level is an appropriate scale for improving data collection efforts. First, CGIAR research effort is not randomly distributed around the globe. Some countries have long-standing partnerships with CGIAR (by virtue of hosting centers and/or large research projects) and are therefore disproportionately more likely to benefit from CGIAR research outcomes. Among the total 200 million households targeted in the design of the current phase of CGIAR Research Programs (CRPs), more than half are located in just six countries: Bangladesh, Ethiopia, India, Nigeria, Tanzania, and Uganda. These countries all host offices and significant research capacity of several CGIAR centers. Nationally representative surveys allow researchers to document the extent to which innovations have scaled up—information that is policy-relevant for the host government as well as for donors. Another advantage of collecting nationally representative data is that it allows linking with other sources such as project-monitoring data or remote-sensing data. Finally, by partnering with national statistics agencies, we are able to institutionalize data collection approaches for the long run.

This report is the first to present SPIA's efforts to document the reach of CGIAR-related innovation in one country, Ethiopia.[1] Ethiopia, a landlocked country with a 2019 population of 112 million, has made significant progress in reducing poverty and promoting growth since

[1] Similar efforts are ongoing in Uganda, and SPIA hopes to expand its approach to Asian countries in 2021.

the early 2000s. The Ethiopian agricultural sector is on a transformational trajectory. Since the establishment of the International Livestock Centre for Africa (ILCA) 40 years ago (now the International Livestock Research Institute, or ILRI), the country has hosted offices and researchers from 11 of the 15 CGIAR centers, and 12 CRPs work in Ethiopia.[2] The Central Statistical Agency of Ethiopia has conducted regular agricultural surveys since 1999. The Ethiopian Socioeconomic Survey (ESS), a nationally representative household survey with a strong focus on agriculture, collects data in partnership with the World Bank Living Standards Measurement Study (LSMS) team. These foundations make Ethiopia an excellent candidate for piloting SPIA's country-level approach.

The first step was to systematically document the innovations to which CGIAR research had contributed. This was done using desk reviews and interviews with CGIAR scientists and staff from the national agricultural research system (NARS) and government agencies in Ethiopia. The results of this stocktaking exercise are available here, in a document that provides details on 52 innovations that could be documented over the 1999-2019 period. These innovations include the core domains of CGIAR research—animal agriculture, crop germplasm improvement, and natural resource management—and some cut across these domains. The stocktaking also documents 22 cases in which CGIAR research and expertise can be linked to national (or regional) policy design, without claiming attribution.

The stocktaking exercise was used to identify which innovations were expected to have scaled up nationally. In collaboration with the World Bank LSMS team and the Ethiopian Central Statistical Agency (CSA), SPIA developed data collection protocols for a subset of these innovations, and the protocols were subsequently integrated into nationally representative household surveys (ESS). This exercise necessarily focused on innovations with distinctive features that could be observed through a survey with household- and community-level modules and for which accurate measurement was deemed possible.[3]

In interpreting the results of this exercise, two things should be noted about the role of CGIAR research. First, not all research contributes directly toward a specific innovation. Rather, most research effort helps explain the biophysical context for agricultural production, works on problems much further upstream in the research process, or helps explain the lived experience of people working in agriculture. Separating out the research efforts that contributed to a particular set of innovations from those that did not is an impossible job (Elven & Krishnan, 2018). Second, among the innovations identified, there are different levels of attribution to CGIAR. The strongest links occur where objective measurement demonstrates a CGIAR contribution—for example, DNA fingerprinting can identify specific varieties of barley, maize, and sorghum that have been bred using CGIAR-related germplasm. At the next level in the

[2] Agriculture for Nutrition and Health (A4NH); Climate Change, Agriculture and Food Security (CCAFS); Grain Legumes and Dryland Cereals; HumidTropics; Forests, Trees and Agroforestry (FTA); Livestock and Fish; Managing and Sustaining Crop Collections (Genebanks); Maize; Policies, Institutions and Markets (PIM); Roots, Tubers and Bananas (RTB); Water, Land and Ecosystems (WLE); and Wheat.

[3] Several innovations did not fit these criteria and thus could not be integrated. The most common reason for excluding an innovation from data collection efforts was the expectation—informed by interviews and/or other supporting evidence—that diffusion (to date) was unlikely to have been broad enough to measure at a national scale. Because we partnered with CSA, we had to be cognizant of the need to avoid adding additional unnecessary burdens to what are already long and complex survey instruments. Furthermore, some innovations required different methods that could not be integrated into the ESS. Section 9 returns to priorities for integrating additional innovations in future surveys.

hierarchy are innovations that can be unambiguously identified through low-cost visual aid protocols, such as orange-fleshed sweet potato or improved kabuli-type chickpea. For the remaining innovations there is no guarantee that what is observed can be reliably attributed to CGIAR research activities. In such cases—for instance, large ruminant crossbreds or soil and water conservation structures—we report not the number of households reached, but the number of households that may potentially be reached by CGIAR research targeting those innovations (that is, an upper bound). Both of the points taken together—the difficulty of costing the research and the varying levels of attribution to CGIAR—imply that the data reported in this study cannot be used for comparing the costs of the underlying research to the benefits realized.

Prior validation of the data collection method was an important part of the process. Visual-aid protocols were demonstrated to have reasonable accuracy—superior to farmer self-reported data, for instance, on the identification of orange-fleshed sweet potato (Kosmowski et al, 2019a) or crop residue coverage (Kosmowski et al., 2017)—and these tools were used to obtain observable measures of CGIAR-related innovations in the nationally representative data. For varietal identification of most other crops, the gap between farmer's self-reported data and the results of DNA fingerprinting has been established in several contexts and for a variety of crops (e.g. Wossen et al., 2017; Le et al., 2019; Wineman et al., 2020). DNA fingerprinting was therefore used as the method of choice, making Ethiopia the first country in which objective measures of crop varietal adoption were incorporated in a large, institutionalized, nationally representative socioeconomic survey.

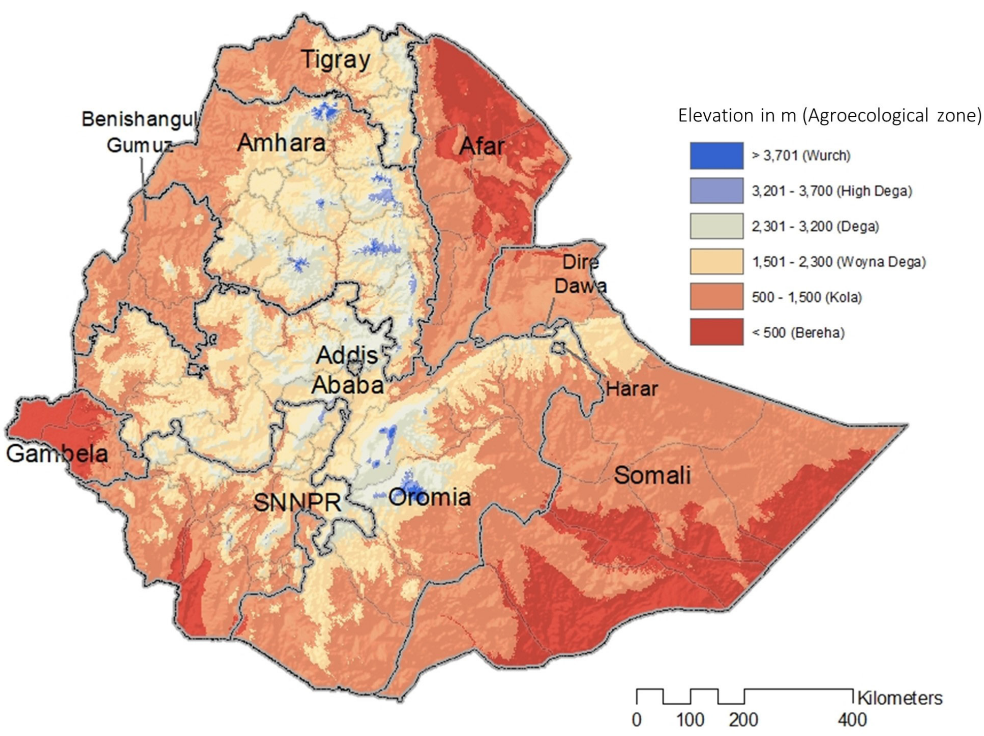
The remainder of the report is organized as follows: section 1 introduces the Ethiopian context, including the remarkable growth of Ethiopian agriculture since 2004. Section 2 presents the country-level framework along with the methods used to identify and integrate innovations into the ESS. Section 3 documents all of the innovations believed to be operating at scale in Ethiopia. Section 4 sheds light on adoption and changes in adoption, using the ESS surveys (2016 to 2019). Section 5 asks, "Who are the adopters?" to determine whether innovations reach subpopulations that are of particular interest to CGIAR. Section 6 documents spatial variations in adoption, and section 7 discusses synergies between innovations—a central question for the CGIAR system, particularly in countries like Ethiopia, where such a variety of CGIAR research programs have been active. Section 8 further highlights the value of the DNA fingerprinting data by demonstrating the issue of misclassification when using farmer self-reported data and how it has the potential to skew our understanding of the true picture. Section 9 suggests priorities for future data collection efforts, and section 10 concludes.

1. Ethiopia's Agricultural Sector: On a Road to Transformation

The diffusion of agricultural innovations in Ethiopia documented in this report did not occur in a vacuum. The broader context of Ethiopia's agricultural sector is crucial in understanding and interpreting the lessons to be drawn. This section highlights some key developments in the Ethiopian agricultural sector and the economy more broadly, documenting institutional developments and economic achievements, both of which arguably provided a favorable environment for the diffusion of agricultural innovations.

A landlocked country located in the Horn of Africa, Ethiopia shares borders with Eritrea, Djibouti, Somalia, Kenya, South Sudan, and Sudan. With 18 major agroecological zones, Ethiopia is characterized by a high diversity of agroecological conditions (FA0, 2013). Altitude ranges from 110 meters below sea level to 4,620 meters above sea level. As the second-most-populous country in Africa, Ethiopia had an estimated population of 112 million in 2019. Approximately 79 percent of the population lives in rural areas and is engaged mainly in agriculture (World Bank, 2015). Administratively, the country is divided into nine regions (regional states) and two cities (administrative states) (Figure 1).

Figure 1: Map of Ethiopia, showing altitude and agroecological zones



Over the past decade, Ethiopia has been among the fastest-growing economies anywhere in the world (IMF, 2020a). Following an economic contraction in 2003 attributed largely to drought, the economy rebounded vigorously between 2004 and 2017, when annual growth averaged 10.5 percent (Bardasi & Getahun, 2009; World Bank, 2020a). Before the COVID-19 pandemic, the International Monetary Fund reported that the country was on a trajectory to reach lower-middle-income status by 2025 (IMF, 2020a).

Agriculture is considered one of the main drivers of this economic growth on the supply side, together with private consumption and public investment on the demand side (Shiferaw, 2017; Moller, 2015). From 2004 to 2014, Ethiopia's agricultural sector grew at an average annual rate of 7.6 percent (Bachewe et al., 2018; Moller, 2015). The most important subsector was crop production, representing 23 percent of Ethiopian GDP in 2018, followed by livestock production (9 percent). Other subsectors, including forestry, contributed slightly more than 3 percent (FDRE, 2019b). Since 2011 the service sector has overtaken agriculture as the leading sector in terms of contributions to GDP (NBE, 2019).

Exports of agricultural commodities—facilitated by significant improvements in Ethiopia's connections to international markets, starting from a low base—have contributed to the country's economic takeoff (Moller, 2015). Of the 12 key export commodities, 6 are crops (coffee, fruits and vegetables, pulses, flowers, oilseeds, and khat) and 3 are livestock related (leather, meat, and live animals). These agricultural commodities accounted for 70 percent of all export value from 2003 to 2017 (Cochrane & Bekele, 2018). In 2017 Ethiopia's most important exports were coffee (accounting for 33 percent of export value), oilseeds (15 percent), pulses (8 percent), vegetables (8 percent), and horticulture (7 percent) (FDRE, 2019b).

The federal Government of Ethiopia (GoE) has prioritized the transformation of the agricultural sector. Government expenditures in the agricultural sector have been steady over the past decade, and large-scale investments have been realized. The Growth and Transformation Plan (GTP) sets Ethiopia's major policy orientations for the 2011–20 period. Among its components, the Agricultural Growth Program (AGP, 2011–15) aimed at increasing agricultural productivity and improving the market performance of selected crop and livestock value chains in highly productive *woredas*[4] (MoA, 2015a). Funded by the GoE and several donors, the AGP drew technical support from the Agricultural Transformation Agency.

The AGP significantly raised productivity for major food crops (cereals, pulses, and oilseeds). Between 2011 and 2015, the use of fertilizer and improved varieties increased by 78 percent and 154 percent, respectively. Major crops that benefited from increased varietal dissemination are maize, teff, and wheat. The number of farmers participating in extension services increased by 1 million, reaching 3.6 million in 2015. Ethiopia has the highest extension agent-to-farmer ratio in the world, estimated at one agent for every 476 farmers. In 2010 the country had 10,000 farmer training centers and trained 63,000 development agents (Alemu & Tripp, 2010).

Following the completion of the AGP, a second phase was designed for the 2016–20 period. This second phase of AGP is regarded as an important step for increasing agricultural productivity and commercialization, contributing to dietary diversity, and raising consumption at the

[4] *Woredas* are the third-level administrative divisions in Ethiopia. There are 670 rural and 100 urban *woredas* in the country.

household level. The program was extended to 157 *woredas* in seven regional states and one administrative state (MoA, 2015a; WFP, 2019).

Alongside these policies, Ethiopia also established two important organizations: the Ethiopian Commodity Exchange (EcX) and the Agricultural Transformation Agency (ATA). The EcX was created in 2008 to ensure the development of an efficient trading system for agricultural commodities. The exchange protects the rights of sellers, buyers, intermediaries, and the general public. Five agricultural commodities are currently traded at EcX: coffee, sesame, common beans, maize, and wheat. In 2010 the Ethiopia created the ATA to accelerate the transformation of agriculture into a highly productive, commercialized sector. Working alongside the MoA, the agency aims to fulfill its mandate within 15–20 years.

Agricultural innovations that impose high labor costs, such as soil and water conservation structures, may also have benefited from the Productive Safety Net Program (PSNP), which has been operational since 2005. The PSNP includes a mix of cash and food transfers to food-insecure households in exchange for household members' contributions to labor-intensive public works, including soil and water conservation measures (Haregeweyn et al., 2015). Approximately 8 million people in chronically food-insecure *woredas* were believed to benefit from the PSNP in its fourth phase (2015 – 2020) (Berhane et al., 2017).

Growth in the agricultural sector has been accompanied by a reduction in poverty. The share of the population living below the national poverty line declined from 47 percent in 2000 to 23 percent in 2016 (World Bank, 2020a). The past two decades have witnessed an expansion in access to social services such as clean water, health care, education, telecommunications services, power generation, and most recently railways (UNDP, 2018; World Bank, 2016). People's access to markets also improved significantly. In 1998, 67 percent of the population lived more than five hours from an urban center; by 2011 this figure had declined to 26 percent (World Bank, 2020a). Despite this remarkable progress, the county remains among the poorest in the world, with a per capita income of $790 per year (World Bank, 2019). Income inequality, as measured by the Gini coefficient, is around 30 percent and has been stable over the past two decades.

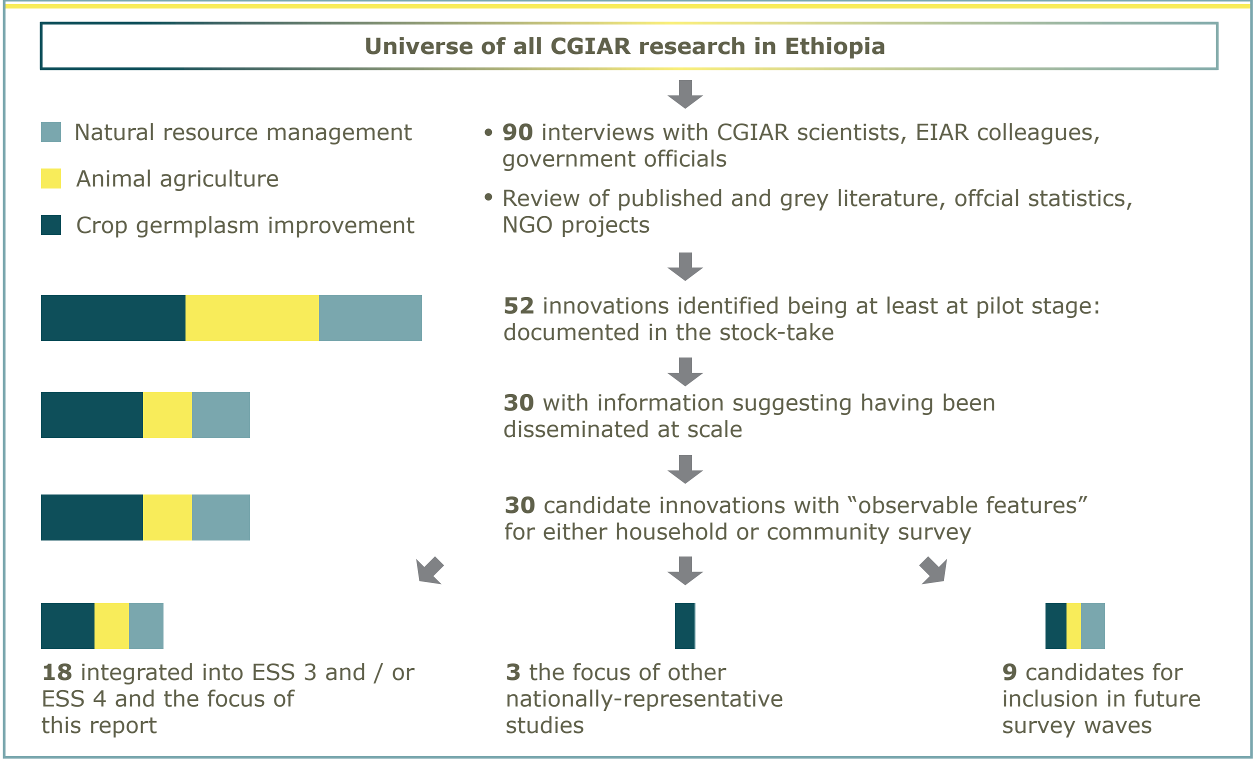
Several challenges have also affected the agricultural sector and the economy more broadly. An agriculture sector that is predominantly rainfed is vulnerable to climate change (Mahoo et al., 2013). The country has experienced several droughts, including the 2015–16 El Niño drought. The country has also been affected by political instability; during the state of emergency from October 2016 to July 2017, for example, government activities were interrupted in most regions.

2. Methods and Data

Establishing the impact of CGIAR agricultural research for development (hereafter AR4D) requires documenting the reach of CGIAR-related innovations. While reach is not sufficient for impact, it is an important prerequisite (SPIA, 2020). To document the adoption and diffusion of agricultural innovations linked to CGIAR research, SPIA has developed a comprehensive, country-level framework (Kosmowski et al., 2019b). The rationale for focusing on data collection efforts at the national level is threefold.

First, some countries stand out as being particular hotspots of CGIAR research activity. This fact is reflected in the design of the CGIAR Research Programs (CRPs), where science leaders in CGIAR outlined ambitious targets for the numbers of households that would adopt CGIAR innovations by 2030. Among the 200 million households targeted overall, more than half are located in six countries—Bangladesh, Ethiopia, India, Nigeria, Tanzania, and Uganda. These countries differ from others because of their large populations and because they host many CGIAR scientists addressing a range of AR4D challenges. Second, nationally representative surveys are available to document the extent to which innovations have scaled nationally, who has been reached, and where such diffusion took place. In combination, these insights can provide policy-relevant evidence for the government as well as for CGIAR partners, management, and donors. Third, country-level data are often well suited for linking to other sources for repurposing—for example, by combining the national survey data with project monitoring data and remotely sensed data to estimate the impact of the roll-out of innovations in a spatially-explicit analysis.

Figure 2: Schematic of the process of identifying priority innovations for improved data collection



2.1 Identifying CGIAR-Related Innovations

The exercise of documenting reach starts with a basic set of questions: What has been the focus of CGIAR research efforts in Ethiopia? Where have these efforts translated into specific innovations? Are these innovations likely to have reached farmers, consumers, and communities?

We address these questions by systematically compiling key information on the past two decades of research activities (1999–2019). Our main objective was to take stock and document a list of potential innovations to consider for future data collection efforts. Our stocktaking summarized the information we collected in our investigations and made it readily accessible. This document then helped guide the selection of innovations for which measurement was integrated in national surveys in a more informed and transparent manner.

Box 1. Terminology

To understand the stocktaking, it is useful to clarify the following specific terms used in this report:

Innovation: A technology, practice, decision support tool, or policy/institutional design that required input from research for its design and/or promotion and is novel to its users.

CGIAR-related efforts for development and/or dissemination: CGIAR Research Programs (CRPs) and/or bilaterally funded projects that developed research outputs that contributed to the development or dissemination of the innovation.

Observable feature: A clear and distinctive feature that allows the innovation to be measured in a survey setting.

2.1.1 Guide to the stocktaking

The full version of the innovation stocktaking, including all innovations identified in Ethiopia, is available here. Table 1 provides examples of three innovations: delivery of improved dairy genetics, drought-tolerant maize varieties, and conservation agriculture. The first column lists the names of the innovations. To be included in this list, an innovation must have used input from research conducted by teams that included CGIAR scientists. An innovation must also be novel to its users. Finally, for our purposes, an innovation must have a distinctive, observable feature that makes it measurable in a survey. This definition is fairly inclusive and encompasses agricultural technologies, practices, and decision-support tools, as well as discrete government or private sector initiatives that are thought to have been influenced by CGIAR policy-oriented research.

The second column in the stocktaking ("CGIAR-related efforts for development and/or dissemination") lists the CRPs and/or CGIAR bilaterally funded projects with research outputs that can be linked to the development or dissemination of the innovation.[5] The third column describes the focus of these efforts.

The column "Observable feature" creates a bridge between the upstream and the downstream aspects of the diffusion process. An innovation pathway starts upstream with the outcomes of research efforts. Downstream, uptake can be assessed only with a clear, observable feature, or marker, of the CGIAR-related innovation. The observable feature helps to ensure that valid data are collected.

The column on scale and location lists information on dissemination that occurred as part of the AR4D research activities. This column documents what is known about the scale and location of those activities at the end of CGIAR projects. This information will be further explained in section 6.

The last column reports on dissemination of innovations beyond the areas and activities that were part of specific CGIAR projects. The work of CGIAR scientists reaches farmers and communities through many different channels. Some innovations can be passed on from farmer to farmer; others are passed on through private sector initiatives, NGO projects, government policies, or donor programs. If information on dissemination at scale by such stakeholders exists, it is captured in this last column.

5 Projects with funding less than US$100,000 were excluded.

Table 1: Examples of stocktaking entries for three CGIAR-related innovations for inclusion in Ethiopia national data systems

Innovation	CGIAR-related efforts for development and/or dissemination	Description	Observable feature	Scale and location of AR4D activities	Notes on known dissemination strategies/ pathways
Delivery of improved dairy genetics	1. Improving the Productivity and Market Success of Ethiopian Farmers (IPMS, ILRI, 2004–12) 2. Livestock and Irrigation Value Chains for Ethiopian Smallholders (LIVES, ILRI, 2013–18)	1 and 2 - Hormonal estrus synchronization (Hormonost & BoviPreg) was tested and introduced for small and large ruminants, allowing better control of cattle heat period.	Livestock keeper owns at least one crossbred large ruminant.	1 and 2 - Asebi and Almata (Tigray), Fogera, Metema and Bure (Amhara), Adaa, Mieso, Goma (Oromia), Dale, and Alba (SNNPR). From 2011 to 2014, 600,000 cows in these four regions were treated with hormone and inseminated.	1 and 2 - Following the training of federal and regional staff, hormonal estrus synchronization was pushed as a practice on farm AI service. This innovation is part of the Livestock Master Plan (LMP), which has a target of 5 million crossbreds by 2020. It is also an objective of the World Bank/ Ministry of Agriculture (MoA) Livestock and Fisheries Sector Development Project (LFSDP, 2017–24).
Drought-tolerant maize (DTMZ) varieties	1. Drought Tolerant Maize (DTMZ, CIMMYT, 2007–13) 2. Drought Tolerant Maize for Africa Seed Scaling (DTMASS, CIMMYT, 2014¬–19)	Since 2007, 10 drought-tolerant varieties have been released: BH546, BH547, BH661, Gibe 2, Melkassa 1Q, Melkassa 6Q, Melkasa2, Melkasa 4, MH 130, and MH140.	Household has grown a DTMZ variety on at least one plot. Identification uses DNA fingerprinting.	1 and 2 - 40 *woredas* in five regions (list of *woredas* is available).	Conventional seed system, farmer-based cooperatives, direct seed marketing, and EcX.
Conservation agriculture (CA)	1. Africa Rising (2011–21) 2. Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA, CIMMYT, 2010–18)	1. Successful agricultural intensification practices are scaled up. The sustainable intensification (SI) approach is described in Vanlauwe (2014). 2. Maize, legume, and fodder/forage varieties were disseminated, farmers were involved in seed-selection trials, and conservation agriculture–based sustainable intensification (CASI) was promoted.	Household has implemented three crop management practices on at least one plot: (1) zero or minimum tillage; (2) permanent soil cover with crop residues or cover crops on at least 30% of the soil surface, and (3) diversification of crop species grown in sequence (crop rotation) and/or associations. Visual-aid protocol is used to assess practice #2.	1. Innovation was scaled up from 4 districts (2011) to 31 districts in four main regions. Project claimed 206,535 households were reached by 2019, compared with target of 700,000 (list of districts is available). 2. Project went from 2 districts (2012) to 29 districts (2015) to 35 districts (2019), including West Badewacho, Arsi Negele, Shashamane, Ilu-Gelen, Diga, and Sibu-Sire (district list available).	1. Regional policy summit resulted in the signing of a ministerial communiqué committing to the mainstreaming of SIMLESA results (October 2015). 2. Amhara has scaled up maize-lupine intercropping in its extension program (training manual prepared); the MoA has established a unit focusing on CASI technologies and adopted a framework for scaling up CASI practices through the national extension program.

2.2 The Ethiopian Socioeconomic Survey (ESS)

Once the CGIAR-related innovations expected to have scaled were identified, based on the stocktaking exercise outlined above, a subset of innovations were selected to be the focus of our efforts to document adoption and diffusion at the household and community level. The following sections will explain in detail the criteria used in this prioritization exercise. To compile data on the adoption and diffusion of CGIAR-related innovations in Ethiopia, SPIA partnered with the Central Statistical Agency and the World Bank's Living Standards Measurement Study. This partnership aims to strengthen statistical capacity to capture CGIAR outcomes at a representative scale in key countries. The Ethiopian Socioeconomic Survey (ESS), a regionally and nationally representative survey, was chosen as the survey instrument for collecting data on the innovations identified.

The ESS is integrated with the CSA's annual Agricultural Sample Survey (AgSS), a survey designed to obtain production estimates for the major crops in each zone. Sampling is based on geographic stratification of the rural areas (CSA, 2019). The ESS sample is a two-stage probability sample. The first stage entails selecting primary sampling units, or CSA enumeration areas (EAs), from the AgSS sample of 1,600 EAs. An EA usually consists of 150–200 households in rural areas (roughly corresponding to a village). EAs are the smallest subdivisions of the country for which agricultural census data are available. The ESS sample design assures representative data at the regional level for the most populous regions of the country. In each EA, 12 households are selected randomly from a complete listing of households.

Box 2. The ESS questionnaire content

The ESS is composed of four survey instruments with the following modules:

Post-planting questionnaire: household roster; parcel roster; field roster; crop roster; seeds roster; miscellaneous holder questions; ownership; change in livestock numbers; breeding; milk production, egg production, and animal power (crop cut and DNA fingerprinting protocols were integrated into the post-planting questionnaire for a subsample of ESS households; see below)

Post-harvest questionnaire: household roster; crop harvest by field; crop disposition

Household questionnaire: household details; education; health; labor; savings and insurance; financial assets; land; livestock ownership; food consumption over past week; aggregate food consumption; nonfood expenditures; food security; shocks; housing; assets; nonfarm enterprises; other household income; assistance; credit.

Community questionnaire: direct observation by supervisor; roster of informants; basic information; access to basic services; agriculture; community needs and actions; Productive Safety Net Program; market prices; economic activities.

The ESS began as the Ethiopia Rural Socioeconomic Survey (ERSS) in 2011/12, which constitutes the first wave of a panel dataset of households from rural and small-town areas. Households that were interviewed in ESS1 in 2011/12 were tracked and re-interviewed in ESS2 (2013/14) and ESS3 (2015/16). The second and third waves additionally include urban areas and thus have an additional layer of representativeness.

In 2018/19 a new panel of households—ESS4—was started, and the sample was extended to ensure the representativeness of regions that had previously been aggregated in an "Other region" category: Afar, Benishangul-Gumuz, Dire Dawa, Gambela, Harari, and Somali. Accordingly, the ESS 2018/19 covers all nine regions and two administrative cities, Addis Ababa and Dire Dawa. ESS4 is representative at the regional level in addition to rural and urban levels.

As part of the core research team for implementing the survey, SPIA supported survey conception, training, data collection, cleaning, and reporting for both the ESS 2015/16 and ESS 2018/19 surveys. In this report, we present data from both surveys, using primarily the rural sample of households shown in Table 2. These datasets are publicly available (see World Bank, 2020b).

Table 2: Distribution of sample EAs and households for ESS3 and ESS4 by region (rural)

	ESS3 2015/16		ESS4 2018/19	
	EAs	**Households**	**EAs**	**Households**
Amhara	61	687	42	475
Oromia	55	625	44	474
SNNPR	74	840	40	423
Tigray	30	346	34	382
"Other" regions	70	737	104	1,235
Afar	N/A	N/A	29	321
Benishangul-Gumuz	N/A	N/A	19	207
Dire Dawa	N/A	N/A	14	161
Gambela	N/A	N/A	19	209
Harari	N/A	N/A	18	191
Somali	N/A	N/A	5	56
Ethiopia	**290**	**3,235**	**264**	**2,899**

Note: N/A = not applicable. Owing to security or logistics issues, some EAs could not be surveyed in the 2018/19 ESS. These EAs will still be part of the next survey wave.

In a given survey year, data collection usually takes place during September–February for post-planting and post-harvest questionnaires, and during May–June for the household and community questionnaires. This timing means the survey is well timed to observe measures of innovation during the *meher* season, but it may miss innovations that are more relevant for the *belg* season (a season possibly more relevant for some CGIAR crops, such as sweet potato). Since the 2018/19 ESS the interviews have been carried out using computer-assisted personal interviewing (CAPI) via the World Bank's Survey Solutions software.

2.3 Measurement Approaches

In recent years it has become apparent that the task of measuring—accurately, at the relevant scale, and at a reasonable cost—all the variables needed to obtain reliable estimates of adoption and diffusion rates requires careful attention (Stevenson et al., 2019; Poets et al., 2020). This section addresses the specific methodological issues related to valid measurement.

In many settings, accurately identifying individual varieties may require DNA fingerprinting. Recent DNA fingerprinting studies have shown that measurement errors in farmer-reported survey data on adoption of varieties are sufficiently large to change the interpretation of the analysis as the measurement error can be biased in a particular direction (Wossen et al., 2017; Le et al., 2019; Wineman et al., 2020). As a result, much effort has gone into refining DNA fingerprinting approaches for varietal identification in challenging field settings (Kretzschmar et al., 2018; Poets et al., 2020). Measurement errors in farmers' self-reported data concern not only the identity of the specific variety being cultivated (which is important for understanding whether farmers could be expecting to benefit from particular traits that are specific to certain varieties) but also, more fundamentally, whole categories of varieties typically used in household surveys—"improved" versus "local" or "traditional."

Varietal identification is certainly not the only aspect of data collection subject to measurement error in large-scale socioeconomic surveys. Related methodological work highlights methods for obtaining more accurate measures of the adoption of natural resource management practices (Kosmowski et al., 2017). SPIA's partners at the World Bank LSMS team have a whole portfolio of research methods for studying and finding solutions to measurement errors in agriculture (World Bank, 2020c). Building on these advances and insights, we incorporated several methodological improvements for measuring adoption into the ESS data collection.

SPIA's efforts to identify CGIAR-related innovations for integration into national statistical surveys in Ethiopia started in 2015. As we collected insights regarding CGIAR activities, we also reviewed the ESS questionnaires. Some innovations relevant to CGIAR activities were already present in the ESS, some were modified to better capture CGIAR-related contributions, and some needed new data collection approaches that we developed and piloted. Innovations believed to be at scale, and for which valid data collection approaches could be found, were integrated into the ESS using survey questions, visual-aid protocols, or the collection of plant material for subsequent DNA fingerprinting.

The following subsections describe the methods used for each innovation identified in the stocktaking and refer to results of the method validation work where relevant. An overview of the questions and protocols used is available in Appendix A. Appendix I provides more details on the methods experiments conducted by SPIA in the past five years, which underpin some of these data collection improvements.

2.3.1 Animal Agriculture

Animal agriculture innovations were already present in the ESS questionnaire. Animal crossbreeds—for large ruminants, small ruminants, and poultry—are captured in the post-planting questionnaire, section 8.1. Users of artificial insemination services for livestock, as well as improved feed and forage, are collected in section 8.3 of the post-planting questionnaire.

2.3.2 Crop Germplasm Improvement

Barley, Maize, and Sorghum Varieties: DNA Fingerprinting

DNA fingerprinting of barley, maize, and sorghum was integrated into ESS4. These three crops are grown by millions of Ethiopian farmers and have been the focus of significant breeding efforts in recent decades. Released varieties resulting from collaborative research have made extensive use of CGIAR centers' collection of germplasm. Of the 60 varieties of barley, 48 varieties of maize, and 46 varieties of sorghum that were released in 2000–19, 12 barley varieties, 23 maize varieties, and 21 sorghum varieties are thought to contain CGIAR-related germplasm.

The ESS is rare among nationally representative household surveys in that it incorporates crop-cuts for agricultural yield estimation. This practice, which is made possible by hiring resident enumerators for survey work,[6] provides an excellent opportunity for taking samples from the crop-cuts for subsequent DNA fingerprinting. In each enumeration area (EA), all the plots cultivated during the agricultural season were listed for 21 "temporary" crops, which are defined in the ESS as being those crops that are planted and then harvested in a single season ("permanent" crops therefore being those that bridge multiple seasons). Up to 10 plots per crop were then randomly selected to be crop-cut. Enumerators were trained to carry out a specific procedure in which a 4-meter-by-4-meter quadrant was randomly laid over the plot. Once the plot was harvested, enumerators weighed the total production of crops harvested from the quadrant and then obtained yield estimates using the dry weight of the sample two weeks after harvesting. To identify crop varieties with DNA fingerprinting, samples were collected from these dried crop-cuts. Barcoded cotton sample bags were provided to enumerators, and an additional barcoded question was integrated into the crop-cut module of the post-planting ESS questionnaire in Survey Solutions.

Figure 3: Enumerator delineating a random 16-square-meter quadrant for the crop-cut protocol in Amhara region, 2018

[6] The Central Statistical Agency has years of experience in performing crop-cuts, as they are used as the measure for the official agricultural yield estimates in the AgSS.

The collection of samples for DNA fingerprinting focused on the following regions: Amhara, Dire Dawa, Harar, Oromia, Southern Nations, Nationalities, and Peoples Region (SNNPR), and Tigray. In each sampled EA, a frame of all the plots in the 20 sample households by crop was used for selecting a systematic random sample of a maximum of 10 fields for each crop. While plots selected from the 20 households were used in the official AgSS crop-cut yield estimates, only the sample of plots belonging to the 12 ESS households were collected for DNA fingerprinting and subsequently reported in the ESS4 data.

The objective of performing DNA fingerprinting on crop varieties is to match the genetic material of a crop sample with the closest genetic match in a reference library constituted from varieties that could conceivably be found in the landscape in question. For maize, the reference library for Ethiopia was previously compiled under a DNA fingerprinting research project conducted by the International Maize and Wheat Improvement Center (CIMMYT) and the Ethiopian Institute of Agricultural Research (EIAR) and funded by the Bill and Melinda Gates Foundation. As no reference libraries were readily available for barley and sorghum, we compiled collections of breeders' seed from the EIAR and its regional centers. For the three crops, the list of varieties released and included in the reference library is available in Appendix C and Appendix D. The data collection resulted in a total of 1,122 DNA fingerprinting samples, representative at the household level across major growing areas (Table 3).

The barcoded, dried field samples were transported to the ILRI campus in Addis Ababa, where they were dried further and then ground to obtain 50 grams of flour. DNA from this material was extracted in Addis Ababa using Qiagen DNeasy plant mini kits. Plates containing the DNA samples were then shipped to the Diversity Arrays laboratory in Canberra, Australia, for genotyping by sequencing using the DarTSeq platform. The DarTSeq platform uses a combination of a proprietary complexity reduction method and next-generation sequencing platforms, described in Kilian et al. (2012). For each sample approximately 200,000 fragments of DNA are sequenced, while matching relies on 20,000 polymorphic markers. The result of this matching yields the name of the crop variety to which each sample was matched, together with the level of purity of the sample. Additional outputs for analysis include the genetic separation between reference library samples as well as the sequenced genomic data.

Table 3: Distribution of DNA fingerprinted samples in ESS4, by region

	Barley		Maize		Sorghum	
Region	**Plot**	**Households**	**Plot**	**Households**	**Plot**	**Households**
Amhara	89	84	134	125	77	64
Oromia	38	33	107	100	57	49
SNNPR	58	51	103	83	61	52
Tigray	64	54	97	90	79	69
Other regions[a]	N/A	N/A	64	49	94	77
Total	**249**	**222**	**505**	**447**	**368**	**311**

[a] Samples were collected in Dire Dawa and Harari.

Orange-Fleshed Sweet Potato (OFSP): Visual-Aid Protocol

Orange-fleshed sweet potato (OFSP) varieties were added in ESS3 and ESS4 surveys in the post-planting questionnaire, crop roster module, section 4. Using a visual-aid protocol available in Appendix A, sweet potato growers were shown two pictures of sweet potato flesh (white and orange) and asked to point out which one was consistent with the predominant variety they were growing. A second photo-based question collected data on skin color (white or pink). As shown by Kosmowski et al. (2019), this protocol allows identification of plots with OFSP with reasonable accuracy and separates them from other sweet potato varieties. The same study highlighted the magnitude of measurement error when using farmer self-reported data for both varietal type and varietal name.

Awassa-83 Sweet Potato Variety: Visual-Aid Protocol

Awassa-83 is a pink-skinned, white-fleshed sweet potato variety. Identification was established using the same visual-aid protocol as above but categorizing the two phenotypic traits that characterize the variety (Kosmowski et al., 2019a): pink skin and white flesh.

Chickpea Desi and Kabuli Types

The desi and kabuli varieties of chickpea fall under the mandate of different CGIAR centers—namely, the International Center for Agricultural Research in the Dry Areas (ICARDA) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), respectively. This distinction was captured in ESS3, in the post-planting questionnaire, crop roster (section 4). The two chickpea varieties can be reliably separated from each other by the color of their flowers (Purushothaman et al., 2014), which serves as an observable feature because all kabuli chickpeas in Ethiopia are derived from ICRISAT germplasm. Thus a visual-aid protocol, available in Appendix A, exploits chickpea flower colors: white for kabuli and purple for desi varieties. Unfortunately, the protocol was not retained in ESS4.

Other Crops

For all other crops, the ESS asked farmers whether they considered the variety they were growing on a plot an improved variety. For completeness, we present the share of farmers reporting the use of improved varieties by crop in Appendix B, but, based on the evidence cited above, these data should not be considered reliable estimates of adoption rates of improved varieties.

In addition, for two of the crops expected to have improved varieties disseminated at scale—wheat and common bean—we draw on evidence from other recent large-scale studies with DNA fingerprinting evidence, conducted by the CGIAR centers (Jaleta et al., 2020; Habte Endeshaw and Enid Katungi, personal communication).

2.3.3 Natural Resource Management (NRM)

Agricultural water management (AWM) and soil and water conservation (SWC) technologies encompass four innovations. Three of them related to irrigation—river diversion, motorized pumps, and treadle pumps—were captured in the field roster, section 3, of the post-planting questionnaire. The fourth innovation, a category of practices related to SWC, was also captured in the field roster.

To identify which farmers use the broad bed maker (BBM), a visual aid (Appendix A) was included in the post-planting questionnaire, section 3, of ESS3 but not retained in ESS4.

To identify farmers practicing conservation agriculture (CA), the three component principles – permanent soil cover, minimum soil disturbance and crop rotation with a legume, were each given separate treatment. A visual-aid protocol was used to identify the percentage of cover provided by crop residues left on the plot after harvest (measuring the principle of permanent soil cover). This was complemented by survey questions on the use of zero tillage (minimum soil disturbance) and crop rotation with a legume. The use of these three practices together identifies the plots on which CA was used, following the definition in Baudron et al. (2014) and Richards et al. (2014). The protocol and questions were integrated into the field roster. The use of the visual aid for crop residue measurement was validated in Kosmowski et al. (2017), where it showed a significant improvement over farmer's self-reported data.

Adoption of avocado, mango, and papaya trees can be identified directly from the ESS crop roster (section 4). It should, however, be noted that the process of tree planting can be assessed only by comparing data between two waves from the same panel sample—something we are currently unable to do given the change in the sample between ESS3 and ESS4—but that approach should be possible in the next survey wave if these questions are retained.

2.3.4 Innovations from government policy

Beneficiaries of the Productive Safety Net Program (PNSP) were identified with a module from the household questionnaire.

The existence of water users associations (WUAs) was proxied in the community questionnaire (module 6 on agriculture).

2.4 Data Analysis

The tables and figures presented in this report aim to summarize the main empirical results obtained through a detailed descriptive analysis of the collected information. The detailed results on which the tables are drawn, complementary empirical analyses, as well as all the program files that allow replication of the analysis, is available at Kosmowski et al (2020b).

2.4.1 Share and Number of Rural Households Reached

In section 4 we report adoption rates for each innovation using the ESS4 sample of rural households.[7] Statistics are reported at the household and enumeration area (EA) levels. The latter broadly correspond to village-level statistics. In all statistics reported, sampling weights are accounted for so that estimates reflect national and regional-level populations. The ESS post-stratification weights were constructed using information from a 2018 pre-census

[7] We focus on the rural sample only because this is the relevant sample for most CGIAR-related innovations and because ESS collects information on crop and plot-related outcomes (such as the NRM practices) only for rural households. That said, because livestock crossbreeding is also relevant for urban and peri-urban areas, we also report estimates for the urban sample in the livestock section.

cartographic database of enumeration areas, and the weight variable is included in the ESS dataset. When this weight is used in a household-level statistic, it sums to the population of households, and the number of households reached was estimated using these weights.

DNA fingerprinting data were collected on a subsample of ESS4 households in six of the nine regions: the four most populous regions (Amhara, Oromia, SNNPR, and Tigray) and two other regions, selected because of the importance of sorghum there (Dire Dawa, Harar). The rural population of these six regions together represents 93 percent of rural households in Ethiopia, allowing for a good approximation of national adoption rates and the number of households adopting barley, maize, and sorghum varieties with CGIAR germplasm.

For the innovations measured in ESS3 and ESS4, we report changes in adoption between the nationally and regionally representative data of both years. Even if the period between the surveys is relatively short, this approach allows us to demonstrate dynamic changes in adoption rates for certain innovations.[8] Comparisons between the two surveys always rely on rural samples only. The ESS3 and ESS4 datasets are publicly available (Central Statistical Agency of Ethiopia & World Bank, 2016, 2020).

Variables used from the ESS questionnaire to report on each innovation are described in Table 21, Appendix A. For each innovation, the proportion of adopters was defined over a specific population that was deemed the most relevant (see Table 9 in section 4).

2.4.2 Description of the Adopters: Who and Where?

To describe the farm-, household-, and village-level characteristics of the households being reached (Section 5), a set of variables was constructed. Innovations that reached fewer than 5 percent of households were excluded from the analysis, given limited power. Detailed information on variable construction and definitions can be found in the program files available for replication (Kosmowski et al (2020b).

To further analyze the spatial variation in adoption in section 6, we calculate distances between EAs and *woreda*-level information on the location of CGIAR-research activities and projects with relevance to particular innovations. This location information is available for a subset of the livestock, crop, and NRM innovations (see Table 31 in Appendix J). While some research activities were limited to very few *woredas* (e.g., four *woredas* had research activities on improved sorghum), others were relatively widespread (e.g., activities on large ruminants took place in 144 *woredas*). We know that CGIAR research activities took place in a total of 511

[8] ESS3 is representative for the population of five regions (Tigray, Amhara, Oromia, SNNP, and "Other regions"), while ESS4 was meant to be representative for all regions (nine regions and two city administrations). For the comparison across years, we therefore first aggregate ESS4 data to five regions (Tigray, Amhara, Oromia, SNNP, and "Other regions") and compare the change between these five regions. Estimates are not completely comparable, however, for two reasons. First, ESS3 is the third wave of a panel that started in 2011, so it is representative of the (non-attrited) population in 2010/11 and not 2015/16. Attrition is limited at 7 percent and given the relatively short period between waves, population changes should not have first-order implications on the comparison. Second, the ESS3 sampling frame excluded three zones of Afar and six zones of Somali region. And in ESS4, owing to security issues, a subset of EAs in other regions could not be surveyed (37 percent of EAs in Benishangul Gumuz), whereas for Somali region the interviews were carried out but some modules were not applicable (Alemayehu Ambel, personal communication). Because Somali and Afar are pastoralist and have low population density, problems of comparability for the statistics related to agricultural innovations are limited. In addition, comparability issues do not affect any of the estimates of the four most populous regions, which represent 93 percent of rural households.

woredas between 1999 and 2019; we were able to get geo-referenced information on *woreda*-level location for 458 of them. For the remaining activities, *woreda* names did not match between data sources. An overview of the locations of CGIAR-related activities is available in Appendix J.

To calculate the distance between these georeferenced locations of research activities and the ESS EAs, we developed an R script using the maptools package (Lewin-Koh & Bivand, 2011).[9] The script first sets spatial coordinates from both datasets and creates a spatial object. For each innovation, a *k*-nearest neighbor classifier is then used to calculate the closest distance from each EA to a *woreda* with research activity for that particular innovation. For each EA, the *k*-nearest Euclidean distance of latitude and longitude coordinates is found (Cover et al., 1967), revealing the closest match within a radius of each georeferenced EA. The associations reported in section 6 are calculated at the EA-level.[10]

9 The R script is available in Supplementary materials.

10 This exercise comes with a number of caveats. First, GPS measurement errors are possible. Second, we do not take the intensity and duration of activities into account, given limited data availability. Third, for many CGIAR research activities, location information was not available, so the compiled dataset underestimates the full extent of CGIAR activities in Ethiopia.

3. CGIAR-Related Innovations in Ethiopia (1999–2019)

The full stocktaking (Kosmowski et al, 2020b) highlights the sheer diversity of CGIAR research effort. Over the 1999–2019 period, we group the research outputs into 52 innovations that could be documented across three core domains of CGIAR research: animal agriculture (n = 18), crop germplasm improvement (n = 20), natural resource management (n = 14).[11]

Two messages stand out from this exercise. First, it is apparent that despite the large number of innovations identified, for the vast majority adoption and impact are undocumented. Second, as shown in the sixth column in the stocktaking (Kosmowski et al, 2020b), within each category of innovation (animal agriculture, crop germplasm improvement, NRM), there are a number of cases where there has been significant effort to disseminate the research through various channels. This section discusses this subset of innovations (where existing information suggest that the innovations could be detectable in a national survey) in more detail. Notably, approximately 500 *woredas* were directly involved with field research and dissemination activities by CGIAR centers—a vast number, considering that the total number of rural *woredas* in Ethiopia is 670. These areas where CGIAR centers have been active were compiled and georeferenced for later matching with the ESS data (see section 6).

In addition, we collected preliminary evidence of the influence of CGIAR centers' research and expertise on 26 different government policies or intervention designs. We discuss a subset of these policies and interventions—those for which we could collect relevant data on their reach in the ESS—in more detail. This complement to the stocktaking provides suggestive evidence on the various channels through which CGIAR research could have had an influence. A common model for influence is through the scaling up of government pilot interventions following impact evaluations conducted by CGIAR centers. In addition, there are cases where the design of policy frameworks has been informed by CGIAR expertise at either the regional or national level.

The inclusion of innovations identified by the stocktaking in the ESS was assessed on a case-by-case basis. For each innovation, the factors considered included the likelihood that the innovation had been taken to scale, the existence of a validated measurement method to capture that innovation, and the feasibility of capturing the innovation using existing survey instruments. Indeed, some innovations were already present in the ESS, others could be included with only marginal modifications of existing survey instruments, and still others required dedicated measurement efforts. Moreover, some innovations were excluded because recent national-level data estimates had already been collected in another survey effort (this was notably the case for improved wheat and beans). In this section, we mention all the innovations that fulfill the inclusion criteira when introducing each core domain. We return to some of the excluded innovations when discussing the prioritization of the research agenda forward. Finally, it is important to note that some innovations that lacked evidence on the best methods for accurate data collection could not be integrated into the ESS.

[11] The natural resource management domain covers a broad range of innovations including the AgData Platform, climate-smart agriculture (CSA), innovation platforms (IPs), and technologies based on two-wheel tractors (2WTs). Not reported here, these innovations are detailed in the stocktaking document.

3.1 Animal Agriculture

The first CGIAR center to establish its presence in Ethiopia, the International Livestock Institute (ILRI), has been working with the Government of Ethiopia (GoE) and other partners since 1975. With a mandate on small ruminants, ICARDA has been present in Ethiopia since 1980. This section documents 4 of the 16 innovations related to animal agriculture identified in the stocktaking. All of these innovations have been the subject of dedicated research efforts, and they also all feature among the technology interventions advocated by the Livestock Master Plan (2015–20).

3.1.1 Delivery of Improved Dairy Genetics

Improved dairy genetics for smallholder farmers has been a long-term commitment of ILRI. Foremost projects include Improving the Productivity and Market Success of Ethiopian Farmers (IPMS, 2004–12), Livestock and Irrigation Value Chains for Ethiopian Smallholders (LIVES, 2013–18), the African Dairy Genetic Gains (AGDD, 2015–2020), and Africa Rising (2011–2021).

Artificial insemination (AI) services—the cornerstone of large ruminant crossbreed adoption—are delivered in Ethiopia by a network of public and private veterinary services. The IPMS and LIVES projects have contributed to the MoA's testing and adoption of hormonal estrus synchronization (Gizaw et al., 2016; Bekuma et al., 2018). The technique facilitates breeding by artificial insemination. As part of the LIVES project, federal and regional staff were trained in the practice of controlling cattle heat period. Overall, 600,000 crossbred cows were treated with hormones and inseminated in four regions. After implementation, the MoA pushed to mainstream the practice in insemination centers. Finally, the method is one of the interventions recommended by the Livestock Master Plan for both highland mixed crop-livestock and peri-urban milk sheds throughout Ethiopia.

Efforts have also been directed at creating the Private-Public Partnerships for Artificial Insemination Delivery program (PAID, 2015–19). In collaboration with Land O'Lakes International and the Government of Ethiopia, ILRI has trained artificial insemination technicians and created demand for crossbreeds in 126 *woredas*. The program's objective was to reach 140,000 farmers and produce 300,000 ear-tagged crossbred animals by 2020.

3.1.2 Delivery of Improved Genetics through Community Approaches

The strategy for delivering improved genetics for small ruminants is different from the one adopted for large ruminants and has mainly relied on community breeding schemes. These schemes have been researched and promoted through several collaborative projects, including the Livestock CRP (2011–21) and the Ethiopia Sheep and Goat Productivity Improvement Program (ICARDA, 2005–10).

These research efforts have resulted in the publication of guidelines for setting up community-based small ruminant breeding programs (Haile et al., 2019). Expected outcomes at the community level include genetic improvements, higher numbers of lamb births, larger lambs at birth and weaning, and reduced mortality rates. A total of eight breeding program sites in the four main regions have been established, with each research site serving up to 14 communities.

Furthermore, ICARDA's approach has been integrated into the country's Livestock Master Plan. Regional authorities in SNPP and Amhara have also invested in community-based breeding, and the Livestock and Fisheries Sector Development Project (LFSDP, 2017–24) is scaling up community-based approaches for small ruminants.

3.1.3 Improvement and Delivery of Improved Chicken Breeds

Two research efforts have been conducted on improved chicken breeds: Improving Village Chicken Production (ILRI, 2008–15) and African Chicken Genetic Gains (ACGG, ILRI, 2015–20). The first project has used selective breeding since 2011 to develop and improve the indigenous Horro breed. Distribution of the breed started in 2014, and its population is currently estimated at 30,000 animals. The second project has tested high-producing genotypes (Koekoek, Fayoumi, Sasso, Kuroiler, Embrapa 051, and improved Horro) that increase smallholder chicken productivity. To evaluate breed adaptability and productivity, researchers distributed 25 chickens each to 2,500 households in 21 *woredas* in the four main regions and in Addis Ababa.

Both the public and private sectors are involved in disseminating and selling crossbred chickens. As recommended by the LMP, the AGP II (2016–20) has focused its efforts on encouraging adoption of crossbred chickens, with the involvement of several universities. The role of the private sector has also been growing. Two notable companies are EthioChicken (established in 2010) and the Holland-Africa Poultry Partners (HAPP) consortium of poultry companies (established in 2012). Originally a public-private partnership with the government of Tigray, EthioChicken now manages eight poultry breeder farms and has distributed the Sasso breed at scale since 2013 (to date an estimated 16 million have been distributed nationally).

3.1.4 Facilitating Access to Improved Forage Varieties

Traditionally, research efforts to improve animal feed have taken two directions: breeding directed at dual-purpose crops, and promotion of improved forage varieties. We focus here on the latter. Projects that have facilitated access to improved forage varieties include the Livestock CRP (2011–21) and Climate-Adaptive Forage Seed Systems in Ethiopia (FeedSeed, 2013–15). More recent projects include Improving Animal Feed Policy and Regulatory Environment in Ethiopia (FEED3, 2018–20), Improved Forage Grasses: Making the Case for Their Integration into Humid- to Sub-Humid Livestock Production Systems in Kenya and Ethiopia (Grass2cash, 2018–21), and Strengthening Smallholder Livestock Systems for the Future (EQUIP, 2017–22). The IPMS, LIVES, and Africa Rising projects mentioned earlier in the case of improved dairy genetics have also featured aspects related to feed delivery.

A vital complement to animal genetic and health improvements, the feed sector in Ethiopia is small. Improved feeds and feeding practices are promoted through NGOs, and a number of these projects have made efforts to kick-start investment by the private sector. As a result, seed enterprises such as Eden Field Agri-seed and the Ethiopian Seed Enterprise have been established.

ILRI's genebank has been a provider of high-quality forage germplasm in Ethiopia since 1983. The genebank collection comprises approximately 1,000 species of forage legumes, grasses, and fodder trees (Kitonga et al., 2019). Since its establishment, the genebank has distributed more than 4,800 samples of forage species in Ethiopia. Cowpea (*Vigna Unguiculate*), lablab (*Lablab purpureus*), and alfalfa (*Medicago sativa*) were the top three distributed species. Rhodes grass (*Chloris gayana*) and sesbania (*Sesbania sesban*) were also requested and distributed. Some of these accessions are exotic species that were introduced in Ethiopia. Napier grass (*Pennisetum purpureum*), captured in the ESS under the name elephant grass, has not been distributed through the ILRI genebank, but it has been the subject of some project interventions to promote it.

Box 3. Other animal agriculture innovations

Other animal agriculture innovations covered in the stocktaking include the following: capacity building for pastoralist women; climate-smart livestock systems; community conversations for women's empowerment; community-based disease control interventions; digital extension services for increased livestock productivity; dual-purpose crops; Feed Assessment Tool (FEAST); livestock insurance (IBLI); National Livestock Market Information Systems (NLMIS); *peste des petits ruminants* thermostable vaccine; public-private partnerships for health delivery services; and "smart" text-based marketing of small ruminants.

Further details on these innovations are available in the stocktaking document.

3.2 Crop Germplasm Improvement

In this section, we focus on seven crop innovations believed to be at scale, five of which SPIA integrated into the ESS (adoption of the other two is documented using other nationally representative data sources). DNA fingerprinting was used for varietal identification of barley, maize, and sorghum; visual-aid protocols were used to distinguish chickpea desi and kabuli types as well as orange-fleshed sweet potato (OFSP) varieties (available in Appendix A). Here, we give some elements of context and document the varietal output of these innovations.

Ethiopia benefits from a functioning formal variety release and registry system that has been operating since 1985. The term "improved variety" is used in Ethiopia to designate a variety that has been tested by breeders and evaluated for its superiority over existing varieties (MoA, 2013). The process leading to seed certification involves several decentralized actors and can take a total of three to four years.

Ethiopia (together with Eritrea and parts of Somalia) is considered one of the world's centers of origin of cultivated food plants. Referred to as the Abyssinian Center, it is one of eight such centers of origin for genetic diversity proposed by Vavilov in 1926 (Vavilov, 1992). This large genetic diversity has naturally attracted the attention of genebanks, and accessions of Ethiopian landraces are held in global collections. Besides this rich diversity of landraces, Ethiopian farmers also widely cultivate crops that were introduced through history—maize, kabuli chickpeas, potato, and sweet potato.

Through its network of genebanks, CGIAR has made improved and diverse sources of crop germplasm available to NARSs, and crop germplasm improvement has thus been a central activity of CGIAR centers in Ethiopia. Improved crop varieties developed through CGIAR research were released through a collaborative research process with the Ethiopian Institute of Agricultural Research (EIAR).

The Ethiopian seed system is predominantly government controlled, with government research institutions and parastatal companies playing a pivotal role in foundation seed production (see Appendix E). Seed assessments – projections of the demand for different varieties – are determined by local agricultural offices or extension agents for the coming cropping season. The MoA then decides on seed quantities to be produced. Several different actors are involved in the production of certified seeds. Regional seed enterprises commonly produce seeds on their own farms, but they may also contract with seed companies or seed unions or buy seed directly from farmers. Seeds produced are subsequently dispatched to the *woredas* at a price determined by regional bureaus of agriculture (BoAs) and Ethiopian seed enterprises (ESE). While farmers can specify the variety they are looking for, they are usually unaware of the seed source by the time it reaches them.

Seed producer cooperatives (SPCs) are a primary channel of seed distribution (Sisay et al., 2017). They produce seeds for a range of crops in an attempt to address local demand. Ethiopia has approximately 327 SPCs, accounting for 37 percent of total seed distributed in the country (FCA, 2016). Sharing features of both formal and informal sectors, SPCs encompass both (1) seed unions, which are legally licensed to produce and sell seeds, often through primary cooperatives; and (2) multipurpose cooperatives that do not have a license to produce seeds but work on a contractual basis with seed companies. SPCs are owned by their members and are usually managed by three committees, including a seed quality committee. Some SPCs do basic seed production, although this is rare – they typically work with researchers to organize on-farm trial demonstrations. These organizations have the opportunity to evolve into medium-scale seed enterprises (Sisay et al., 2017).

Finally, the MoA also has 72,000 development agents, who perform a wide range of tasks, including seed dissemination and promotion. Recent seed policy developments in the Ethiopian seed sector are described in section 3.4.1.

3.2.1 Barley Varieties

Ethiopia is a center of origin and diversity for barley, and landraces have been cultivated by farmers for more than 5,000 years. The country is also the top barley producer in Sub-Saharan Africa, with 3.7 million growers in 2019 (CSA, 2019).

Barley varieties are usually classified in two categories: food barley and malt barley. Breeding efforts on food barley have focused on enhancing food security through increased productivity and higher nutritional quality. Malt barley is primarily destined for the brewing industry but is also used for the production of vitamin-rich yeast extracts. Research on malt barley has concentrated on meeting the specific quality standards of malt factories. Public-private partnerships have been developed to link farmers with breweries directly. Ethiopian production of malt barley is insufficient to meet domestic demand, and the country imports nearly two-thirds of its consumption.

Since 1990 federal and regional research institutes have released a total of 65 varieties of barley. ICARDA-derived germplasms have played a role in the development of seven food barley and seven malt barley varieties (Table 4).

Table 4: Number of barley varieties released, by germplasm origin, 1990–2019

Germplasm origin	1990–1999	2000–09	2010–19	Total
Food barley				
Pure line selection NARS	4	18	17	**39**
ICARDA line/selection NARS	0	4	3	**7**
Subtotal	4	22	20	**46**
Malt barley				
Pure line selection NARS	1	2	9	**12**
ICARDA line/selection NARS	0	3	4	**7**
Private sector line/selection NARS	0	0	0	**0**
Subtotal	1	5	13	**19**
Total	**5**	**27**	**33**	**65**

CGIAR research projects on improved barley varieties include the Dryland Cereals CRP (2011–16) and the project Deployment of Malt Barley and Faba Bean Varieties and Technologies for Sustainable Food and Nutritional Security in Market Opportunities in the Highlands of Ethiopia (2014–18).

Other CGIAR projects have also worked to disseminate improved barley seeds through the establishment of public-private partnerships. One such project is Deployment of Malt Barley and Faba Bean Varieties and Technologies for Sustainable Food and Nutritional Security in Market Opportunities in the Highlands of Ethiopia (2014–18), which distributed improved varieties through a revolving seed fund. In this approach, approximately 100 kilograms of seeds were delivered to farmers, who then passed a proportion of their harvest on to other farmers to use as seed in subsequent seasons.

3.2.2 Desi and Kabuli Chickpea Varieties

Chickpea is an economically important crop that was grown by 900,000 Ethiopian farmers during the last agricultural season (CSA, 2019). Used in several Ethiopian dishes, chickpea is appreciated for its high protein content. From an agronomic perspective, chickpeas fix nitrogen, which helps to regenerate the soil, and it is generally grown in rotation with cereals. Ethiopia is the leading exporter of chickpea in Africa and the seventh-largest producer in the world. Each year, Ethiopia exports an average of 34,000 tonnes of chickpea, providing a source of cash for smallholder producers.

There are two groups of chickpeas—desi and kabuli—which differ by the size of the seed as well as by shape and color. Recent evidence from crop genetics shows that the kabuli type arose multiple times during the phase of phenotypic diversification, after the initial domestication of cultivated chickpea (Varma Penmetsa et al., 2016). Kabuli chickpeas have been the subject of ICRISAT breeding efforts, whereas ICARDA has concentrated on desi chickpeas. The large-seeded kabuli chickpea, with a cream-colored coat, is preferred for export. The term "chickpea revolution" has been coined to describe the large-scale adoption of market-preferred large-seeded kabuli chickpea varieties for export (ICRISAT, n.d.).

CGIAR research on improved chickpea varieties was conducted by the Grain Legumes and Dryland Cereals CRP (2012–16); the Tropical Legumes I, II, and III (2007–19) program; and the project Better Livelihoods for Smallholder Farmers through Knowledge-Based Technology Interventions in the Highlands of Ethiopia: Increasing Chickpea Productivity in Wheat-Based Systems (ICARDA, 2014–18). In parallel with breeding efforts, seed grower associations have also been established (Monyo and Varshney, 2016). This was also the focus of the project Better Livelihoods for Smallholder Farmers through Knowledge-Based Technology Interventions in the Highlands of Ethiopia: Increasing Chickpea Productivity in Wheat-Based Systems (2014–18).

Table 5: Number of chickpea varieties released, by germplasm origin, 1990–2019

Germplasm origin	1990–1999	2000–09	2010–19	Total
Pure line selection NARS	0	0	0	**0**
ICARDA line/selection NARS (desi type)	2	5	4	**11**
ICRISAT line/selection NARS (kabuli type)	0	8	6	**14**
Total	**2**	**13**	**10**	**25**

As suggested by Table 5, released chickpea varieties are derived almost entirely from ICARDA (desi type) and ICRISAT (kabuli type) germplasm collections. These collections were largely leveraged by the EIAR.

3.2.3 Maize Varieties

Maize, the most common cereal in Ethiopia, was cultivated by 9.8 million farmers in the last agricultural season (CSA, 2019). Crucial for food security, maize is adapted to all agroecologies of Ethiopia but is grown mostly in high-rainfall, mid-altitude areas. Maize also plays an important role in animal feed, as its leaf and stalk are conserved for livestock.

CIMMYT's collaboration with the EIAR maize-breeding program started in 1988. The first hybrid maize variety derived from CIMMYT germplasm, BH-660, was released in 1993. The Maize CRP (2012–21), as well as the Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA, 2010–18) project, have funded breeding efforts. Specific maize traits were researched through the Drought Tolerant Maize (DTMZ, 2007–13) and Drought Tolerant Maize for Africa Seed Scaling (DTMASS, 2014–19) projects. Since 2012, the Nutritious Maize for Ethiopia (NuME, 2012–19) project has aimed at developing varieties with higher protein content.

Overall, 54 maize varieties have been released in Ethiopia since 1990, and 34 of them are thought to contain CIMMYT-related germplasm (Table 6). Two varieties, released in 1986 and 2001, were created from parent lines from the International Institute of Tropical Agriculture (IITA). Varieties that contain CGIAR-related germplasm span the diversity of Ethiopian agroecologies. Ten are open-pollinated varieties (OPVs), and 25 are hybrids. In the past 20 years ten drought-tolerant varieties and eight quality protein maize (QPM) varieties have been released.

Table 6: Trend in the number of maize varieties released, by germplasm origin, 1990–2019

Germplasm origin	1990–99	2000–09	2010–19	Total
Cross NARS	4	6	0	**10**
IITA line/selection NARS	0	1	0	**1**
CIMMYT line/selection NARS	2	17	15	**34**
Drought-tolerant maize (DTMZ)[a]	*0*	*3*	*7*	***10***
Quality protein maize (QPM)[a]	*0*	*3*	*5*	***8***
Other	*2*	*12*	*4*	***18***
Private sector line	1	5	3	**9**
Total	**7**	**29**	**18**	**54**

[a] Two varieties, Melkassa-1Q and Melkassa-6Q, are considered both DTMZ and QPM.

Changes in seed policies, through the Direct Seed Marketing (DSM) program, are expected to affect varietal turnover. Representing a shift from the centralized system of seed delivery, the DSM system enables both public and private seed producers to supply adequate amounts of high-quality seed directly to farmers in specific *woredas*, in a timely fashion, and at competitive prices (see section 3.4.1).

3.2.4 Sorghum Varieties

Ethiopia is the second-largest sorghum-growing country in Eastern and Southern Africa, with an estimated 4.7 million growers in the 2018/19 main agricultural season. Ethiopia is considered a center of origin and diversity for sorghum, and four out of the five morphological races of sorghum (bicolor, guinea, caudatum, durra) are still cultivated. A dryland cereal, sorghum is most widely produced in low-rainfall areas of Ethiopia.

Sorghum breeding in Ethiopia began in universities in the mid-1950s, and the Ethiopian Sorghum Improvement Project (ESIP) was formally established in 1972. Because sorghum is known to be affected by drought during various growth stages, breeding efforts have concentrated on traits such as earliness, drought tolerance, and resistance to striga (Adugna, 2007).

Introduced materials, including ICRISAT germplasm, have been a source for released varieties. EIAR accessed 1,723 accessions of sorghum from ICRISAT global collections. Since 1990, 45 varieties have been released, and ICRISAT germplasm played a role in 20 of these (Table 7). From 2009 to 2016, three hybrid varieties containing ICRISAT-related germplasms were released (ESH-1 to ESH-3).

Table 7: Number of sorghum varieties released, by germplasm origin, 1990–2019

Germplasm origin	1990–1999	2000–09	2010–19	Total
Pure line selection NARS	2	10	13	**25**
ICRISAT line/selection NARS	1	14	5	**20**
Total	**3**	**24**	**18**	**45**

While ICRISAT involvement in sorghum research is long-standing, more recent large-scale research programs on sorghum include the Grain Legumes and Dryland Cereals CRP (2012–16) and the project Harnessing Opportunities for Productivity Enhancement (HOPE I and II, 2009–19).

3.2.5 Sweet Potato Varieties

The number of sweet potato producers has increased in recent decades, and the crop is now grown by 1.3 million farmers (during the main agricultural season). Sweet potato is used mainly for household consumption, and its flexible growing season (3–10 months) allows households to cope with the slack season, when food shortages are common. The crop requires low levels of inputs and can grow easily on degraded soils. Sweet potato has famously become a candidate crop of choice for biofortification; the breeding and dissemination of varieties enhanced with vitamin A (orange-fleshed sweet potatoes, OFSP) are a particular focus.

Projects that have focused on OFSP include Better Potato for a Better Life (USAID, 2010–16); Africa Rising (2011–21); Sweet Potato to Action for Security and Health in Africa (SASAHA, 2014–19); Quality Diet for Better Health (QDBH, 2017–21); Strengthening Institutional Systems for Scaling Up Orange-Fleshed Sweet Potato (OFSP) for Improved Nutrition and Food Security (2017–19); and Scaling Sweet Potato-Led Intervention to Improve Smallholders' Nutrition and Food security (2019–20).

Since 1990, 18 white-fleshed and 8 orange-fleshed sweet potato varieties have been released in Ethiopia. The trend in the number of varieties released since 1990 demonstrates continuous use of CIP germplasm, for both orange-fleshed and white-fleshed varieties (Table 8). All eight OFSP varieties released are the result of the CIP collaboration with EIAR.

Table 8: Number of sweet potato varieties released, by germplasm origin, 1990–2019

Germplasm origin	1990–99	2000–09	2010–19	Total
Selection NARS	5	5	1	**11**
CIP line/selection NARS (non-OFSP)	1	4	2	**7**
CIP line/selection NARS (OFSP)	1	4	3	**8**
Total	**7**	**13**	**6**	**26**

The sweet potato seed system is almost entirely informal and relies on model farms that take vine cuttings obtained from mature crops. Evidence suggests that farmers currently produce three main varieties that were released after CIP-EIAR collaborations: Awassa-83 (white-fleshed) and Kulfo and Tula (both orange-fleshed) (Gurmu & Mekonen, 2017).

3.2.6 Common Haricot Bean Varieties

Common haricot beans were grown by 2.9 million farmers in 2019 (CSA, 2019). It is an economically valuable crop, purely dedicated to export, and required by law to be traded at the Ethiopian Commodity Exchange (ECX) since 2010.

Breeding efforts started in the early 1970s, and 57 varieties have since been released. The International Center for Tropical Agriculture (CIAT) has played a role in at least 50 of these. Research efforts were conducted within the Grain Legume CRP (2011–16) and the project Tropical Legumes I, II, and III (2007–19). In 2018 CIAT and EIAR conducted a DNA fingerprinting study to assess adoption.

3.2.7 Wheat Varieties

Wheat was grown by 4.8 million farmers in the last agricultural season (CSA, 2019).[12] The Wheat CRP, along with several projects, has resulted in the release of eight rust-resistant varieties derived from CIMMYT germplasms that are still under production. Of the 133 varieties released since 1974, CIMMYT and ICARDA played a role in at least 80. As part of the CIMMYT-EIAR DNA fingerprinting project, data on adoption of improved wheat were collected in both 2016 and 2018.

Box 4. Other crop innovations

Other crop innovations included in the stocktaking are cold-tolerant rice varieties, crop variety recommendations with citizen science, diffused light storage (DLS) for potato seeds, improved faba bean varieties, improved lentil varieties, improved potato varieties, other improved rice varieties, public-private partnership for seed dissemination, and the sweet potato Triple S System.

Further details on these innovations available in the stocktaking document.

3.3 Natural Resource Management (NRM)

3.3.1 Landscape-Level Sustainable Land Management (SLM)

Ethiopia, a mountainous country, suffers from severe land degradation. In past decades, watersheds have become the predominant geo/hydrological unit for regenerating soils and for increasing farmers' resilience. The origins of research-led sustainable land management in Ethiopia can be traced back to the Africa Highland Initiative (1999–2007). During this project, the EIAR established integrated watershed management research units in every regional center, with the objective of scaling up watershed management approaches. The approach soon attracted the interest of the Government of Ethiopia, which has committed to scaling up resilient landscape development interventions through national Sustainable Land Management Projects (SLMPs).

In 2008 the World Bank provided funds through the first Sustainable Land Management Project (SLMP-I, 2008–13). It was followed by SLMP-II (2013–18) and is currently formulated as the Ethiopian Resilient Landscapes and Livelihoods Project (ERLL, 2019–24). At the time of writing, MoA interventions had been supported in a total of 223 major watersheds in the regions of Amhara, Benishangul-Gumuz, Gambella, Oromia, SNNPR, and Tigray. Adapted to the local context, the watershed-level interventions include terracing, trenches, check-dams, area closures, afforestation, agroforestry, climate-smart agriculture, and the rehabilitation of gullies produced by soil erosion.

[12] This figure includes white and red haricot beans, following the CSA categorizations.

Although this approach emerged in Ethiopia with the help of the original African Highland Initiative, the large-scale government programs that followed did not directly involve CGIAR centers. Among the sustainable land management practices disseminated during the three phases of these projects, there is no obvious marker of CGIAR research we can readily identify. A large majority of these practices are internationally recognized, and the SLMP design follows information provided by the World Overview of Conservation Approaches and Technologies (WOCAT, 2020).

CGIAR centers directly involved in their own SLM activities in Ethiopia include CIAT, World Agroforestry (ICRAF), ICRISAT, and the International Water Management Institute (IWMI). Several projects have conducted activities in selected watersheds, including the Water Land and Ecosystems CRP (2012–21), the Nile Basin Development Challenge (NBDC, 2010–13), Improved Capacity in Rainwater Management (ICRAF, 2008–11), REACH Water Security and Local Monitoring (IWMI, 2016–17); Feed the Future Innovation Lab for Small-Scale Irrigation (ILSSI, 2013–18), ILSSI II (2018–23), and Support to the Horn of Africa Resilience (SHARE, EU, 2017–19). These projects have focused on selected watersheds and disseminated a set of context-specific innovations.

Such watershed-level SLM practices partly overlap with farm-level agronomic or NRM practices, documented in the following four subsections.

3.3.2 Agricultural Water Management (AWM) Innovations

The GoE has made massive investments in irrigation structures in recent decades. Currently an estimated 300–400 irrigation schemes are in operation, covering 1.4 million hectares of agricultural land. The Agricultural Growth Program (AGP), for instance, has supported irrigation schemes in 157 districts (MoA, 2015a).

Among CGIAR projects, AWM innovations have been the focus of the AgWater Solutions Project (2009–12); Livestock and Irrigation Value Chains for Ethiopian Smallholders (LIVES, 2012–18), Africa Rising (2011–21) and ILSSI (2013–23). These projects have focused on developing value chains linked to irrigation (fruits, vegetables, and fodder) and piloting small-scale irrigation technologies to support them. Among the AWM options deemed to be technically feasible and affordable for smallholder farmers, IWMI has studied and promoted river stream diversion, motorized pumps, treadle pumps, and soil water conservation activities.

3.3.3 Broad Bed Maker (BBM)

The broad bed maker is an innovation developed by ILRI in the late 1980s. Designed specifically for vertisols, the BBM is an oxen-drawn plow developed for Ethiopian conditions that helps alleviate and prevent waterlogging. It is made out of two *mareshas* – traditional Ethiopian ard ploughs – that are connected in a triangular structure. The BBM is part of a wider technology package along with improved seeds, fertilizer, herbicides, pesticides, credit, and training. The innovation was generated by the Joint Vertisol Project (1986–1991).

Between 1995 and 1998 the Ethiopian Bureau of Agriculture (BoA) bought approximately 2,400 BBMs. The largest numbers of BBMs were supplied in North-West Shewa, West Shewa, and East

Gojam zones (Rutherford et al., 2001) and the MoA endorsed the innovation. In 2004 the design of the BBM evolved into a single-beam *maresha*. The innovation has been scaled up by Aybar Engineering (http://www.aybareng.com/index.php), a company founded by a former EIAR staff member. This company, with 432 branches all over the country, has been manufacturing BBMs since 2017.

3.3.4 Conservation Agriculture (CA)

Conservation agriculture (CA) consists of a set of principles for on-farm natural resource management—namely, minimal mechanical disturbance of the soil, permanent soil cover, and diversification of crops cultivated on any given plot. Farmers can follow a variety of practices to fulfill these principles. Minimum soil disturbance may involve zero or minimum tillage, ripping, basin planting, or other practices. Farmers may retain crop residues covering at least 30 percent of the soil surface (following a rule of thumb promoted by the Food and Agriculture Organization of the United Nations) or plant cover crops between seasons. And they may practice either crop rotation (cereals one season, a legume the next) or intercropping (in which cereals are planted with a legume).

Conservation agriculture-based sustainable intensification been researched and promoted as part of the project Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA, 2010–18).

3.3.5 Tree Seed Centers

Since its establishment in Ethiopia, the World Agroforestry Center (ICRAF) has been promoting better access to high-quality planting seeds for trees. Research programs such as Trees for Food Security Project I and II (T4FS, 2012–14 and 2017–20) and Provision of Adequate Tree Seed Portfolio in Ethiopia (PATSPO, 2017–20) have worked to establish and scale up tree seed centers, breeding seed orchards, and rural resource centers. Species include fruit trees (avocado, mango, papaya) as well as multipurpose and ornamental trees (*Cordia africana, Grevillea robusta, Croton macrostachyus,* and *Acacia abyssinica*).

These efforts to increase access to high-quality planting material have the potential to help to achieve the Green Legacy Challenge project. With support from Norway, Sweden, and the United Nations Development Program (UNDP), GoE has pledged to plant 20 billion trees under the Green Legacy Challenge project within the next few years.

Ethiopia currently has 1.9 million avocado growers (CSA, 2019). The fruit is both nutritionally valuable and economically important: Ethiopia is one of the top five avocado producers in Sub-Saharan Africa. It is also home to 1.6 million and 700,000 mango and papaya growers, respectively (CSA, 2019).

Box 5. Other NRM innovations

Innovations included in the stocktaking include farmer-managed natural regeneration (FMNR), forest-landscape restoration, integrated termite management (ITM), option by context interaction (O x C), and *woreda* participatory land use planning (WPLUP).[13]

Further details on these innovations are available in the stocktaking document.

3.4 Innovations in Government Policy

This subsection details five major initiatives of the Ethiopian government. These are highlighted here as each has a plausible link to CGIAR policy research in some capacity, has onward links to embodied innovations that can be measured in survey data, and represents a significant scale and potential to foster adoption of these embodied innovations. For example, the Direct Seed Marketing (DSM) program has the potential to speed up the dissemination of improved maize varieties in Ethiopia. The Livestock Master Plan (LMP) and Market-Oriented Extension (MOE) policy guidance have established recommendations for increased use of artificial insemination and livestock crossbreed adoption. The Productive Safety Net Program (PSNP) program, through the use of community labor, may have promoted the spread of labor-intensive natural resource management practices, particularly physical structures. Finally, the creation of water users associations (WUA) offers an institutional framework for medium- and large-scale irrigation structures to be built in Ethiopia.

3.4.1 Direct Seed Marketing (DSM)

The GoE introduced the Direct Seed Marketing (DSM) system in 2011 as a pilot program into two *woredas* of the Amhara region, together with Integrated Seed Sector Development (ISSD) as partner. The DSM system aims to enable public and private seed producers to supply adequate amounts of high-quality seed directly to farmers in convenient locations, in a timely fashion, and at competitive prices through their own sales staff or agents, which can include farmers' primary cooperatives and cooperative unions (MoA & ATA, 2014). Although the government still operates the conventional seed-marketing system through the MoA, the DSM represents a partial liberalization of the seed sector.

The MoA has a mandate to oversee the implementation of DSM across the country, and the ATA's role is to support evidence-based decision-making to strengthen the seed system (Mekonen et al., 2019). In 2013 the International Food Policy Research Institute (IFPRI) undertook an ex ante impact assessment of the DSM program (Benson et al., 2014), based on the results of the original ISSD pilots. The findings demonstrated positive results on several dimensions and provided support for scaling up the program. The MoA and the ATA subsequently agreed to expand the program in 2015–16 (PIM, 2019). IFPRI followed up with a second study in 2015 showing that DSM performed as well as conventional seed marketing

[13] Two innovations previously mentioned in Kosmowski et al. (2019b) were not retained in the stocktaking given limited evidence on specific research efforts in Ethiopia.

while significantly reducing public expenditure and that farmers were satisfied with the new system.

In 2018 DSM was expanded to 228 *woredas* covering 63 percent of seed supply in the four major regions: 45 percent in Amhara and SNNPR, 56 percent in Tigray, and 74 percent in Oromia. In March 2018 the MoA enacted Seed Marketing Guidelines and a Certificate of Competence for the One-Stop-Shop Directives. Currently, DSM coverage has increased to more than 290 *woredas*. Crops now operational under DSM include maize, teff, and wheat.

3.4.2 Livestock Master Plan (LMP)

The development of the Livestock Master Plan (Shapiro et al., 2015) was a collaborative process led by ILRI. ILRI researchers and partners used their modeling expertise to identify investment interventions in three key livestock value chains—poultry, crossbred dairy cows, and red meat. The identified series of five-year development plans are to appear in Ethiopia's Growth and Transformation Plan (GTP II) as a guide for public and private investments. The ultimate objective is to lift more than 2 million households out of poverty and impact more than 2.3 million of Ethiopia's 11 million livestock-keeping households (Randolph, 2018).

In addition to the GoE, various actors including the World Bank have used the LMP to shape their investments. The World Bank/MoA Livestock and Fisheries Sector Development Project (LFSDP, 2017–24) exemplifies the wider influence the LMP has had on livestock policies. The LMP provides a clear policy framework for fostering the adoption of animal agriculture innovations in Ethiopia.

3.4.3 Market-Oriented Extension (MOE)

The projects Improving the Productivity and Market Success of Ethiopian Farmers (IPMS, 2004–12) and Livestock and Irrigation Value Chains for Ethiopian Smallholders (LIVES, 2013–18) have promoted market-oriented agricultural development in Ethiopia. ILRI and IWMI designed and implemented these projects.

These large-scale projects aimed to kick-start a shift from production-oriented to market-oriented extension services in economically important agricultural commodities. Training was organized, and guidelines have been published (Gebremedhin et al., 2012). Extension workers were trained in skills including better production planning, collection and communication of market-related information, linking of farmers to buyers, support for collective marketing, and building the marketing capacity of producers.

Following the IPMS project, the MoA adopted a more market-oriented approach to extension as part of its Growth and Transformation Plan (GTP I). Markers of this policy influence include a change of discourse at the government level, with more attention given to the formal livestock sector (for example, discussion of increasing the coverage and effectiveness of artificial insemination and improving systems of forage seed supply). The mandate of extension services was also formally extended to include these newly acquired market-related skills.

3.4.4 Productive Safety Net Program (PSNP)

Ethiopia's national Productive Safety Net Program (PSNP), funded by the GoE and the World Bank, has been operational since 2005. Most PSNP beneficiary households (80 percent) receive payments for undertaking public works such as road construction and maintenance, small-scale irrigation, and reforestation (World Bank, 2013). A small proportion of beneficiaries (largely households with elderly or disabled members) receive unconditional cash payments and food transfers. This scheme is regarded as a success for its role in reducing rural poverty.

The program has used a combination of geographic and community-based targeting to identify households in chronically food-insecure *woredas*. Over its four phases, the PSNP program has expanded from 262 chronically food insecure *woredas* in 2005 to more than 318 *woredas* today. In addition to the four main regions (Amhara, SNNPR, Oromia, Tigray) the regions of Afar, Somalia, Dire Dawa, and Harari were later included (MoA, 2015b). The fourth phase of the PSNP supports approximately 8 million people (Berhane et al., 2017).

Since the inception of the program in 2005, IFPRI, working with the government of Ethiopia and development partners, has offered policy support. Based on data on PSNP beneficiaries collected by the Central Statistical Agency (CSA), IFPRI has provided biannual assessments of the program's impact. This work has resulted in improvements in key aspects of the program design, increased the program's efficiency, and shaped decisions about scale-up (PIM, 2017).

3.4.5 Water Users Associations (WUA)

Ethiopia has made massive investments in irrigation structure in recent decades through its Agricultural Growth Program (AGP). According to a recent estimate, medium- and large-scale irrigation schemes cover 400,000 ha of agricultural land (WOCAT, 2020).

To function efficiently, irrigation schemes need an institutional framework. In 2014 IWMI was involved in drafting the "Irrigation Water Users' Associations Proclamation No. 841/2014" (FDRE, 2014). Following Act 841/2014, IWMI published two training manuals: "Establishing and Strengthening Irrigation Water Users Associations" (Lempériere et al., 2014) and "How to Support Effective and Inclusive Irrigation Water Users' Associations: A Guide for Practitioners" (Merrey & Lefore, 2018). These manuals, which support the development of specialized formal WUAs for creating or collectively managing irrigation schemes, were used to train people and support the regional governments of Tigray, Amhara, Oromia, and SNNPR. In addition, IWMI has researched the performance of WUAs.

Box 6. Other policy innovations

Government policy innovations included in the stocktaking include acidic soils mitigation with lime marketing (2018); agronomy data-sharing policy (June 2019); artificial insemination scaling up through hormonal estrus synchronization; community conversations for women's empowerment; creation of the National Watershed and Agroforestry Multi-Stakeholder Platform (NWAMP, 2019); Food Safety Index performance; forage seed certification; health-first, risk-based, and market-led investments for food safety (2018); institutionalization of land certification; estimation of irrigated areas; water pricing for irrigation schemes (to be enacted in 2020); land use planning for rangelands (2018); mobile and real-time plant disease diagnostic (MARPLE); Monitoring and Evaluation for Land in Africa (MELA, 2007–present); National Livestock Market Information System (NLMIS); nutrition-sensitive policies; soil fertility Information systems; tax exemption for small-scale irrigation (Ref. No. 30/7/35, 2019); video-mediated extension services (2017); and mainstreaming of the watershed approach into the National Agricultural Research Centers (NARC) and subsequently into policies (2000–present).[14]

Further details on these innovations are available in the stocktaking document.

[14] One innovation previously mentioned in Kosmowski et al. (2019b) was not retained in the stocktaking document: multiple-use water services (MUS). We could not find evidence of policy influence.

4. Adoption Rates and Changes

In this section, we discuss adoption rates for the CGIAR-related innovations for which data were collected as part of the Ethiopian Socioeconomic Survey (ESS). Each of the core domains of CGIAR activity feature in the ESS in some capacity: there are five innovations on animal agriculture, eight on crop germplasm improvement, and five on natural resource management, as well as two that can be traced to the influence of CGIAR research through government policy interventions. Here we report national and regional estimates and, when possible, make use of the two survey waves during which adoption data were collected. We further link these adoption estimates with previously published estimates from the literature.

The innovations included in the stocktaking include both embodied and disembodied innovations. As a result, only some innovations will exhibit clear markers of CGIAR research—OFSP is a prototypical example. Other innovations on which we report data may have been the subject of CGIAR research, but our reporting the adoption statistics here does not imply that those figures are attributable to CGIAR. CGIAR researchers have worked on avocado planting and on soil and water conservation practices in Ethiopia, but not every farmer we observe growing avocado trees or using soil and water conservation practices does so as a result of CGIAR research. This section hence discusses the interpretations of the nationally representative statistics reported on the reach of CGIAR-related innovations for each innovation separately, as the implications are heterogeneous across innovations and research domains.

Table 9 reports the nationally representative estimates, drawing mostly on the 2019 data (ESS4) but including 2015 estimates (ESS3) when more recent ones are not available. We also compare these new nationally representative estimates with prior estimates on adoption rates in the literature. Table 28 in Appendix F reports additional estimates from 2015/16 to illustrate any short-term changes in adoption rates.

As explained in section 2, adoption rates in Table 9 are calculated for different subpopulations. This is in part because the most relevant subpopulations differ between innovations. For example, when measuring the adoption of crossbred poultry, animal-owning households are the relevant group. When measuring adoption of kabuli chickpea varieties, or of conservation agriculture, then crop-cultivating households are the most relevant group. In column 2 of Table 9 we report the share over the population as defined in column 3, which is a broadly defined relevant population (animal-owning households, crop-cultivating households, all rural households etc). We do so because innovations can both lead farmers that were already growing a specific crop, or rearing a given type of animal, to shift to an improved variety or breed, but can also induce households to start growing particular crops, or to start rearing particular animal types. Representing the shares over these broadly defined relevant populations (defined in column 3) also facilitates comparisons between different innovations.

In column 4 of Table 9 we then report the share of households with a given crop or animal innovation among the subset of households cultivating that specific crop or animal. This corresponds to adoption rates more typically reported in other referenced work, so facilitates that type of comparison. It also maps into the particular samples used to calculate some of the adoption rates: notably, because the DNA fingerprinting data for maize, barley, and sorghum were collected specifically among households cultivating those particular crops, the adoption rates for CGIAR maize, barley, and sorghum varieties can be calculated as the share of households that grow those particular crops.

Finally, column 5 in Table 9 also reports the total estimated number of households for which we could find observable characteristics of each innovation. Because these are absolute numbers, they are directly comparable between different innovations, and they represent the estimated total number of households in rural Ethiopia reached by each innovation.

All results refer to the number or share of households or EAs with a given innovation. For the crop and NRM innovations, it would undoubtedly also be interesting to know the total area under cultivation with given innovations. However, because the ESS is representative at the household level but not at the area level, it does not allow us to reliably calculate such area estimates.

Table 9: Adoption rates at enumeration area (EA) and household levels (in %), and estimates for the absolute numbers of households

	% of rural EAs	% of households with innovation (among households defined in next column)	Conditions applied	% of households with innovation among household with the specific animal/crop	Estimated number of households
	(1)	(2)	(3)	(4)	(5)
Animal agriculture					
Artificial insemination use	5.6	1.1	Animal-keeping households	1.3	142,090
Crossbred large ruminant	20.9	6.6	Animal-keeping households	7.7	851,446
Crossbred small ruminant	1.5	0.3	Animal-keeping households	0.6	42,871
Crossbred poultry	53.2	13.1	Animal-keeping households	21.3	1,758,000
Forages	4.5	2.2	Animal-keeping households	N/A	279,339
Crop germplasm improvement					
CGIAR barley varieties	33.5*	3.9	Crop-cultivating households[a]	18.6	462,985
CGIAR maize varieties	78*	34.2	Crop-cultivating households[a]	62.6	4,071,507
CGIAR sorghum varieties	2*	0.3	Crop-cultivating households[a]	1.1	30,645
Chickpea kabuli varieties	16.3	4.7	Crop-cultivating households[a]	52.9	677,591
Orange-fleshed sweet potato varieties	5.2	1.1	Crop-cultivating households[a]	15.9	133,112
Awassa-83 sweet potato varieties	9.4	3.5	Crop-cultivating households[a]	52.1	436,449
Common bean varieties[b]	N/A	N/A	N/A	29 % of plots	N/A
Wheat varieties[c]	N/A	N/A	N/A	95 % of area	N/A

	% of rural EAs	% of households with innovation (among households defined in next column)	Conditions applied	% of households with innovation among household with the specific animal/crop	Estimated number of households
	(1)	(2)	(3)	(4)	(5)
Natural resource management					
River diversion	16.2	5	Crop-cultivating households[a]	N/A	685,148
Motorized pumps	6.1	1.3	Crop-cultivating households[a]	N/A	350,913
SWC practices	89.2	71.6	Households with cultivated, pasture, fallow, or forest land[a]	N/A	9,443,849
Broad bed maker	4.8	0.5	Crop-cultivating households[a]	N/A	64,814
Conservation agriculture (min. tillage)	18.5	4.3	Households with cultivated, pasture, fallow, or forest land[a]	N/A	550,237
Conservation agriculture (zero tillage)	7	1.3	Households with cultivated, pasture, fallow, or forest land[a]	N/A	161,628
Afforestation	34.6	9.9	Households with cultivated, pasture, fallow, or forest land[a]	N/A	1,218,463
Mango	28.3	9.9	Crop-cultivating households[a]	N/A	1,237,414
Papaya	17.5	4.3	Crop-cultivating households[a]	N/A	538,461
Avocado	27.4	10.6	Crop-cultivating households[a]	N/A	1,322,893
Policy influences					
Productive Safety Net Program (PNSP)	36.1	12	Rural households	N/A	1,303,080
Water users associations	57.7	N/A	Rural EAs	N/A	N/A

Note: All estimates are based on ESS4, with the exceptions of chickpea types and the broad bed maker, which are estimated based on ESS3. All estimates use sampling weights to calculate the shares of EAs and households. Estimates in column 2 are calculated as shares over the populations defined in the “conditions applied” column. Estimates in column 4 are calculated as shares over the estimated populations of households with the specific type of animal (large ruminant, small ruminant, poultry) or crop (barley, maize, sorghum, chickpea, sweet potato).

[a] Where crops include both seasonal and permanent crops.

[b] Habte Endeshaw and Enid Katungi, personal communication

[c] Jaleta et al. (2020)

* Percentage of EAs calculated only over EAs with the specific crop.

4.1 Animal Agriculture

4.1.1 Delivery of Improved Dairy Genetics

Adoption estimates from the literature are relatively scarce. Tesfaye et al. (2016) estimate adoption of crossbred dairy cows based on data collected on 1,630 households in eight zones in the Oromia region, using farmers' elicitation methods. They find an overall adoption rate of 28 percent, with North Shewa exhibiting the highest adoption rate (73 percent) and West Hararghe the lowest (3 percent). Tamru (2020) reports on changes in Ethiopia's dairy sector from 2004 to 2014. Dairy farmers have increasingly adopted artificial insemination (AI); Tamru notes an 11-fold increase in AI practices, from 230,000 calves born in 2005. The share of crossbred dairy cows also grew considerably from 2004 to 2014. This positive dynamic starts from a low base and is driven by income growth and urbanization.

In the nationally representative ESS data from 2019 the use of artificial insemination services for dairy cows at the national level reached an estimated 1.1 percent of animal-owning households (Table 9). While this figure at the household level is similar between the two ESS surveys, EAs with adopters of artificial insemination services decreased from 12.5% in 2016 to 5.6% in 2019, suggesting an increasing concentration in locations where AI services operate.

At the national level, 6.6% of animal-owning households declared keeping a large ruminant crossbreed in 2019 (Table 9). These animals can be found in one-fifth of enumeration areas, suggesting that few households in each area keep such breeds (15% on average). As with artificial insemination services, one observes a decrease in the number of EAs with households keeping crossbred large ruminants, from 31% in 2016 to 21% in 2019. Adoption is slightly higher in urban areas (9% of households).

In 2019 we estimate that 851,446 households owned a large ruminant crossbreed while 142,090 households had used artificial insemination services. Not all of these households, of course, would necessarily have benefited from CGIAR research on dairy genetics.

4.1.2 Delivery of Improved Genetics through Community Approaches

In 2019 the share of rural households that kept a crossbred small ruminant was less than 1%, representing an estimated 42,871 rural households (Table 9). Slightly more small ruminant crossbreeds are found in urban areas (4% of households; see Table 29 in Appendix G).

4.1.3 Improvement and Delivery of Improved Chicken Breeds

Adoption studies on improved chicken breeds in Ethiopia are rare. Tsadik & Tamir (2015) examined the adoption of crossbred chickens in three *woredas* in the Oromia region (Wolmera in the highlands; Ade' a, mid-altitude; and Boset, lowlands). Using farmers' self-reporting of 180 samples, the study found that 40.6% of households adopted chicken crossbreeds. Adoption varied by agroecology: rates were 51.7% for highlands, 33.3% for mid-altitude, and 36.7% for lowlands.

The nationally representative ESS data from 2019 show that more than half of the rural enumeration areas had at least one adopter of a poultry crossbred animal (53% of rural EAs, see Table 9). Adoption estimates at the household level were 13% of animal-owning households, or 1.76 million households, suggesting widespread adoption. Similar levels of adoption were observed in urban areas. Not all of these households, of course, would necessarily have benefited from CGIAR research on improved chicken breeds. On average, for the subset of EAs where there is at least one household growing improved chicken breeds, the rate of diffusion is 27%. These figures are significantly higher than in ESS3 in 2015/16, when adoption of crossbred chickens could be seen in only a quarter of the EAs and 4.8% of households in aggregate (urban and rural), suggesting a substantial diffusion of crossbred chicken in the three years between the survey waves.

4.1.4 Facilitating Access to Improved Forage Varieties

Using a panel survey of 212 farmers (1993–1997), Gebremedhin et al. (2003) examined the adoption of oats–vetch in three *woredas* in Addis Ababa, Holetta, and Addis Alem. The study found that 56% of adopters allocated 0.5 ha or less to oats–vetch. Bashe et al. (2018) similarly studied the adoption of other forages (desho grass, elephant grass, pigeon pea, and cowpea) in Sodo Zuria *woreda*, (SNNPR). Using a sample of 121 households, they found a 64% rate of adoption, based on farmers' self-reporting.

The ESS data from 2019 shows that forages (specifically Napier grass, Rhodes grass, sesbania and alfalfa) have limited levels of adoption (2.2% of animal-owning households, see Table 9). Among these forages, alfalfa has the hightest adoption (present in 4.2% of EAs and 1.7% of households). These figures are constant between the two ESS surveys (see Table 28 for a comparison). An estimated 279,367 households adopted improved forage grasses in 2019. Data from the ESS surveys also reveal that industry by-product feeds are somewhat more common than forage grasses. These manufactured products can be found in 13% of Eas and were used by 3% of households in 2019.

4.2 Crop Germplasm Improvement

We report adoption estimates from ESS—for barley, maize, and sorghum varieties (using DNA fingerprinting) and for sweet potato varieties and chickpea variety types (using visual-aid protocols)—as well as from other sources. In recent years, DNA fingerprinting studies have also been carried out on common bean (by CIAT) and wheat (by CIMMYT) in Ethiopia. These surveys were designed with different objectives from those that have guided SPIA's country-level approach [15] and are thus not directly comparable with estimates for the other crops. However, the adoption estimates from these studies are reported here for completeness and in light of the importance of the crops for farmers in Ethiopia.

4.2.1 Barley Varieties

Estimates of improved barley adoption have previously been published. Using a sample of 1,469 households in Amhara, Oromia, and SNNPR, Yirga et al. (2017) reported adoption rates of improved barley at 37%, based on farmers' self-reported data. Based on expert opinion, Yigezu et al. (2015) estimated that 29% of barley farmers were growing improved varieties at a national level.

In ESS4 barley varieties were identified using a representative sample of barley growers collected in four regions: Amhara, Oromia, SNNPR, and Tigray. Seed samples were analyzed with DNA fingerprinting. The reference library comprised 41 of the 46 food barley varieties released and 17 of the 19 malt barley varieties released in Ethiopia since 1990. No outright landraces were included, but many of the improved varieties are pure line selections from landraces. All varieties containing ICARDA-derived germplasm were present in the reference library.

The origin of released varieties can be broken down into three categories: pure lines selected from landraces, CGIAR-derived germplasm, and germplasm derived from the private sector (Heineken, Meta Abo, or GMS). At the household level, 19% of barley producers planted a variety with CGIAR germplasm (identified with at least 70% purity level). [16] This translates to a total of 462,985 households that cultivated barley with CGIAR origin. The three varieties with CGIAR germplasm most commonly adopted by farmers were HB-1966 (10%), Miscal-21 (2%), and Tilla (1%).

[15] These data sources are representative at different levels and do not necessarily include data on households' socioeconomic status and other variables used to document reach.

[16] Four percent of households grew a barley variety for which the purity level of the sample was less than 70%.

Table 10: Distribution of barley by variety planted during the 2018/19 growing season

Variety	N	% of barley samples	Variety type	Age (years since release)	Breeder/ maintainer	Origin/pedigree
Felamit[a]	75	30.1	Food	8	Mekelle University	Landrace—pure line selection
Estaysh[a]	60	24.1	Food	15	Sirinka ARC	Landrace—pure line selection
Abay[a]	27	10.8	Food	21	Adet ARC	Landrace—pure line selection
HB-1966	25	10.0	Food	2	Holeta ARC	ICARDA pure line
HB-52	16	6.4	Malt	18	Holeta ARC	EIAR cross
Adena[a]	14	5.6	Food	3	Mekelle University	Landrace—pure line selection
Miscal-21	4	1.6	Malt	13	Holeta ARC	Crossing and selection by ICARDA
Setegn	5	2.0	Food	15	Adet ARC	Landrace—pure line selection
Traveller	3	1.2	Malt	6	Holeta ARC	Heineken cross, selection by EIAR
Mezezo[a]	2	0.8	Food	15	Debre Birhan ARC	Landrace—pure line selection
Wolelay[a]	2	0.8	Food	3	Mekelle University	Landrace—pure line selection
Holker	1	0.4	Malt	40	Holeta ARC	EIAR cross—Holetta mixed/Kenya research
Tilla	1	0.4	Food	12	Adet ARC	Crossing and selection by ICARDA
Not identified	14	5.6	N/A	N/A	N/A	N/A

Note: Varieties are from the National Variety Registry of the MoA.

N/A = not applicable

[a] These varieties have an insignificant level of genetic separation from each other in the reference library.

ARC = Agricultural Research Center.

Table 10 further describes the varieties identified, along with their characteristics, and provides four insights. First, food barley varieties comprised 85% of samples, and 10% were identified as malt barley varieties. Five percent of seeds could not be identified—either the purity was too low to be matched to an existing reference library sample, or the variety was simply not present in the reference library. Of the varieties that were identified, 80% of samples had at least 95% purity.

Second, a group of varieties that are pure lines selected from local landraces could not be distinguished from each other with a high level of confidence: Felamit, Estaysh, Abay, Adena, and Wolelay. Thus, we are cautious in attributing the precise identity of these seeds. These varieties were spatially widespread and found in all regions sampled.

Third, the most-adopted CGIAR-derived variety is a very recently introduced food barley variety, HB-1966 (Tsige et al., 2019). This variety was found on one-tenth of the plots sampled. The second-most adopted CGIAR-derived variety, Miscal-21 is a malt barley variety; a previous study under the Diffusion and Impact of Improved Varieties in Africa (DIIVA) project identified

Miscal-21 as the most widely-adopted (Walker et al., 2014). More than half of the samples identified as one of these CGIAR-derived varieties had purity levels above the 95% threshold.

The average age of varieties in farmers' fields has been proposed as a metric for monitoring varietal turnover and, by implication, the effectiveness of breeding programs and extension systems (Brennan & Byerlee, 1991; Atlin et al., 2017). In 2019 the average age of barley varieties in plots in the ESS sample was 11 years. Food barley varieties are, on average, from more recent releases (mean year of release 2008) than malt barley varieties (2004). Driven by adoption of the 2017-released HB-1966, the average age of the CGIAR-derived varieties across plots in the sample was four years.

4.2.2 Chickpea Desi and Kabuli Varieties

Chickpea desi and kabuli types differ by seed size, shape, and color as well as by flower color. Kabuli types have white flowers, while desi types have purple flowers. We use this phenotypic difference to identify the type of chickpea grown by households in ESS3 (see the protocol in Appendix A). Kabuli varieties were introduced into Ethiopia through plant breeding, and all such varieties contain CGIAR-derived germplasm. In contrast, among the desi varieties there are both local and improved varieties (and the visual aid protocol does not allow for distinguishing between the two).

Alemu & Bishaw (2019) report the results of a survey in 36 *kebeles* [17] from 18 chickpea-producing *woredas* in Amhara and Oromia regions in 2017. They find one-third of households engaged in improved kabuli production, 57% engaged in desi production, and 10% engaged in both. These estimates are based on farmer's self-reported data.

Using a panel survey from 2007 to 2014, Verkaart et al. (2019) document the diffusion of improved chickpea varieties in three *woredas* in Amhara region. In these *woredas*, the adoption of improved chickpea varieties rose from 30 to 80%. This change was driven by improved kabuli varieties, for which adoption increased from 30 to 73%, while adoption of desi varieties rose only from 2 to 5.6%. Yigezu et al. (2015) report that expert focus groups found 19% adoption of improved varieties at the national level; the most-adopted varieties were Arerti, Shasho, Habru, and Natoli.

The nationally representative data from ESS3 for 2016 show that 4% of rural households were growing desi and 5% were growing kabuli varieties. This finding translates to 677,591 adopters of chickpea with a clear marker of CGIAR origin (i.e., all the kabuli varieties) in 2016.

4.2.3 Maize Varieties

The transformation of the maize sector in Ethiopia has been well documented (e.g., Abate et al., 2015; Bachewe et al., 2018). The past two decades have seen an expansion of the area cultivated to maize—at a rate of 4% a year—along with an estimated average annual increase in productivity of 6.3% from 2004 to 2013. Average yields in Ethiopia have reached 3 tonnes/ha, compared with an average of 1.8 tonnes/ha in Sub-Saharan Africa as a whole (Abate et al.,

[17] A *kebele* is smallest administrative unit in Ethiopia, smaller than a *woreda*.

2015). Using the AgSS survey, Abate et al. (2015) estimate that in 2013, 40% of maize area was cultivated with maize varieties released after 1973.

Zeng et al. (2015) surveyed 1,396 households from 30 *woredas* in Oromia, Amhara, Tigray, and SNNPR. The data are self-reported by farmers and suggest an adoption rate of improved varieties of maize of 39.1% by area. A panel survey in nine *woredas* located in Oromia, SNNPR, and Benishangul-Gumuz was carried out in 2011 and 2013 by Yirga et al. (2017). Adoption of improved varietals was assessed using farmer's self-reported data for a sample of 898 households. Authors found adoption rates equivalent to 84% and 88% of maize growers in the two survey waves. It was also reported that half of the maize growers were cultivating a single improved variety released in 1995, BH540. Jaleta et al. (2018) used a sample of 2,327 households from 39 districts in five regions of Ethiopia (Amhara, Benishangul-Gumuz, Oromia, SNNPR, and Tigray). Based on farmers' self-reported data, they found that over a quarter of households (27%) were adopters of improved maize varieties.

ESS4 identified maize varieties by using DNA fingerprinting of the crop-cuts as described in section 2.4. Data from a representative sample of maize growers were collected in six regions: Amhara, Dire Dawa, Harar, Oromia, SNNPR, and Tigray. The reference library, used by CIMMYT in an earlier DNA fingerprinting project, was composed of all released maize varieties and their parent lines (Appendix D).[18] All field samples are estimated to be above the 70% purity threshold, with 90% of samples having purity above 90% and 53% above the 95% threshold.

CGIAR-related germplasm was identified on maize plots grown by 62.6% of maize-growing households in 2019. This translates to a total of 4,071,507 households that cultivated maize with CGIAR germplasm in 2019.

[18] While nationally representative data on maize DNA fingerprinting were already collected in Ethiopia by EIAR/CIMMYT in the AgSS survey, given the importance of the crop and the available evidence on high levels of improved maize adoption, maize data were also collected in the ESS4 in order to obtain a more recent estimate (given recent policy changes in the sector), to analyze whom these innovations are reaching and where, and to capture synergies between innovations from the perspective of the CGIAR system (see section 7).

Table 11: Distribution of maize by variety planted during the 2018/19 growing season

Variety	Number of maize samples	% maize samples	Variety type	Age (years)	Breeder/maintainer	Origin/pedigree
Gibe-1[a]	130	25.7	OPV	18	Bako ARC	EIAR
Kuleni[a]	68	13.4	OPV	24	Bako ARC	CIMMYT/EIAR
BH-661[a]	61	12.1	Hybrid	8	Bako ARC	CIMMYT/EIAR
BH-660	52	10.3	Hybrid	26	Bako ARC	CIMMYT/EIAR
BH-540	45	8.9	Hybrid	24	Bako ARC	EIAR
Shone	38	7.5	Hybrid	13	Pioneer Hi-Bred Seeds	Crossing by Pioneer Hi-Bred
Limu	28	5.5	Hybrid	7	Pioneer Hi-Bred Seeds	Crossing by Pioneer Hi-Bred
Melkassa-2	26	5.1	OPV	15	Melkassa ARC	CIMMYT/EIAR
AMH-850	26	5.1	Hybrid	11	Ambo ARC	EIAR
BH-140[a]	10	2.0	OPV	31	Bako ARC	EIAR
Damote	6	1.2	Hybrid	4	Pioneer Hi-Bred Seeds	Crossing by Pioneer Hi-Bred
AMH-852Q	5	1.0	Hybrid	3	Ambo ARC	CIMMYT/EIAR
Jabi	5	1.0	Hybrid	24	Pioneer Hi-Bred Seeds	Crossing by Pioneer Hi-Bred
BH-670	3	0.6	Hybrid	17	Bako ARC	EIAR
Melkassa-1	2	0.4	OPV	18	Melkassa ARC	CIMMYT/EIAR
Melkassa-1Q	1	0.2	OPV	6	Melkassa ARC	CIMMYT/EIAR

Note: Varieties are from the National Variety Registry of the MoA. OPV = open pollinated variety. ARC = Agricultural Research Center. EIAR = Ethiopian Institute of Agricultural Research. CIMMYT = International Center for Maize and Wheat Improvement.

[a] These varieties were identified through two different seed sources in the reference library.

Varietal-level identification reveals interesting insights about current evolutions in the maize seed sector in Ethiopia (Table 11). Open-pollinated varieties (OPVs) account for 47% of the samples collected. Two OPV varieties, Gibe-1 and Kuleni, were dominant, grown by 40% of sampled plots. Gibe-1, a variety released in 2001, has been reported to be favored by farmers because of its high mean grain yield and stability (Elmyhun & Mekonen, 2016). The adoption of hybrid varieties is dominated by three varieties: BH661, BH660, and BH540. Released more than 25 years ago, BH660 has long been known as the dominant hybrid maize variety in Ethiopia (Abate et al., 2015; Walker et al., 2014). Noticeably, BH661, a much newer, drought-tolerant hybrid that performs well under both drought and normal conditions, is now adopted on slightly more maize plots (12% compared with 10% for BH660). Both varieties were derived from the CIMMYT germplasm collection. Only two quality protein maize (QPM) varieties—AMH852Q and Melkassa-1Q—were identified in farmers' fields, accounting for 1% of our sample.

Maize is the crop with the highest involvement of the private sector. Both domestic and international companies have released and commercialized hybrid varieties. Varieties released by the commercial sector (Shone, Limu, Damote, and Jabi) accounted for 15% of sampled plots.

The picture is, therefore, one of a seed system that remains dominated by relatively old varieties. The average age of varieties identified was 20 years for OPVs and 15 years for hybrids. Despite the apparent replacement of BH660 by BH661, a variety released in 2011, the average age of CGIAR-derived varieties in farmers' field was 19 years. The large number of households still growing Kuleni (released in 1995) and BH660 (released in 1993) explain this figure to a great extent. As expected, plots where OPVs are cultivated had lower levels of purity than hybrids. Among the varieties derived from CGIAR germplasm, 36.4% of samples had purity levels higher than 95%.

4.2.4 Sorghum Varieties

Three past studies have reported estimated adoption rates of improved sorghum. Cavatassi et al. (2011) used a household survey (n = 720) carried out in three *woredas*. Using farmers' self-reported data, the authors found that 11% of households were adopters of improved varieties. Using ancillary data on seed production from formal sources (extension and research centers) and informal sources, Kinfe and Tesfaye (2018) estimated that improved sorghum adoption had reached 9.5% in 2018. Finally, Mahdi et al. (2010) reported the results of a survey in Awbere *woreda* in Somali regional state. Here, 37% of households had adopted improved varieties, based on self-reported data and on a limited geographic scale.

Investigating farm-level adoption of sorghum technologies in a small sample of farmers in Tigray, Wubeneh & Sanders (2006) found that a few years after Striga-resistant cultivars were disseminated through demonstration trials and extension services, approximately 8% of the farmers in the *woreda* they studied had adopted them. Previous estimates of adoption showed that improved lowland varieties—Melkam, Dekeba, Meko, and Teshale—had reached 28% of households (EIAR, 2019).

Sorghum varieties were identified in the ESS4. A representative sample of sorghum growers was taken in six regions—Amhara, Dire Dawa, Harar, Oromia, SNNPR, and Tigray—and varieties were assessed through DNA fingerprinting. A total of 29 varieties were included in the reference library, including all varieties that are still under production by EIAR.[19] Nine of these varieties contain ICRISAT germplasm.

Our results from DNA fingerprinting show that all samples could be matched with a reference library sample. All field samples are above the 70% purity threshold, but only two-thirds of collected samples have a purity greater than 90%, indicating a relatively low mean level of purity. A large majority of samples are varieties selected from local landraces. The most striking result from Table 12 is that a selected landrace released in 1970 still accounts for 46% of the sorghum varieties farmers are growing. This landrace is likely the closest genetic match for a cluster of landraces. Dano and Chemeda varieties, released more recently, were cultivated on 11% and 10% of sampled plots, respectively. Relatively few households are growing exotic germplasm, and even fewer households had traces of CGIAR-derived germplasm (1.1% of sorghum-growing households; see Table 9).[20] Out of the ICRISAT varieties included in the

[19] We are in the process of supplementing the reference library with three additional accessions of varieties from ICRISAT that were no longer produced or maintained by EIAR and will reestimate our results as a robustness check. We do not expect the missing samples to make a material difference to these estimates.

[20] This share is lower than expected, contradicting prior findings on the project's scale, number of varieties released, and dissemination efforts, based on government statistics. The reference library comprised breeder seeds collected at EIAR of varieties considered to be under current production. We are in the process of verifying the reference library to make sure that all ICRISAT-related germplasm was correctly included.

reference library, the only varieties found in the field samples were the hybrid ESH-1 and the OPV variety Melkam.

Table 12: Distribution of sorghum by variety planted during the 2018/19 growing season

Variety	Number of sorghum samples	% sorghum samples	Variety type	Age (years)	Breeder/maintainer	Origin/pedigree
AI-70	171	46.0	OPV	49	Haramaya University	Pure line selection from local landrace
Dano	42	11.3	OPV	13	Bako ARC	Pure line selection from local landrace
Chemeda	38	10.2	OPV	6	Bako ARC	Pure line selection from local landrace
Miskir	24	6.5	OPV	12	Sirinka ARC	Cross of local landraces
Assosa-1	21	5.6	OPV	4	Assosa ARC	Pure line selection from local landrace
Murya-1	21	5.6	OPV	19	Haramaya University	Pure line selection from local landrace
Birhan	15	4.0	OPV	17	Sirinka ARC	Crossing by Purdue University
ESH-I	9	2.4	Hybrid	10	Melkassa ARC	Crossing by ICRISAT
Lalo	8	2.2	OPV	13	Bako ARC	Pure line selection from local landrace
Fendisha-1	7	1.9	OPV	4	Haramaya University	Pure line selection from local landrace
Gemedi	7	1.9	OPV	6	Bako ARC	Pure line selection from local landrace
Girana-1	5	1.3	OPV	12	Sirinka ARC	Pure line selection from local landrace
Melkam	2	0.5	OPV	10	Melkassa ARC	ICRISAT pure line
Adakura	2	0.5	OPV	4	Assosa ARC	Pure line selection from local landrace

Note: Varieties are from the National Variety Registry of the MoA.

4.2.5 Sweet Potato Varieties

A visual-aid protocol was integrated into both the ESS3 and ESS4 survey rounds to capture sweet potato skin color and flesh color. Earlier this protocol had been the subject of a larger methodological experiment, published in Kosmowski et al. (2019a), that established its reasonable accuracy. We estimate that in 2019 orange-fleshed sweet potato (OFSP) varieties were grown by 1.1% of crop-growing households and cultivated by at least one household in 5% of enumeration areas (Table 9). At a national level, this translates to 133,112 households.

The Awassa-83 sweet potato variety was grown by 3.5% of crop-growing households and cultivated by at least one household in 9.4% of EAs. At a national level, this translates to 436,449 households, an increase from an estimated 372,219 households in ESS3.

An important caveat for the estimates of adoption of sweet potato varieties is the fact that ESS4 does not cover the *belg* season, which is possibly more important for sweet potato than the main season.

4.2.6 Common Bean Varieties

A DNA fingerprinting study of beans was carried out in Ethiopia by EIAR and CIAT and is in the process of being analyzed and written up (Habte Endeshaw and Enid Katungi, personal communication). For each variety name provided by a farmer, a sample of seed was taken, tracked with a unique identifier, and planted out in the lab before leaf samples were sent for genotyping. In total, samples were taken from 829 plots across four regions (Amhara, Benishangul Gumuz, Oromiya, and SNNPR) in the 2016 main agricultural season, though there were many plots that could not be sampled because farmers had already planted all their seed by the time of the survey. Among other objectives, the study aims to understand which varieties promoted by the Tropical Legumes projects (TL I and II) have been accessed by targeted users and diffused among smallholder farmers.

Results show that 67% of the plots in the final sample were cultivating improved varieties (from any source). Overall, 38% of bean plots were cultivated with older improved varieties, while those promoted under the Tropical Legumes projects accounted for 29% of bean plots. Data from Amhara and Benishangul Gumuz showed the highest adoption rates (above 89%), followed by data from Oromia (57%) and SNNPR (45%). These adoption rates should not be considered representative, given the multiple ways in which plots slated for sampling were eventually left out of the final dataset.

4.2.7 Wheat Varieties

Jaleta et al. (2020) report results from a nationally representative survey of wheat DNA fingerprinting collected during the 2016/17 main cropping season (n = 3,771). This study took advantage of the AgSS to collect seed samples in a similar but wider design than the ESS. The sample covers the regions of Amhara, Oromia, SNNPR, and Tigray.

A total of 47 unique wheat varieties could be identified in the reference library, and a purity level of 70% was set as a cutoff point for varietal matching. Adoption of improved varietals was estimated to be 95% in terms of wheat area, and 86% of samples were linked to CIMMYT germplasm collections. As the authors rightly point out, these results must be reported with caution as some of the wheat varieties identified were released as long as three to four decades ago.

4.3 Natural Resource Management

4.3.1 Innovations in Agricultural Water Management and Soil and Water Conservation

Large-scale government-led programs such as the SLMP have encouraged and facilitated the adoption of NRM practices in Ethiopia (Adimassu et al., 2018). Diffusion may also have occurred through the PSNP scheme, through which households receive payments in exchange for providing for public works such as road construction, plot-level terracing, or small-scale irrigation (World Bank, 2013).

There is an abundant literature on the adoption of soil and water conservation (SWC) practices (though many studies have small and/or selected samples). Bekele and Drake (2003) reported the results of a survey in the Hunde-Lafto area, Western Hararghe zone (n = 145 households), using self-reported plot-level data. They found that 65% of farmers interviewed were using SWC structures (traditional, modified, and recommended). Kassie et al. (2011) investigated terrace adoption in northwestern Ethiopia (Anjeni) using self-reported plot-level data (n = 148 households and n = 1,290 plots). The study found that *fanya juu* terraces were adopted on one-third of households' plots. Adoption estimates in three selected watersheds (Debre Mewi, Anjeni, and Dijil) in Amhara region were also reported in Teshome et al. (2016). From a sample of 298 households, the authors found that SWC technologies (soil and *fanya juu* bunds) were adopted by 30.9% of households and practiced for more than five years in the sloping farm area.

Motorized and treadle pumps are another agricultural water management (AWM) innovation for which adoption studies were carried out. Getacher et al. (2013) sampled 301 farm households from Adikesindad and Abraha-Atsebeha *woredas* in the Tigray region to estimate the adoption and impacts of irrigation technology. Using self-reported data, the study found that 34% of the farmers interviewed were using motor and/or treadle pumps. Results are also reported in Gebregziabher et al. (2014), who analyzed 800 farm households in the four main regions (Amhara, Oromia, SNNPR, and Tigray). Using self-reported data, the authors found adoption rates of 33% for motor pumps, 2.5% for electric pumps, and 2.5% for treadle pumps.

Four AWM and SWC innovations that have been the focus of CGIAR research were captured in the ESS: river diversion, motor pumps, treadle pumps, and soil and water conservation structures. While river diversion from surface water can benefit several households in a community, the ESS survey captures the innovation at the farm level. River diversion was present in 16% of EAs and adopted by 5% of households at the national level. Orders of magnitude are similar in the 2016 survey. An estimated number of 685,148 households were practicing river diversion in 2019.

Water-lifting devices such as motor pumps and treadle pumps were adopted by 1% of households in 2019. The absolute number of adopters was estimated to be 350,913 households. Six percent of EAs had at least one household with a water pump. Again, these figures were similar in ESS3 and ESS4 (2015/16 and 2018/19).

Soil and water conservation (SWC) structures were adopted by 72% of rural households at the national level in 2019. Nine out of ten EAs have at least one household using an SWC practice at the plot level. In absolute numbers, this represents 9.4 million households. Terracing, the construction of small walls along the contours of the land, requires significant labor to build and maintain yet is among the most commonly adopted practices, followed by contour plowing and water catchments.

4.3.2 Broad Bed Maker

Two prior empirical studies have focused on the adoption of the broad bed maker (BBM). Gezahegn (1999), using a sample of 142 farmers in two *woredas* in the southeast Shewa zone, found that half of households were adopters of BBM technology. Rutherford (2008) reported on an ex post adoption study of BBM technology carried out 23 years after the BBM was introduced in 1986. Results show that the proportion of wheat and teff area under the BBM increased from 0.02% in 1998 to 1.3% in 2008. The number of adopters was estimated to be slightly fewer than 100,000 in 2008.

The BBM was integrated into the ESS3 with a visual-aid protocol; results show that, at the national level, adoption occurred in 4.8% of enumeration areas and 0.5% of rural households, or an estimated 64,814 households in total.

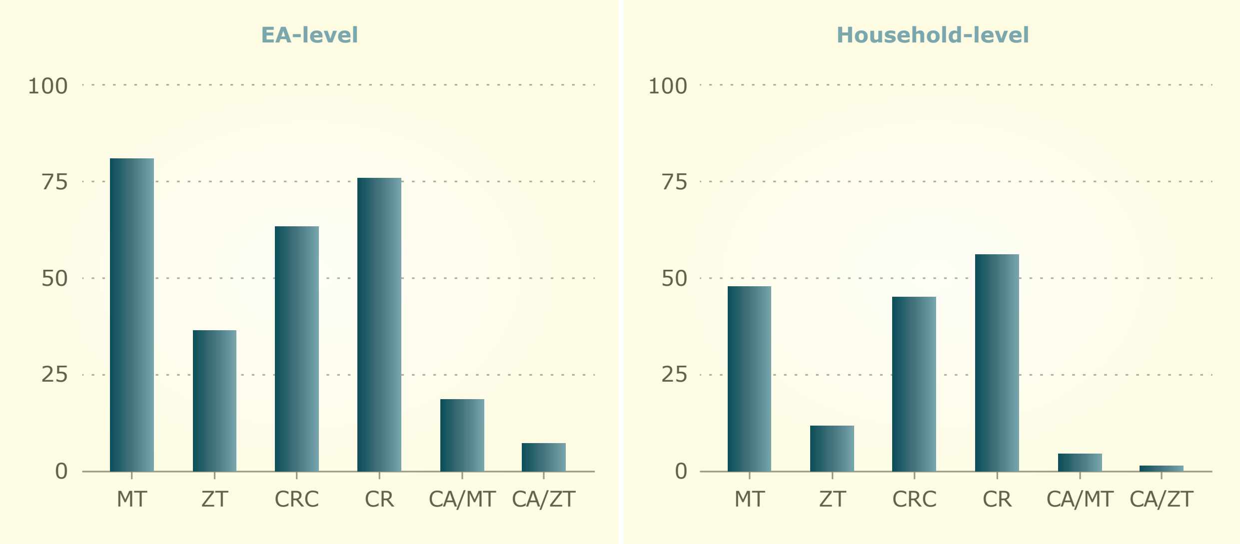
4.3.3 Conservation Agriculture

The adoption and impact of conservation agriculture (CA), a farm-level NRM practice, have been the subject of contentious debate in Sub-Saharan Africa (e.g., Phalan et al., 2007; Giller et al., 2009; Andersson and D'Souza, 2014; Stevenson et al., 2014; Stevenson et al., 2019). Estimates of CA adoption in Ethiopia can be found in three studies. Kassie et al. (2015) used a household survey (n = 2,540) carried out in nine *woredas* in Benishangul, Oromia, and SNNPR regions. Farmers' self-reported data showed that adoption of minimum tillage with crop residues was 30%. A second study documented the changes in the adoption of CA-based practices in 35 *woredas* (Bedru et al., 2018). These districts are major maize- and common bean-growing areas in Amhara, Benishangul Gumuz, Oromia, SNNPR, and Somali. Using self-reported data in 2013 and 2016, the authors found that adoption rates increased from 0.95% to 9% for minimum tillage and from 28% to 31% for maize-legume rotation or intercropping. Finally, Teklewold et al. (2013) reported the adoption rate of sustainable agricultural practices among 900 farm households (n = 1,644 maize plots) in nine *woredas* in Amhara, Oromia, and SNNPR regions. From self-reported data, they found adoption rates of 23.3% for maize-legume rotation, 36.4% for minimum tillage, and 52.5% for improved maize seeds. On 5.4% of the plots, all three practices were used simultaneously.

Adoption estimates using nationally representative data from ESS4 for each of the three component practices of CA, as well as these practices in combination, are displayed in Figure 4.

Figure 4: Adoption estimates for conservation agriculture (CA) as a complete package and broken down by constituent practices (ESS4 data)

MT = Minimum tillage; ZT = Zero tillage; CRC = Crop residue cover (visual aids); CR = Crop rotation; CA/MT = Conservation agriculture with minimum tillage; CA/ZT = Conservation agriculture with zero tillage



Taken separately, minimum tillage, residue cover, and crop rotation were practiced on at least one plot by 40–55% of rural households in 2019. Zero-tillage practices were adopted to a lesser extent, by one-tenth of rural households. CA proponents suggest that practices need to be applied together to achieve benefits to the soil and long-run productivity—indeed the FAO definition of conservation agriculture requires such joint or bundled adoption. This full CA package was adopted with minimum tillage by 4.3% of rural households (550,237 households) and with zero tillage by 1.3% of rural households (161,628 households).

Comparing the two ESS survey waves shows some changes in adoption level. Crop rotation and minimum tillage were practiced in fewer EAs in 2019 compared with 2016, whereas minimum residue cover and zero tillage practices expanded. The practice of zero tillage on at least one plot increased from 1% of crop-cultivating households in 2016 to 12% in 2019 (from 4% to 36% of EAs with at least one household adopting). Adoption of the CA package with minimum tillage fell from 27% to 18% of EAs.

4.3.4 Tree Seed Centers (TSCs)

The ESS data show the presence of three fruit trees that have been the focus of CGIAR efforts to increase access to high-quality planting material. Avocado, mango, and papaya trees were grown by at least one household in 27%, 28%, and 18% of EAs respectively. All these figures were stable, with no noticeable change between the two surveys. In 2019 the number of households growing avocado was estimated at 1.32 million; 0.54 million households were growing papaya, and 1.24 million households were growing mangoes.

Agroforestry is also captured in the ESS through a question on afforestation, which is practiced to control plot-level soil erosion. Although the practice can generate direct economic value through the sale of fruit, farmers are often seeking to simply increase soil organic matter. The survey question does not detail the tree species that were planted, but it is informative about the extent of agroforestry adoption. In 2019 afforestation was practiced by one-tenth of crop-cultivating households at the national level, representing an estimated 1,218,463 households. One-third of EAs had at least one plot with afforestation practices.

4.4 Innovations from Government Policy

4.4.1 Productive Safety Net Program

In 2019, 12% of rural households had at least one member benefiting from the Productive Safety Net Program (PSNP). These households received, on average, the equivalent of US$118.6 a year. Geographic coverage increased between the two surveys from 28% of EAs in 2016 to 36% of EAs in 2019.

4.4.2 Water Users Associations

In 2019, 58% of EAs had a community irrigation scheme in place.

5. Who Are the Adopters?

CGIAR has three broad strategic goals: reducing poverty, enhancing food and nutrition security, and improving natural resources and ecosystem services. These goals provide strategic direction for the CGIAR in setting research priorities, and align with the United Nations Sustainable Development Goals (SDGs). As part of the mission defined for the current One CGIAR reform, five broad impact areas have been identified: nutrition and food security; poverty reduction, livelihoods, and jobs; gender equality, youth, and social inclusion; climate adaptation and greenhouse gas reduction; and environmental health and biodiversity. To understand the possible pathways through which the CGIAR-related innovations are advancing progress in these impact areas, it is useful to understand not only how many farmers, but also which types of farmers, are potentially being exposed to the innovations.[21]

In this section, we therefore shed light on the characteristics of adopters. The richness of the ESS data allows us to document the characteristics of households reached by CGIAR-related innovations along several dimensions that link directly to the One CGIAR impact areas. We specifically analyze whether adoption is correlated with farm size (as smallholder farmers are often the specific target of CGIAR innovations) and remoteness. We also define a set of variables to measure the gender, social inclusion, and youth dimensions (Table 13) and document their association with adoption (Table 14). We focus this analysis on the subset of innovations for which there is sufficient variation in the data.[22]

[21] Note, however, that there are many other pathways through which households could benefit from CGIAR innovations, even if they do not adopt practices on their own farm, so this necessarily presents only a partial picture. Nevertheless, comparing the characteristics of the adopters with the theories of change of the particular innovations can provide useful feedback on whether the hypothesized pathways are reflected in the reality on the ground.

[22] More precisely, we excluded from the analysis innovations adopted by fewer than 4 percent of households: delivery of improved dairy genetics (artificial insemination users), delivery of improved genetics through community approaches, delivery of improved forage varieties, improved sorghum varieties, orange-fleshed and Awassa-83 sweet potato varieties, treadle pumps, and minimum tillage.

Table 13: Overall descriptive statistics of variables related to smallholder farmers' context, gender, social inclusion, and youth among rural households in ESS4

Variable	Observations	Mean	Standard error
Smallholder context			
Total area cultivated per household (ha)	2,759	0.97	0.03
Main access road surface is tar/asphalt (%; EA-level)	253	10.8	2.42
Distance to nearest large weekly market (km; EA-level)	253	4.47	0.64
Distance to nearest informal savings and credit cooperative (SACCO) (km; EA-level)	253	15.1	2.79
Gender, social inclusion, and youth			
% of households with female head	2,775	21.5	0.01
% of households with at least one female member listed on a parcel title	1,791	68.6	1.37
% of households with a female livestock manager/keeper	2,275	88.7	0.87
% of households with female share of family labor > 50%	2,759	6.14	0.60
Age of household head (years)	2,775	44.9	0.41
Nominal annual consumption per adult equivalent (ETB)	2,775	13,136	294
% of households in bottom 20% of annual consumption	2,775	26.8	1.13
% of households in bottom 40% of annual consumption	2,775	51.2	1.32
Asset index	2,775	-1.818	0.02
Productive asset index	2,775	1.501	0.03
Annual off-farm income (ETB)	2,775	1,710	130

Note: EA = enumeration area. SACCO = savings and credit cooperative. ETB = Ethiopian birr. Consumption quintiles are calculated over the full sample of urban and rural households. The asset index and productive asset index are the first principal component of a series of assets (following Filmer and Pritchet, 2001), standardized over the national population. The asset index combines information on ownership of 35 household items and productive assets, as well as the number of rooms. The productive asset index includes mostly assets with use in agriculture (sickle, ax, pickax, plow, water pump, solar device).

Table 14 provides an overview of the correlations between some of these characteristics and the probability of adopting the different innovations (results on wider set of covariates reported in the online detailed results tables). The table indicates substantial heterogeneity in the types of farmers and communities potentially exposed to the different CGIAR innovations. Adoption of barley and maize with CGIAR germplasm, as well as certain NRM practices (including tree planting and river diversion), are equally likely to reach smallholders and larger farmers. Large ruminant crossbreeds, not surprisingly, kabuli chickpea as well as some other NRM practices (SWC and minimum tillage CA) appear more likely to be adopted by farmers with larger landholdings. Considering the indicators of poverty or welfare (consumption per capita, bottom two quintiles of consumption), the data show that poorer households may be equally or even more likely to adopt a number of the NRM practices than wealthier households. The opposite holds true for improved barley. A similarly mixed picture emerges for gender, with adoption of improved poultry more likely among female managers, while female participation in farm activities is negatively associated with improved large ruminants, but also with conservation agriculture. Most other innovations, however, appear equally accessible for male and female farmers. Finally, most innovations appear equally likely to reach younger and older farmers.

5.1 Animal Agriculture

5.1.1 Delivery of Improved Dairy Genetics

At the household level, adopters of artificial insemination (AI) services are wealthier than non-adopters, as proxied by the asset index ($p < 0.01$). EAs with AI adopters are closer to the nearest *woreda* town ($p < 0.01$); are closer to the nearest savings and credit cooperative (SACCO), an informal loan scheme ($p < 0.01$); and have significantly fewer households that benefit from PSNP ($p < 0.01$).

As with insemination services, EAs with adopters of large ruminant crossbreeds are located closer to the nearest large weekly market ($p < 0.01$). Adopters also have higher annual off-farm income ($p < 0.05$), and own larger quantities of agricultural land ($p < 0.01$). Household adopters of large ruminant crossbreeds have significantly fewer female members participating in agricultural labor ($p < 0.05$).

5.1.2 Improvement and Delivery of Improved Chicken Breeds

At the household level, adopters have lower annual off-farm income (ETB 919 compared with ETB 1,977 a year for non-adopters, $p < 0.0001$). They do also own less productive assets than non-adopters. Annual consumption per adult equivalent did not correlate with crossbred poultry adoption. Crossbred poultry adoption is significantly associated with having a female manager/keeper ($p < 0.01$).

In general, EAs with adopters are more likely to have a main asphalt road of access ($p < 0.01$) and are located closer to the nearest large weekly market ($p < 0.05$).

The relationship between adoption and remoteness differs between the two surveys. In 2016 adopters were located in EAs that are closer to the nearest major roads ($p < 0.01$), while there is no significant relationship between road access and EA-level adoption in 2019 data. Household adopters are located closer to the nearest markets in both surveys ($p < 0.01$).

Table 14: Summary of variables associated with the adoption of agricultural innovations

Variable	Total size of parcels	Distance to market (km)	Asphalt as a main access road	Livestock manager is female	Female share of family labor is > 50%	Annual consumption per capita (ETB)	Bottom 40% annual consumption	Productive asset index	Annual off-farm income (ETB)	Age of household head
Animal agriculture										
Large ruminant crossbreed	0.5***	-3.17***	n.s	n.s	-0.03**	n.s	n.s	n.s	1,874**	n.s
Poultry crossbreed	n.s.	-2.78**	0.14***	0.06***	n.s	n.s	n.s	-0.16*	-1,058***	n.s
Crop germplasm improvements										
Barley varieties	n.s	n.s	-0.15***	-	n.s	4,870**	-0.28***	0.39**	n.s	n.s
Chickpea kabuli varieties	1.18***	n.s	-0.14**	-	n.s	n.s	n.s	n.s	n.s	n.s
Maize varieties	n.s	n.s	n.s	-	n.s	n.s	n.s	n.s	n.s	n.s
Drought-tolerant maize varieties	n.s	n.s	n.s	-	n.s	n.s	-0.19**	n.s	n.s	-5.2**
Natural resource management										
River diversion	n.s	-2.58**	n.s	-	n.s	n.s	n.s	n.s	n.s	n.s
SWC practices	0.25***	-7.03***	0.10***	-	n.s	-1,620**	n.s	0.22***	1,041***	n.s
Minimum tillage CA	0.51***	n.s	n.s	-	-0.05***	-2,722***	n.s	0.42***	n.s	n.s
Mango	n.s	-2.18**	n.s	-	n.s	-1,876***	n.s	0.45***	n.s	4.3***
Papaya	n.s	n.s	n.s	-	n.s	n.s	n.s	0.47***	n.s	n.s
Avocado	n.s	n.s	0.04**	-	n.s	-1,873***	0.15***	0.36***	n.s	n.s
Policy influences										
Productive Safety Net Program (PNSP)	-0.29***	n.s	n.s	n.s	n.s	-3,088***	0.20***	-0.27***	-1,124***	n.s
Water users associations	-	n.s	-4.51**	-	-	-	-	-	-	-

Note: Each cell is a coefficient estimate from a separate regression of the row variable on the column variable. For statistically significant relationships, the magnitude of the difference is indicated. Green shows a positive relationship while red demonstrates a negative relationship. All estimates are based on ESS4, except for estimates for chickpea, which use data from ESS3. Water users association correlates were investigated only at the EA-level. The analysis excludes innovations adopted by fewer than 4 percent of households.

*** $p < 0.01$. ** $p < 0.05$. n.s = non-significant. ETB = Ethiopian birr. SWC = soil and water conservation. CA = conservation agriculture.

5.2 Crop Germplasm Improvement

5.2.1 Barley Varieties

Adopters of barley varieties with CGIAR germplasm were wealthier, with annual consumption per capita on average 4,870 ETB higher than non-adopters ($p < 0.05$) and more productive assets ($p < 0.05$). Adopters were less likely to be among the 40% of poorest households ($p < 0.01$). Additionally, growers of improved barley were located farther from the closest market while also being less likely to have asphalt as the main access road ($p < 0.01$ for both).

5.2.2 Chickpea Kabuli Varieties

The adoption of chickpea kabuli varieties was positively associated with household holdings and negatively with road access. No association emerged with poverty metrics.

5.2.3 Maize Varieties

No significant association could be found for adopters of improved maize varieties derived from CGIAR germplasm. This largely also holds for drought tolerant maize varieties.

5.3 Natural Resource Management (NRM)

5.3.1 Innovations in Agricultural Water Management and Soil and Water Conservation

Use of river diversion was not correlated with any of the variables we considered, with the exception of a negative correlation between adoption and the road access ($p < 0.01$).

Adopters of soil and water conservation practices are on average poorer, as measured by annual consumption per capita ($p < 0.05$). Nonetheless, adopters had larger agricultural holdings (1.12 compared with 0.87 ha, on average), owned more productive assets, and generated more off-farm income than non-adopters ($p = .01$). The adoption of SWC practices was also significantly associated with having asphalt as the main road access and being closer to weekly markets.

Considering plot-level correlations, plots where SWC practices are used are less often cultivated with permanent crops (14% compared with 30%, $p = .01$). Interestingly, farmers use higher quantities of fertilizers on these plots. This is true for all chemical fertilizer types—urea, DAP, and NPS ($p = .05$)—but no association was found with manure. SWC plots are also more often associated with higher use of improved crop varieties ($p = .01$). Overall, these plot-level associations suggest that SWC plots are privileged by farmers for more intensive farming (see Table 30 in Appendix H for details).

5.3.2 Conservation Agriculture

Adopters of conservation agriculture (CA) were on average poorer as measured by annual consumption per adult equivalent ($p < 0.001$) but less likely to have large female share of family labor. There was no detectable association with other variables associated with social inclusion. These results hold for both CA with minimum tillage and CA with zero tillage. Total parcel size is positively associated with adoption of CA with minimum tillage, suggesting that adopters own more land on average than non-adopters.

At the plot level, the adoption of CA was negatively associated with the use of fertilizers and improved varieties ($p < 0.05$; see Table 30 in Appendix H for details). Households that practice minimum tillage also use animals for land preparation significantly less than non-adopters.

5.3.3 Tree Seed Centers (TSC) and related

Two variables related to social inclusion were found to be correlated with agroforestry adoption: mango growers were significantly older than non-adopters ($p < 0.01$), and avocado growers were negatively associated with having at least one female owner of the parcel in the household ($p < 0.05$, not shown). On average, tree owners were poorer than non-adopters.

5.4 Innovations from Government Policy

5.4.1 Productive Safety Net Program (PNSP)

As expected, PSNP beneficiaries were associated with all poverty metrics ($p < 0.01$). On average, beneficiaries also own small holdings ($p < .01$).

5.4.2 Water Users Associations

Beneficiaries of irrigation schemes and water users associations were located in EAs that were less likely to have asphalt as the main road access. No other significant correlates were found at the EA-level.

6. Where Are the Adopters?

In this section, we investigate the third question: where have innovations reached households? Relying on the methods described in section 2.4, we attempt to shed light on spatial variations in adoption using (1) variations between Ethiopian regions; (2) concentration of adoption within EAs; and (3) association of the location of CGIAR-related research activities with the spatial distribution of adopters as observed in the ESS. This complements the insights on the association between remoteness and adoption from the previous section. Understanding the geographic spread of innovations helps document their reach and can reveal possible regional disparities. It is also can help analyze whether innovations are being diffused in the agroecological zones where they could be expected to have the highest returns. As such, this spatial analysis can provide key insights for the geographic targeting of future diffusion efforts. The regional representativeness of the ESS data make them well suited for this analysis. That said, agroecological zones do not perfectly overlap with regions, and heterogeneity within agroecological zones can also matter, so the geospatial variation presented here is not necessarily granular enough to produce detailed targeting recommendations (which would require more specialized studies).

Table 15 shows large regional differences between the four main regions for a number of innovations. Different innovations show different regional patterns (discussed in detail below), resulting in a wide overall reach of CGIAR-related innovations. For presentation purposes, Table 15 aggregates information from the other regions together, while Table 33 in Appendix K shows the disaggregated statistics by region for these less-populated areas.

Table 15: Summary of adoption rates by regions at the EA and household levels (%)

Innovation	Amhara		Oromia		SNNPR		Tigray		Other regions[a]	
	EAs	Households	EAs	Households	EAs	Households	EAs	Households	EAs	Households
Animal agriculture										
Artificial insemination use	4.8	0.5	7.1	1.6	5.1	1.1	4.5	0.8	0.0	0.0
Large ruminant crossbreed	27.4	6.8	16.0	8.2	25.2	5.3	19.1	2.7	5.2	0.6
Small ruminant crossbreed	0.0	0.0	2.1	0.7	2.7	0.3	0.0	0.0	0.6	0.1
Poultry crossbreed	56.0	14.5	48.7	11.4	54.1	11.3	88.9	33.5	19.1	4.3
Forages	0.0	0.0	4.5	2.4	10.6	5.2	3.4	0.4	0.3	0.0
Crop germplasm improvement										
CGIAR Barley varieties	0.0	0.0	71.1	51.3	42.6	20.1	0.0	0.0	0.0	0.0
CGIAR Maize varieties	75.6	63.8	71.2	58.4	90.8	62.9	95.6	79.3	92.7	81.5
CGIAR Sorghum varieties	0.0	0.0	0.0	0.0	5.4	3.7	7.1	2.0	4.4	4.5
Chickpea Kabuli varieties	28.6	6.6	14.9	6.1	2.9	0.5	17.3	3.5	4.6	0.7
OFSP varieties	0.0	0.0	6.5	1.2	10.0	2.2	0.0	0.0	7.3	3.5
Awassa-83 sweet potato varieties	0.0	0.0	9.7	1.3	23.0	12.7	0.0	0.0	5.7	1.4
Natural resource management										
River diversion	26.8	8.7	12.7	4.5	7.6	1.0	25.2	4.9	17.0	11.2
Motorized pump	11.6	1.6	5.5	1.6	0.0	0.0	7.4	1.1	8.7	4.0
SWC practices	100.0	89.4	87.1	63.7	83.0	61.5	96.3	87.2	57.8	63.6
Broad bed maker	5.6	0.5	5.4	0.6	3.0	0.3	3.6	0.5	3.9	0.1
Conservation agriculture (min. tillage)	16.4	4.4	20.9	4.1	17.0	4.7	14.1	1.9	22.5	10.9
Conservation agriculture (zero tillage)	7.1	1.6	9.3	1.5	2.5	0.5	6.4	0.9	7.3	1.4
Afforestation	40.5	8.3	31.6	9.5	41.9	13.3	15.7	4.0	9.7	2.3
Mango trees	16.7	5.3	28.7	8.9	44.4	16.7	12.3	1.7	37.3	35.9
Papaya trees	9.1	1.9	16.2	3.3	31.4	8.9	6.1	0.6	28.7	14.1
Avocado trees	0.0	0.0	30.6	9.9	62.1	27.4	5.1	0.5	16.0	5.6
Policy influences										
Productive Safety Net Program (PNSP)	46.1	14.5	23.0	3.6	31.3	6.8	70.3	19.4	40.9	16.2
Water users associations	85.5	N/A	47.9	N/A	38.1	N/A	68.8	N/A	42.0	N/A

Note: EA = enumerator area. OFSP = orange-fleshed sweet potato. SWC = soil and water conservation. All estimates are based on ESS4, with the exceptions of chickpea types and broad bed maker, which are estimated based on ESS3. All estimates use sampling weights to calculate the shares of EAs and households over the populations defined in the "conditions applied" column in Table 9 (as in column 2 of Table 9), except for Barley, Maize and Sorghum varieties, which are defined in this table as estimated number of households with CGIAR varieties over the number of households with the specific crop (as in column 4 of Table 9).

[a] See Table 33 in Appendix K for a breakdown of these regions.

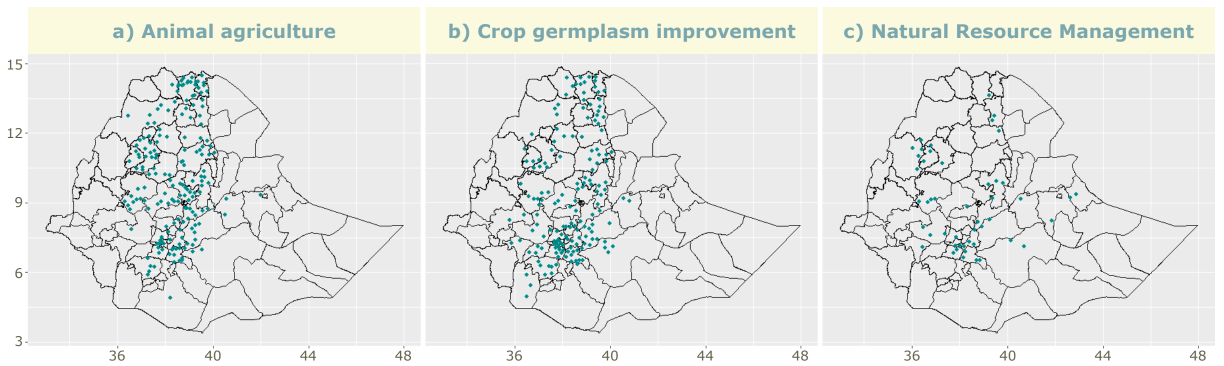
6.1 Insights from the Location of Research Activities

A full understanding of the geographic spread of agricultural innovations would benefit from information on dissemination activities by the many different actors that can be involved in technology diffusion. Because of the decentralized and often market-driven nature of technology diffusion, such data are hard to compile and left for future work. Analyzing the relationship between the location of research activities and the spatial variation of adoption can, however, provide some first insights on the possible causal pathways toward adoption at scale. This is the case both because CGIAR research activities often purposely occur in specific agroecological zones, and because exposure to such research activities by the various partners (government, NGOs, the private sector, local leaders, farmers) can trigger social learning about the returns to particular innovations.

The integration of household and GIS analysis for studying technology adoption is a growing area of research (Staal et al., 2005). While the exercise we report here is exploratory, it shows the potential for using such matching for further analysis. The analysis to date (detailed for each innovation below) shows that there is overall little relationship between the location of CGIAR research activities and dissemination of CGIAR-related innovations (Table 32 in Appendix J).

The locations of activities under three core domains of CGIAR research are mapped in Figure 5. It is noteworthy that a high number of *woredas* were covered by research on animal agriculture (Figure 5a) and crop germplasm improvement (Figure 5b). The main regions of Amhara, Oromia, SNNPR, and Tigray appear to be relatively well covered. Other regions such as Gambella, Benishangul-Gumuz, and Somali had no research activities conducted. Research projects on NRM were fewer in number and were mainly located in Amhara, Oromia, and SNNPR.

Figure 5: Location of CGIAR projects in Ethiopia by core domain, 1999–2019



Among the *woredas* hosting research projects, one quarter were visited by at least two projects. The *woreda* of Adami Tulu, for instance, featured in projects related to five very different types of innovation (poultry crossbreeds, landscape-level sustainable land management, improved barley varieties, OFSP, and QPM varieties).

6.2 Animal Agriculture

6.2.1 Delivery of Improved Dairy Genetics

Turning back to the ESS data, EAs where households have benefited from artificial insemination services are located in the four main regions but are more numerous in Oromia (7.1% of EAs). The "other" regions, composed of Benishangul Gumuz, Dire Dawa, Gambella, Harari, and Somali have no adoption of artificial insemination services. On average, within EAs where AI services are reported, 14% of households are adopters.

Divergences exist between regions regarding adoption of large ruminant crossbreeds. Oromia has the largest population of large ruminant crossbreeds (8.2% of households), followed by Amhara and SNNPR. Tigray and the "other" regions category show more limited adoption, with 2.7% and 0.4% of households, respectively. In EAs where adoption occurred, an average of 15% of households were adopters.

No significant association could be found between the location of research and dissemination activities and large ruminant crossbreed adoption in ESS4.

6.2.2 Delivery of Improved Genetics through Community Approaches

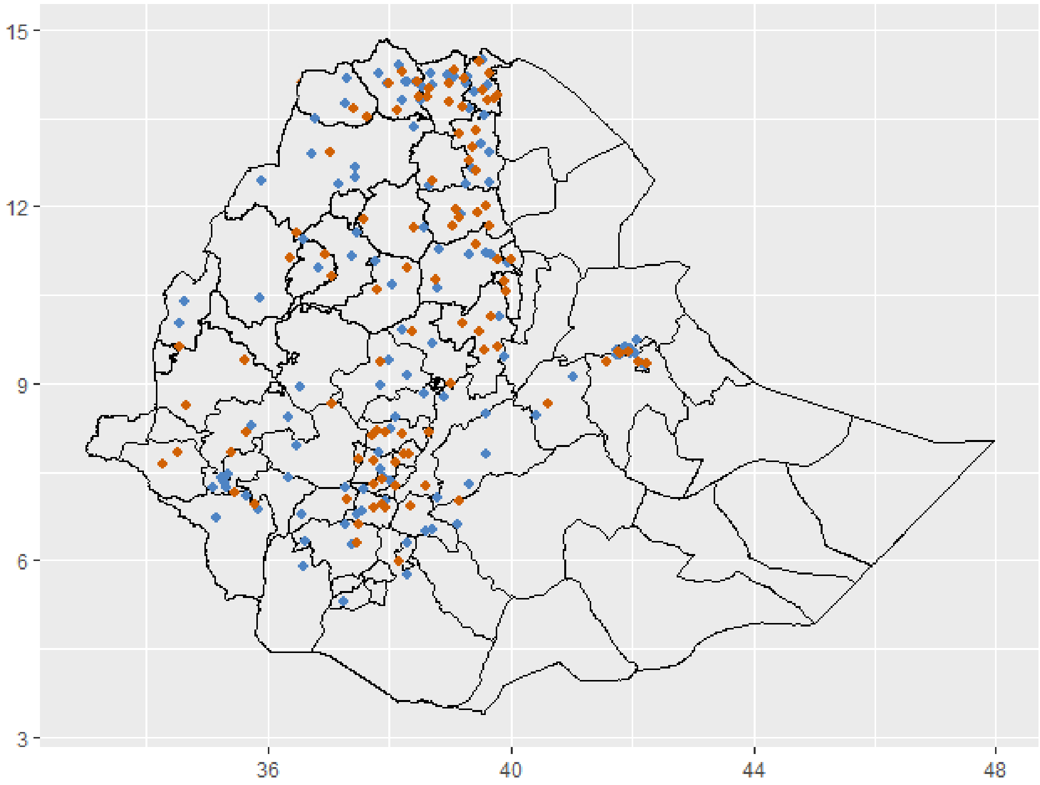
EAs with at least one small ruminant crossbreed are located in Oromia and SNNPR. On average, within EAs with at least one household adopting small ruminant crossbeeds, 7% of households within the EA are adopters. No small ruminant crossbreeds are reported in the "other" regions.

6.2.3 Improvement and Delivery of Improved Chicken Breeds

Stark contrasts exist between regions: poultry crossbreed adoption is observed for one-third of households and is present in 89% of EAs in Tigray. Amhara (56%), Oromia (49%), and SNNPR (54%) have levels of adoption that are very close to national estimates. Much lower adoption has occurred in the "other" regions (19% of EAs).

In ESS3 (2015/16) poultry crossbreeds appear concentrated in the areas close to urban centers and major asphalt roads. This is apparent in the South, from Gurage to Gamo Gofa *woredas* as well as in the Amhara region along the road connecting Addis Ababa to Mekelle (Figure 6). A concentration of adopters around Dire Dawa is also visible. By 2018/19 adoption had become more geographically spread (Figure 6).

Figure 6: Map of enumeration areas with at least one household adopter of poultry crossbred in 2015/16 (orange) and 2018/19 (blue)



There was no association between the location of CGIAR-related activities on crossbred poultry and adopters in ESS4.

6.2.4 Facilitating Access to Improved Forage Varieties

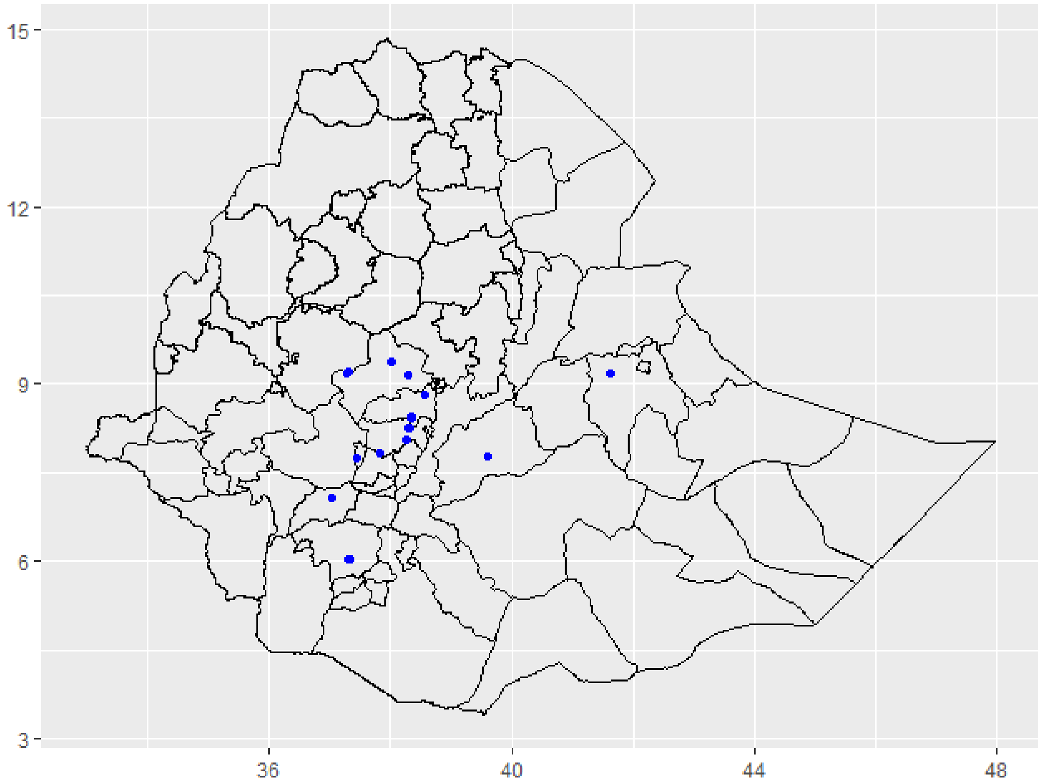
Adopters of forage grasses (4.3% of households at the national level) are located mainly in Oromia and SNNPR.

6.3 Crop Germplasm Improvement

6.3.1 Barley Varieties

For HB-1966, a CGIAR-related variety released in 2017 but already found on one-tenth of the plots sampled, most samples appear to originate from Oromia and SNNPR (Figure 7). This figure is an example of a new variety being rapidly adopted with some degree of geographic dispersion. If anything, adoption is lower in places close to *woredas* in which research activities took place (Table 32 in Appendix J).

Figure 7: Map of enumeration areas with at least one adopter of HB-1966 barley variety



6.3.2 Chickpea Kabuli Varieties

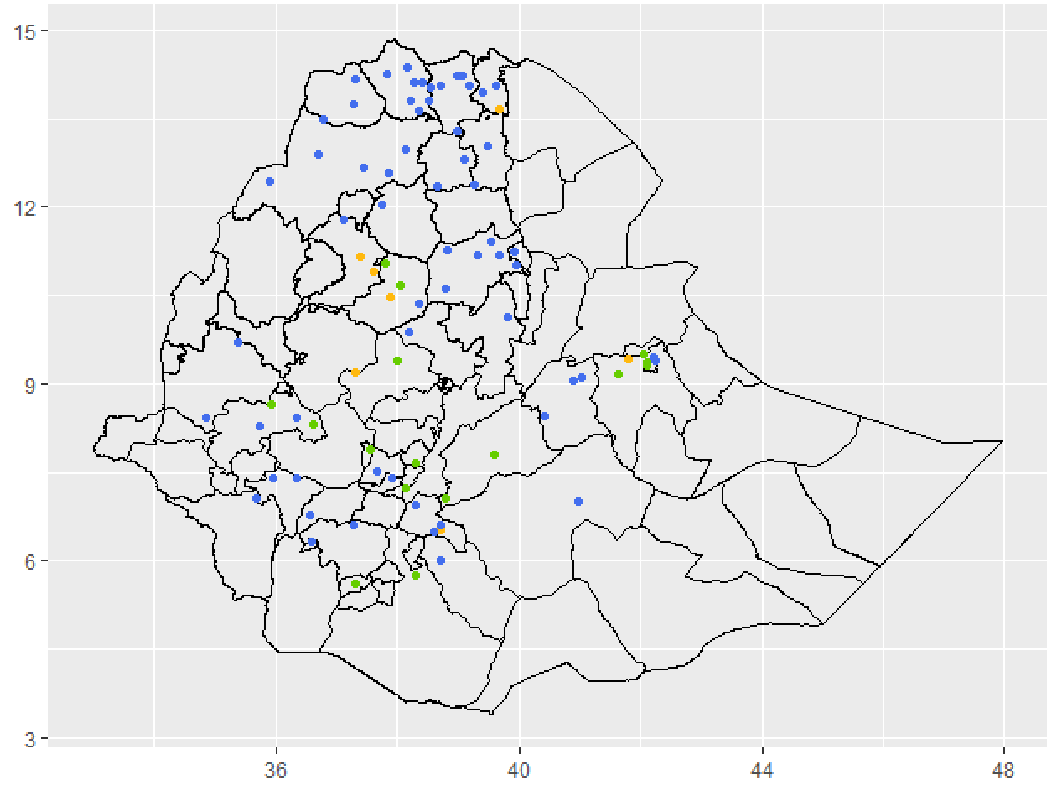
Adopters of chickpea kabuli varieties are located in Amhara (6.6%), Oromia (6.1%), and Tigray (3.5%) regions.

6.3.3 Maize Varieties

Improved maize varieties with CGIAR germplasm were highly adopted in the "other" regions of Harar and Dire Dawa (accounting for 81% of adopters). Adoption was also important in Tigray (79.3% of households), followed by Amhara and SNNPR (63% of households) and Oromia (58.4% of households).

Notably, drought-tolerant maize varieties have been adopted in several regions (Figure 8). In EAs with yellow dots, the BH661 variety is the only improved maize material identified. In EAs with green dots, drought-tolerant varieties were identified alongside other improved varieties (Gojjam area, West Shewa, and parts of SNNPR). Adoption appears limited, however, in the northern (dry) parts of Ethiopia, which are dominated by varieties such as Gibe-1, BH660, and Kuleni.

Figure 8: Adoption of improved maize varieties in Ethiopia, 2019



Note: Dots correspond to enumeration areas where drought-tolerant varieties (yellow), other improved varieties (blue), or both (green) were identified.

6.3.4 Orange-Fleshed Sweet Potato (OFSP) Varieties

Adopters of OFSP are located primarily in the "other" regions, where 3.5% of households have adopted it on at least one plot. SNNPR and Oromia have adoption rates of 2.1% and 1.2%, respectively. In EAs where adoption has occurred, an average of 22% of households are adopters of OFSP.

We find no evidence of a relationship between OFSP adopters in ESS4 and the location of the past research activities focused on OFSP.

6.3.5 Awassa-83 Sweet Potato Variety

Adopters of Awassa-83 sweet potatoes are located primarily in SNNPR, where 13% of households have adopted it on at least one plot. Oromia and the "other" regions also show adoption but at a rate of less than 2% of households. In EAs where adoption has occurred, on average one-third of households are adopters of Awassa-83.

6.4 Natural Resource Management (NRM)

6.4.1 Innovations in Agricultural Water Management and Soil and Water Conservation

Irrigation methods are unevenly distributed across regions: river dispersion was reported in 26% of EAs in Amhara and Tigray—but only 7% of EAs in SNNPR. In EAs where adoption has occurred, on average 27% of households were adopters of river diversion. Adoption of Motorized pumps is also more common in EAs in Amhara (12%) and Tigray (7%), and absent in SNNPR. Motorized pumps were also reported in 9% of EAs from the "other" regions, where household level adoption rates are 4% In EAs where adoption has occurred, on average 18% of households were adopters of motorized pumps.

In 2019 SWC practices were adopted by almost 9 out of 10 households in Tigray and Amhara regions (87% and 89%, respectively). In Oromia, SNNPR, and the "other" regions, 6 out of 10 households were adopters.

6.4.2 Conservation Agriculture

Conservation agriculture (CA) with minimum tillage was found to be more commonly practiced in the "other" regions (11%) than elsewhere. Eighteen percent of EAs had at least one household adopting, and for EAs with at least one household adopting, 19% of households per EA were adopters of minimum-tillage CA and 14% were applying zero-tillage CA on at least one plot. No relationship was found between the location of research and dissemination activities on CA and adopters of CA in ESS4.

6.4.3 Tree Seed Centers and Related

A large share of EAs with fruit trees planted are located in SNNPR, where 62%, 44%, and 31% of EAs had at least one household growing an avocado, mango, and papaya tree, respectively. Oromia and the "other" regions also have between one-sixth and one-third of EAs with at least one plot with a tree planted.

In ESS4 a significant relationship was found between areas of research and avocado growers. Adopters were significantly more numerous in EAs located within 25 km of a research area ($p < 0.01$). This relationship existed along the entire location gradient, from 25 to 150 km. There were only five research project areas, so this finding may simply result from the fact that the environment favorable to avocado growing is somewhat limited in Ethiopia.

Looking at afforestation practices, on average 26% of households are adopters in EAs where adoption has occurred. Adoption is apparent in SNNPR (42% of EAs), Amhara (40%), and Oromia (32%). Tigray and the "other" regions had, respectively, 16% and 10% of EAs with at least one plot with afforestation in 2019.

6.5 Innovations from Government Policy

6.5.1 Productive Safety Net Program (PNSP)

The share of the rural households participating in PSNP was 19% for Tigray, 15% for Amhara, and 16% for the "other" regions. Only 7% of the households in SNNPR and 4% of households in Oromia were PSNP beneficiaries. Similarly, the share of EAs with participants of PSNP is also the lowest in these two regions.

6.5.2 Water Users Associations

In 2019 irrigation schemes were located in Amhara (85% of EAs), Tigray (69%), Oromia (48%), SNNPR (38%), and the "other" regions (42%).

7. Synergies between CGIAR-Related Innovations

To optimize economic, social, and environmental co-benefits in agricultural systems, CGIAR implements a system-based approach. This integrative approach forms the backbone of several conceptual frameworks such as sustainable intensification (Vanlauwe et al., 2014), mixed crop-livestock systems (Thornton & Herrero, 2014) and climate-smart agriculture (Thornton et al., 2018). The efficiency gains in an integrative approach can be important, and exploiting synergies between agricultural innovations has been among the objectives of CGIAR research. Previous research on the joint use of innovations in Ethiopia includes work on soil and water management methods and improved seeds (Kassie et al., 2012), water use efficiency of livestock production (Ergano, 2015), and improved maize breeding for higher stover fodder quality (Ertiro et al., 2013).

The evidence in the previous sections showed that different innovations are being adopted by different types of households and in different regions. This is not surprising, as context and households' internal and external constraints likely make adoption of certain innovations more attractive than others. Several studies have pointed to this fundamental heterogeneity to explain lower-than-expected adoption of any particular innovation (Suri, 2011). Considering the different innovations together, as we do in this report, helps analyze these insights further, as it naturally leads to a prediction that different types of innovations will be of interest to different households. At the same time, the returns to certain innovations can depend on whether the household manages to simultaneously adopt other innovations. It is these synergies that motivate the system-level research. For both these reasons, we exploit the unique advantage of having measurement of multiple CGIAR-related innovations in the same dataset.

We hence look at joint adoption of different innovations, across core domains, as measured in ESS4 (Table 16). For each pair of innovations, the table shows the share of households adopting both innovations. The colors indicate whether we observe complementarity (green) or substitution (red) between innovations; i.e., the color indicates whether this joint share is higher (green) or lower (red) than the joint share one would expect if innovations were adopted orthogonally from each other. For example, dark green indicates strong positive synergy, with the probability of adopting one innovation at least 10 percentage points more likely when the other innovation is also adopted. The striking finding illustrated by Table 16 is that there is no clear consistent evidence of synergies between innovations; if anything, there are quite a few combinations for which it appears that innovations are substitutes rather than complements. This is consistent with different innovations reaching different types of households (farmers) rather than a subset of farmers being reached by many of the innovations. We discuss these findings considering different types of synergies between domains.

Table 16: Summary matrix of joint adoption rates

		A		B			C		
		Animal crossbreeds	Forages	CGIAR Barley varieties*	CGIAR Maize varieties*	CGIAR Sorghum varieties*	AWM and SWC practices	CA	Agroforestry practices
A	Animal crossbreeds	–							
	Forages	1.0	–						
B	CGIAR Barley varieties*	2.4	0.0	–					
	CGIAR Maize varieties*	10.9	3.0	NA	–				
	CGIAR Sorghum varieties*	0.0	0.0	NA	NA	–			
C	AWM and SWC practices	11.4	3.9	14.6	53.2	0.6	–		
	CA	0.0	0.0	0.8	3.4	0.0	3.4	–	
	Agroforestry practices	2.8	0.8	0.0	9.9	0.8	10	1.3	–
D	Productive Safety Net Program (PSNP)	1.6	0.1	1.5	7.8	0.0	8.5	0.4	0.9

Note: Percentages indicate the unconditional incidences of joint adoption between innovations. Dark green indicates strong positive synergy, with the probability of adopting one innovation being at least 10 percentage points more likely when the other innovation is also adopted. Light green indicates weak positive synergy, with the probability of adopting one innovation being between 1 and 10 percentage points more likely when the other innovation is also adopted. Red indicates negative synergy (weak and strong). No color indicates neither positive nor negative synergy.

A = animal agriculture; B = crop germplasm improvements; C = natural resource management; D = policy influences. Animal crossbreeds = large ruminants, small ruminants, and poultry. CA = conservation agriculture with minimum or zero tillage. NA = Not available; * implies adoption rates calculated as share of households with that specific crops.

7.1 Animal Agriculture–Crop Germplasm Improvements

Mixed crop-livestock systems play a critical role in developing countries. The combination of livestock and crops has been promoted as a viable alternative to specialized livestock or cropping systems (Thornton and Herrero , 2014).

In 2019, 10.9% of households were joint adopters of animal crossbreeds (large ruminant, small ruminant, and poultry) and improved maize germplasm, and a comparison with overall adoption rates of the individual innovations points to slight positive synergies. This combination concerned 20.8% of households in Tigray, 17.7% in Amhara, and 10.4% in the "other" regions. The joint use of forage grasses with improved maize concerned 3% of households.

Improved barley varieties were less often adopted by crossbred animal owners, and combined adoption concerned 2.4% of households, with slight negative synergies.

7.2 Animal Agriculture–Natural Resource Management

Synergies between crossbred animal adoption and NRM practices were also prevalent in the ESS data. Overall, 11.4% of crossbred animal owners were at the same time adopters of SWC or agricultural water management (AWM) innovations; this rate is higher than what individual adoption rates would predict, pointing to positive synergies. Regions where SWC practices are widespread are the ones where joint adoption occurred the most: 21.2% of households in Tigray and 13.8% in Amhara were joint adopters. One-tenth of households in SNNPR and Oromia, as well as 3.1% in the "other" regions, were joint adopters. Animal crossbreeds and agroforestry practices were jointly adopted by 2.8% of households.

Finally, adopters of forage grasses were also cultivating plots with SWC or AWM innovations in 3.9% of the ESS4 sample.

7.3 Animal Agriculture–PSNP

Being the owner of a crossbred animal as well as being a PSNP beneficiary was rare in 2019: this situation concerned only 1.6% of households.

7.4 Crop Germplasm Improvement–Natural Resource Management

Previous research has shown positive synergies between improved seeds, conservation agriculture, and other improved soil management techniques. Soil and water management techniques can complement the productivity gains from improved seeds and mineral fertilizers (Kassie et al., 2015). Table 16 shows, however, that such positive synergies were observed for only a subset of crop-NRM innovation pairs.

In 2019 slightly more than half of the households surveyed (53.2%) were adopters of CGIAR-related maize germplasm and SWC or AWM innovations, with slight evidence of positive synergies. These adopters were mostly located in Tigray and the "other" regions (76 and 71% of joint adoption, respectively). Adopters of improved maize varieties were also jointly adopters of agroforestry practices (9.9% of households, located in Oromia, SNNPR, and "other" regions). Joint adoption of improved maize with conservation agriculture practices (zero or minimum tillage), while only concerning 3.4% of households, is higher than expected based on the adoption rates of maize and conservation agriculture alone.

In contrast, barley varieties containing CGIAR germplasm were adopted in combination with SWC or AWM innovations by only 14.6% of surveyed households. These households were located almost entirely in the Oromia region. Joint adoption with other NRM practices was also rare.

Despite the low percentage of households adopting varieties of sorghum with CGIAR-derived germplasm, there is a large and positive synergy with the adoption of agroforestry practices but a negative one with SWC and AWM innovations.

7.5 Crop Germplasm Improvement–PSNP

The incidence of adoption of CGIAR-related maize germplasm by particicpants of the PSNP concerned 7.8% of households. These households were located mostly in Tigray and Amhara, with 19.6 and 13.1%, respectively, of households. The corresponding figure was 1.5% for improved barley adopters.

7.6 Natural Resource Management–PSNP

In 2019 joint adoption of SWC or AWD practices among PSNP participants concerned 8.5% of households, suggesting positive synergies, or at least the accessibility of the SWC and AWD practices by the poor, who tend to be PSNP beneficiaries. One could also hypothesize that the PSNP, by subsidizing community labor, could have directly facilitated some of the labor investment needed for certain SWC practices (such as terracing, water catchments, or river diversion). However, there is no synergy (either positive or negative) between SWC/AWD practices and PSNP at the EA-level (not shown) and thus no empirical support for this hypothesis. Other NRM innovations—conservation agriculture and agroforestry—showed joint adoption rates below 1% of households.

8. DNA Fingerprinting: What Do We Learn from the Comparison with Survey Data?

ESS4 is the first nationally representative multipurpose household survey incorporating varietal identification through DNA fingerprinting for multiple crops (worldwide). It therefore provides an important opportunity to illustrate how and to what extent empirical analysis on the adoption of improved varieties can be misguided when it relies on farmers' self-reporting about varietal adoption, which is more commonly used. This section therefore first documents the measurement error that would have resulted from using farmers' self-reportung in this context and analyzes what can be inferred from using the self-reported and the DNA fingerprinting data together. We also illustrate how using self-reported measures instead of DNA fingerprinting would have affected some of the main findings of the report. We focus the discussion on findings for maize, with additional results on barley and sorghum in Appendix M, and on the correlates of the measurement error in Appendix L.

8.1 Misclassification: Measurement Error across Categories

The comparison between crop varietal identification from DNA fingerprinting and farmers' self-reported data provides an estimate of farmers' misreporting of their adoption of improved varieties of maize, barley, and sorghum. This form of measurement error in the self-reported data (i.e., corresponding to errors across discrete categories) is referred to as misclassification.

We analyze how farmers' self-report on whether they grow "improved varieties" compares with the objective measure of whether the varieties have CGIAR-derived germplasm. We use data on the varietal identification of the entire maize sample, regardless of the purity of the seed or the age of the variety, and then check the robustness to the imposition of thresholds for purity and age. Farmers' responses are considered as

- *True positive* when they report that they are growing an improved variety and this is supported by CGIAR-derived germplasm DNA fingerprinting data;
- *True negative* when they report growing local varieties and this is supported by the DNA fingerprinting data;
- *False negative* (type II error) when they report cultivating a local variety yet the DNA fingerprinting data suggest that it is indeed an improved variety with CGIAR germplasm;
- *False positive* (type I error) when they report cultivating an improved variety yet DNA results show that it does not have any CGIAR-derived germplasm.

Taking the self-reported data at face value, 45.4% of farmers report adopting improved maize varieties (Table 17). DNA fingerprinting data, however, show that only about half of those self-reported adopters were cultivating CGIAR-derived varieties. Of the 54.6% of farmers who declared that they were not cultivating improved varieties, the samples taken from their plots show that approximately two-thirds of them were in fact predominantly cultivating varieties with CGIAR-derived germplasm. Thus, there are errors on both sides—false positives (22.2%) and false negatives (37.3%)—which are unbalanced such that using self-reported data from farmers alone would underestimate the share of farmers cultivating CGIAR derived varieties by 15 percentage points.

Table 17: Misclassification rate of adoption status of CGIAR-derived maize varieties at plot level

DNA fingerprinting results: CGIAR-related germplasm?	Self-reporting			
	Improved	Not improved	Total	N
Yes	23.3%	37.3%	**60.6%**	329
No	22.1%	17.3%	**39.4%**	177
Total	**45.4%**	**54.6%**	**100.0%**	**506**

Raising the threshold to be considered an improved variety from 70% purity (all 329 field samples growing CGIAR-related germplasm) to 90% (306 of 329 field samples) results in little change in misclassification rates. However, further restricting the purity threshold to 95% (126 out of 329 field samples) results in a sharp drop in the rate of false negatives. This shift from a 90% to 95% purity threshold means false negatives become true negatives under the tighter definition of improved variety. This picture is consistent with a scenario in which farmers growing a variety with CGIAR germplasm who know that their seed is no longer pure, as a result of recycling over multiple seasons, may no longer consider their seed to be improved.

The concept of "improved variety" is open to different interpretations, and farmers will almost certainly not have perfect information. Consider the possibility that, rather than attributing all the mismatches between DNA fingerprinting results and farmers' self-reported data to be on the side of the farmers' misclassification, we instead consider that there is a signal in self-reported data. In this example, we see that the majority of the maize samples established as having CGIAR germplasm by DNA fingerprinting are reported as "not improved" by farmers, and by quite a margin (118 farmers to 189, or 23.3% versus 37.3% of our sample of 506 farmers). By incrementally tightening the definition of improved varieties to include a threshold for purity or maximum varietal age, it is possible to induce a switch where true positives dominate false negatives as shown in Tables 18 and 19. It follows that these samples have a higher bar to reach to still be considered "improved," and so represent a much smaller fraction of the total. This implies a lower effective adoption rate under these additional conditions of 27.3% for CGIAR-related varieties at purity greater than 95%, or 16.0% for CGIAR-related varieties less than 10 years old.

Table 18: Rates of misclassification of varietal status for farmers adopting CGIAR-related germplasm (as confirmed by DNA fingerprinting) when the definition of adopter of an improved variety additionally incorporates a minimum threshold for genetic purity

CGIAR-related germplasm AND Purity level threshold imposed of:	Self-reported data (classification status) Improved (true positive)	Not improved (false negative)	N	Implied adoption rate under combined conditions	Samples not meeting combined conditions
Above 70%	23.3%	37.3%	329	60.6%	177
Above 90%	23.0%	34.6%	306	57.6%	200
Above 95%	18.3%	9.0%	126	27.3%	380

Table 19: Rates of misclassification of varietal status for farmers adopting CGIAR-related germplasm when definition of adopter of an improved variety additionally incorporates a maximum limit for varietal age

CGIAR-related germplasm AND year of release being:	Self-reported data (classification status) Improved (true positive)	Not improved (false negative)	N	Implied adoption rate under combined conditions	Samples not meeting combined conditions
After 1990	22.9%	35.5%	319	58.4%	187
After 2000	13.7%	22.2%	199	35.9%	307
After 2010	11.7%	4.3%	67	16.0%	439

Finally, Table 20 illustrates how using self-reported data can lead to misguided conclusions on the identity of the adopters of CGIAR innovations. The self-reported data on using improved maize varieties suggest, in particular, that adoption is more likely among larger farmers and households with lower female participation in agriculture and less likely among the poor; these results could all be interpreted to mean that CGIAR innovations are not reaching their target audiences. Importantly, however, the results with DNA fingerprinting contradict this finding and indeed suggest that adoption is more equitable, as neither farm size, gender, nor poverty is predictive of adoption rates.

Table 20: Summary of variables associated with maize varietal adoption using DNA fingerprinting and self-reported data

Variable	Self-reported data	DNA fingerprinting data
Total parcels size	0.38***	n.s
Distance to market (km)	n.s.	n.s
Asphalt as a main access road	n.s.	n.s
Female share of family labor is > 50%	-0.05**	n.s
Annual consumption per capita (ETB)	n.s.	n.s
Bottom 40% annual consumption	-0.20***	n.s
Productive asset index	n.s.	n.s
Annual off-farm income (ETB)	n.s.	n.s
Age of household head	n.s.	n.s

Note: Each cell is a coefficient estimate from a separate regression of the row variable on the column variable. For statistically significant relationships, the magnitude of the difference is indicated. Green shows a positive relationship while red demonstrates a negative relationship.

*** $p < 0.01$, ** $p < 0.05$, n.s. = non-significant. ETB = Ethiopian birr.

9. The Way Forward: Priorities for Future Surveys

The outcomes of the stocktaking exercise were presented to stakeholders in Addis Ababa in February 2020. Participants in the workshop included representatives from all CGIAR centers hosted in Ethiopia, the Central Statistical Agency (CSA), the World Bank, and the Ethiopian Institute of Agricultural Research (EIAR) as well as government officials from the Ministry of Agriculture (MoA), the Agricultural Transformation Agency (ATA), the Integrated Seed Sector Development Program in Ethiopia (ISSD Ethiopia), and the Planning and Development Commission (PDC). Group discussions were conducted to validate and complement the final version of the stocktaking, on which this report relies.

Government officials often mentioned data quality and timeliness and recognized the CSA researchers for their independence and attention to detail. The Ministry of Agriculture representative noted that the ministry has a theory of change for the agricultural sector, and the adoption of improved technologies is "at the center of it", suggesting that a continued focus on adoption estimates would be appropriate. Other voices spoke of how the food sector is changing, with the emergence of new data needs related to development of agro-industry over the coming years. For example, pasta-processing plants that are opening in Ethiopia are looking for certain quality traits in wheat. Can we ensure that assessments of adoption rates reflect participation in these value chains by farmers? Can we ensure that DNA fingerprinting is sufficiently institutionalized to identify where farmers are accessing seeds for varieties with these market-demanded traits? As Ethiopia transforms further, its data needs will change.

To deepen and continue updating the evidence on the reach of CGIAR innovations, SPIA envisions extending, deepening, and institutionalizing the overall approach described in this report. For Ethiopia, there remain innovations for which we were unable to incorporate data collection protocols into the ESS to date. Apart from wheat and beans, other examples include improved varieties of faba bean, potato, and rice.[23] The next wave of the ESS may offer potential for strengthening the attribution to CGIAR research for some innovations. For instance, public-private partnerships for artificial insemination delivery in dairy systems have established an ear-tagging system for new crossbred animals in the regions of Amhara, Oromia, SNNPR, and Tigray. It is worth exploring whether a protocol for identifying crossbreeds through this observable feature can be integrated into existing survey procedures.

Outcomes from the workshop regarding new data inclusion in the ESS can be found in the last column of the stocktaking. Innovations not yet captured and potentially at scale that are candidates for inclusion in new survey waves are the AgData Platform and two-wheel-tractor (2WT)-based technologies. Innovations in government policies include participatory

[23] Accounting for the evidence described in this report, there is now DNA fingerprinting evidence at scale for most crops for which CGIAR efforts have occurred and for which the stocktaking indicates they could be widely adopted at the national level, with the possible exception of faba beans and chickpea. For the latter, we report evidence of CGIAR germplasm based on a visual aid, but DNA fingerprinting evidence would be needed for varietal identification of both desi and kabuli types. Potato and rice have had CGIAR germplasm released, but adoption is expected to still be mostly concentrated in certain areas.

forest management (PFM) and water users associations (WUAs). Capturing adoption of these innovations will require establishing sound survey instruments at the community level and subjecting them to methodological validation exercises.

Thus there are two important ways forward. First, it is important to keep pushing on the frontier of measurement methodologies, advancing these ideas but also widening the scope to include measurement challenges for landscape-level research. Such work could benefit from, for instance, recent advances in remote-sensing analysis for establishing benchmark methods for measuring adoption. Second, it is vital to consolidate and institutionalize the stocktaking and measurement approach explained in this report, building on the strengths of CSA and EIAR and exploring possibilities for additional partnerships. The next round of the ESS survey will form a panel with the 2018/19 round, so repeat measures of the same innovations will allow for dynamic analysis of adoption and diffusion, which is of particular interest for innovations that are rapidly diffusing.[24]

In terms of the other steps on the analytical agenda, this report arguably raises many questions that were purposely left for further research. Diffusion patterns for several innovations highlighted in this report, for instance, would benefit from further investigation to uncover the mechanisms underlying the descriptive statistics reported here. Examples include ruminant and poultry crossbreed diffusion patterns, the factors underlying the rapid adoption of the BH661 barley variety, the process of community mobilization that has facilitated the widespread adoption of soil and water conservation structures, and the fact that intensification of modern inputs is apparent for plots where soil and water conservation practices are adopted but not for conservation agriculture plots. As introduced in section 7, many of these topics can be explored in a spatially explicit framework by taking the ESS dataset(s) and crossing it with administrative or monitoring and evaluation data (where possible to compile). Moreover, for innovations related to animal agriculture and soil and water conservation methods, dynamic analysis is possible; information on these innovations was collected in ESS1, ESS2, and ESS3. For yet other innovations, a careful qualitative research agenda can be well suited to complement the findings of this report.

Future work should include a more in-depth analysis of who adopts specific innovations and where, with the goal of generating evidence relevant for targeting and scaling up policies. At a different level, analysis of the relationships between agricultural innovations and community- or regional-level development could help improve understanding of structural transformation processes in Ethiopia.

[24] The ESS survey has a panel dimension that could not be exploited in the current report owing to the panel refreshment that occurred between ESS3 and ESS4.

10. Summary and Conclusions

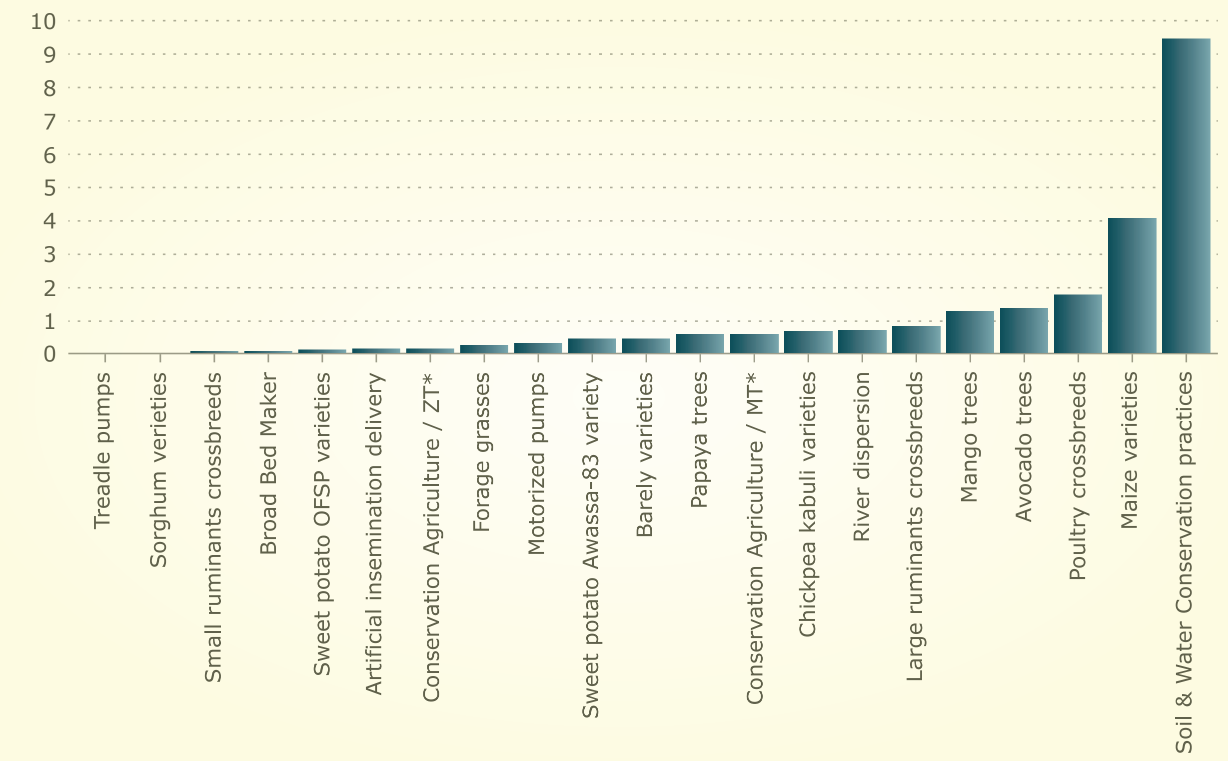
Research conducted by CGIAR and its national partners has contributed to a large set of innovations potentially affecting Ethiopian rural households' farming activities, livelihoods, and environments in a wide variety of ways. This report provides a systematic stocktaking of these innovations across the different domains of the CGIAR's portfolio and provides the first-ever effort to empirically document the reach of different CGIAR-related innovations at the country level. Based on a compilation of information on the last two decades of research activities (1999–2019), section 3 documented 52 innovations that can be traced to CGIAR research efforts, resulting from research of 13 centers, in close collaboration with national partners. This is complemented with narrative evidence of how CGIAR centers' research and expertise have provided input into 26 different government policies or intervention designs.

Of the 52 innovations, a combination of desk reviews and expert interviews pointed to 18 for which diffusion (through private and/or public initiatives) was expected to have occurred. Building on these insights, measurement of these innovations was incorporated into the survey instruments of the nationally representative panel household survey, through a partnership with CSA and the World Bank's LSMS-ISA team. In addition, two of the policy influences also led to institutional innovations observable through information incorporated in the household survey. This report draws on these data to provide nationally representative empirical evidence of the reach of CGIAR-related innovations, showing not only the number of households that are being reached, but also the geographical spread and the socioeconomic characteristics of the households being reached, as well as the possibly local-level synergies between these innovations.

The unique nationally representative empirical results presented in this report allow us to draw a number of important conclusions and related lessons and also point out a number of outstanding questions. First, AR4D efforts have resulted in a large number of innovations within an overall context of growth and transformation of the agricultural sector in Ethiopia. CGIAR scientists and their national partners have generated a plethora of new ideas, many of them leading to adoption, some of them to adoption at scale. As section 4 shows, in total, between 4.1 and 11 million Ethiopian rural households have been reached by agricultural innovations linked to CGIAR research. In some cases, diffusion of new innovations has gone remarkably fast. In many other cases, diffusion is slower or more limited.

Indeed, while many innovations are being adopted by some farmers, only a few are reaching large numbers of households. This is exactly what one would expect given the uncertainties related to research, the many factors outside the control of the researcher, and the differences in timelines, diffusion efforts, and characteristics of the different innovations. Notably, the three innovations with the largest reach, as measured with the current data, result from different types of CGIAR research efforts, relating to NRM and policy research, crop breeding, and livestock research. In addition, contemporaneous evidence suggests that improved wheat and bean varieties have a large reach. The vast majority of other innovations have much lower levels of diffusion. This skewed distribution in the reach of innovations, when they are considered individually, is in line with evidence from investments in other innovation systems. It also means that considering the diffusion of agricultural innovations one at a time provides an incomplete picture, as different innovations reach different households and regions. This result sheds new light on ongoing debates about why farmers may not be adopting a given technology and suggests that focusing on a portfolio of possible of innovations, and the possible trade-offs between them, rather than on a single one, could be a promising avenue, both for future academic work and for the design of public policies to promote agricultural growth.

Figure 9: Number of rural households adopting each CGIAR-related innovation in Ethiopia in 2019, based on ESS4*



Note: This graph includes only innovations measured within the ESS surveys. It does not include wheat or beans, for which adoption estimates from other sources are available. ZT = zero tillage; MT = minimum tillage. Y axis in millions of households.

* Estimates based on ESS4, with exception of Kabuli chickpea and Broad Bed Maker, which were measured in ESS3.

Indeed the evidence in this report shows a remarkable heterogeneity in the types of households being reached by different innovations (section 5) and a wide geographical scope (section 6). According to the evidence, it is not necessarily the case that a certain type of farmer is more likely to adopt many different innovations at once. This finding implies that in the real world, farm-level synergies between different innovations are limited (section 7). This does not necessarily mean that there are no potential gains from such synergies, but rather that current constraints may limit joint adoption. It could also mean, however, that different innovations could be partial substitutes for each other.

The results also show that, in Ethiopia, many innovations are not disproportionally more likely to be adopted by male, larger, richer, more educated, or more connected farmers. This suggests that the innovations manage to reach the types of farmer and rural households and communities that many CGIAR research efforts explicitly target, arguably an important precondition for obtaining intended impacts along the CGIAR's five impact areas, including on poverty reduction, food security, gender equality, and social inclusion. Results for individual innovations do not all point in this direction, but considering the portfolio altogether provides a picture of more inclusive reach.

While the whole is hence much larger than the sum of its parts, one can still wonder why some individual innovations have diffused at a much larger scale than others. This exercise is speculative, at best, given the obvious lack of a counterfactual. Even so, it is striking that, for the innovations that have been documented to reach multiple millions of households, in each case we observe how scaling of innovations generated by biophysical research in part can be linked to supportive government policies influenced by policy research. For instance, research on soil and water conservation practices by several CGIAR centers was able to feed into policy priority setting and large government programs like SLM. Similarly, the relatively swift recent diffusion of drought-tolerant maize likely benefited from the policies of the Agricultural Transformation Agency, and in particular the large-scale rollout and improvements in the Direct Seed Marketing system, whose design was informed by CGIAR policy research. And the relatively rapid diffusion of poultry crossbreeds can be directly linked to a public-private partnership and ties in with interventions promoted by Ethiopian's Livestock Master Plan, a planning exercise in which CGIAR researchers played a prominent role.

Arguably, this pattern aligns well with the rationale for One CGIAR as a system, and more specifically, the complementarities between the research activities of the different centers, as well as the synergies and mutual interdependence among research, interventions, policies, and actions supported and implemented by their public and private national and international partners. It also suggests that, at certain moments, when conditions are right and partnerships are in place, there is potential for research to have a major influence on a process of development and transformation.

Apart from the innovations that have already scaled up, the report also provides evidence of the presence on the ground of CGIAR-related innovations that appear well placed to play a key role in the national agricultural transformation agenda. Through their alignment with government priorities, innovations such as malt barley varieties, chickpea kabuli varieties, and small and large ruminant crossbreds could help the agricultural sector take advantage of increasing domestic demand and export opportunities. While this conclusion is admittedly a bit speculative, it may nevertheless be a useful input into the design of agricultural and rural development policies by national stakeholders and their international partners. Other innovations, such as those resulting from improvements in fruit trees and the promotion of tree seed centers, are closely aligned with recent government priorities and large-scale efforts on afforestation, and as such have potential to reach many more households and communities soon. They are worth tracking closely over the coming years.

The report also documents, however, diffusion levels that may be lower than expected, as well as innovations that may not be reaching targeted farmers or intended agroecological contexts and regions. This is true both for innovations that may have been expected to easily diffuse through market mechanisms and for innovations for which specific scaling efforts already took place. For a number of these innovations, findings go counter to earlier publicity or impact success stories promoted by CGIAR. Such evidence hence cautions against making bold claims of diffusion (let alone impact) without rigorous evidence.

An analysis of the possible underlying reasons for the limited adoption of each of these innovations is beyond the scope of this report, but the evidence presented (as well as underlying database, which allows for a more in-depth analysis) provides a good basis for reevaluating the theories of change (ToCs) regarding the scaling up of these different innovations and for identifying which assumptions in these ToCs may need to be adjusted. It would be worth analyzing the existing ToCs in light of, for instance, assumptions made about the expected benefits of innovations for certain types of farmers (e.g., smallholders, women, young farmers, or capital-constrained farmers) or certain agroecological zones. The empirical evidence presented in this report likely shows that these types of farmers are not in fact adopting these innovations or that diffusion has not yet occurred in regions where benefits could be the largest. Down the road, such an exercise can help identify possible complementary policy interventions that may be needed to lift households' and communities' internal or external constraints to adoption and help them obtain the anticipated gains. It could also provide important input on the geographic targeting of such interventions and related diffusion efforts. Importantly, a reevaluation of the ToC with this empirical evidence can provide feedback into the research process itself by, for instance, helping refine product profiles for additional breeding or agronomy research.

Finally, this report also serves as a proof of concept for the systematic collection of data on CGIAR-related innovations, using accurate measures, as part of an integrated household survey with rich socioeconomic and agricultural information, and for the type of evidence and lessons that can be derived from such an exercise. Here too, arguably, the report demonstrates that the whole is more than the sum of its parts. The incorporation of measures informed by biophysical expertise into a socioeconomic survey leads to a win-win by substantially increasing the potential for obtaining unbiased answers to research questions relevant not only to the agricultural research agenda but also to agricultural and rural development public policy more generally. Section 8 demonstrates that using self-reported measures instead of the DNA fingerprinting data would have led to erroneous conclusions about the level of adoption and the types of farmers being reached by CGIAR innovations. The detailed information on households' agricultural activities obtained in the same survey also provides the possibility of more in-depth analysis on each of these innovations in future work.

The exercise does come with important caveats, as there will always be logistical limits to the integration of high-quality measures of all possible innovations in the same survey instrument. Because of such constraints, a number of innovations were not included in the current exercise. A prioritization exercise led to the exclusion of innovations for which other recent national-level evidence exists (wheat, beans), innovations with limited geographical coverage (such as potato), and innovations for which objective measurement data could not yet be validated or was still too costly to collect at scale. Moreover, data was collected only for the main season of the year, which may underestimate the coverage of innovations for certain crops from the *belg* season. Also, for the innovations that are included, the links to CGIAR research are necessarily of varying strengths, complicating aggregation and leading us to report a wide confidence interval when considering the overall reach of CGIAR in Ethiopia. Even so, the report provides a baseline for studying dynamic changes in the adoption and diffusion of a wide variety of innovations by incorporating similar measures in future waves of the survey. It also suggests a number of ways forward for improved measurement in future data collection efforts in Ethiopia and beyond and for the analytical agenda (section 9). The data and empirical evidence presented are not meant to answer all relevant questions, but rather intended to provide a starting point for discussions on their implications and to stimulate more in-depth analysis and engagement by a wide variety of stakeholders and researchers.

In conclusion, agricultural research carried out by CGIAR scientists and their national partners generates many new ideas for innovations that might help address pressing policy concerns. Only some of these candidate innovations survive the early stages of research for development to actually enter serious piloting. Of those that are piloted (and often adapted or modified in the process), only some innovations look promising for scaling up. Of those that are promoted through meaningful investments, only a few will take off in a way that results in substantial reach and ultimately impact at a large scale. Others may have more localized impacts or provide a basis for potential future successes. By systematically tracking this process for CGIAR research efforts across different domains and centers, the stocktaking exercise presented in this report aimed at shining a brighter light on the reach of innovations that can be traced back to these CGIAR research activities.

CGIAR’s contribution to Ethiopia’s agricultural development is complex and wide-ranging, and while some aspects cannot be captured by survey data, this new source of adoption and diffusion data helps identify the scale and scope of CGIAR’s reach in Ethiopia. Looking ahead, SPIA’s experience in Ethiopia demonstrates the potential of this approach in other countries where CGIAR works.

References

Abate, T., Shiferaw, B., Menkir, A., Wegary, D., Kebede, Y., Tesfaye, K. & Keno, T. (2015). Factors that transformed maize productivity in Ethiopia. *Food Security*, 7(5), 965–981.

Abebe, Y., & Bekele, A. (2015). Analysis of adoption spell of improved common bean varieties in the central rift valley of Ethiopia: A duration model approach. *Journal of Agricultural Economics and Development*, 4(3), 37–43.

Adimassu, Z., Langan, S., & Barron, J. (2018). *Highlights of soil and water conservation investments in four regions of Ethiopia*. IWMI Working Paper 182. Colombo, Sri Lanka: International Water Management Institute (IWMI). doi: 10.5337/2018.214.

Adugna, A. (2007). The role of introduced sorghum and millets in Ethiopian agriculture. *SAT eJournal*, 3(1).

Alemu, D., & Tripp, R. (2010). Seed system potential in Ethiopia: Constraints and opportunities for enhancing production. IFPRI Working Paper. Washington, DC: International Food Policy Research Institute.

Alemu, D., & Bishaw, Z. (2019). Yield gaps, adoption, and seed commercial behavior: Implications for chickpea seed system in Ethiopia. *African Journal of Agricultural Research*, 14(33), 1778–1784.

Andersson, J. A., & D'Souza, S. (2014). From adoption claims to understanding farmers and contexts: A literature review of conservation agriculture (CA) adoption among smallholder farmers in southern Africa. *Agriculture, Ecosystems & Environment*, 187, 116–132.

Atilaw, A., & Korbu, L. (2011). Recent development of seed systems in Ethiopia. In: Improving Farmers' Access to Seed, eds D. Alemu, S. Kiyoshi and A. Kirub, 13-30. Addis Ababa: EIAR-JICA.

Atlin, G. N., Cairns, J. E., & Das, B. (2017). Rapid breeding and varietal replacement are critical to adaptation of cropping systems in the developing world to climate change. *Global Food Security*, 12, 31–37.

Bachewe, F. N., Berhane, G., Minten, B., & Taffesse, A. S. (2018). Agricultural transformation in Africa? Assessing the evidence in Ethiopia. *World Development*, 105, 286–298.

Bardasi, E., & Getahun, A. (2009). *Ethiopia toward the competitive frontier: Strategies for improving Ethiopia's investment climate*. Washington, DC: World Bank.

Bashe, A., Bassa, Z., & Tyohannis, S. (2018). The determinants of probability in improved forage technology adoption in Wolaita zone: The case of Sodo Zuria district, Southern Nations and Nationalities Peoples state of Ethiopia. *Open Access Journal of Science*, 2(4), 228–231.

Baudron, F., Jaleta, M., Okitoi, O., & Tegegn, A. (2014). Conservation agriculture in African mixed crop-livestock systems: Expanding the niche. *Agriculture Ecosystems & Environment*, 187, 171–182.

Bedru, B., Tadesse, B., Legesse, H., Feyera, M., Goshime, M. & Yalfal, T. (2018). Enhancing agricultural resilience and sustainability in Eastern and Southern Africa: Key findings and recommendations for Ethiopia. Synthesis report Ethiopia. Addis Ababa: Ethiopian Institute of Agricultural Research (EIAR) and International Maize and Wheat Improvement Center (CIMMYT).

Bekele, W., & Drake, L. (2003). Soil and water conservation decision behavior of subsistence farmers in the Eastern Highlands of Ethiopia: A case study of the Hunde-Lafto area. *Ecological Economics*, 46(3), 437–451.

Bekuma, A., Tadesse, T., Fita, L., & Galmessa, U. (2018). Milk and milk products processing, preservation and utilization in Gimbi district, West Wollega zone, Ethiopia. *Scientific Journal of Animal Science*, 7(5), 504–510.

Benson, T., Spielman, D., & Kasa, L. (2014). Direct seed marketing program in Ethiopia in 2013: An operational evaluation to guide seed-sector reform. IFPRI Discussion Paper 01350. Washington, DC: International Food Policy Research Institute.

Berhane, G., Hoddinott, J. F., & Kumar, N. (2017). *The impact of Ethiopia's Productive Safety Net Program on the nutritional status of children: 2008–2012*. IFPRI Discussion Paper 1604. Washington, DC: International Food Policy Research Institute.

Brennan, J. P., & Byerlee, D. (1991). The rate of crop varietal replacement on farms: Measures and empirical results for wheat. *Plant Varieties and Seed*, 4, 99–106.

Cavatassi, R., Lipper, L. & Narloch, U. (2011). Modern variety adoption and risk management in drought-prone areas: Insights from the sorghum farmers of eastern Ethiopia. *Agricultural Economics*, 42(3), 279–292.

Central Statistical Agency of Ethiopia & World Bank. (2016). Socioeconomic Survey 2015-2016, Wave 3. Accessed October 12, 2020. https://microdata.worldbank.org/index.php/catalog/2783. Addis Ababa, Ethiopia.

Central Statistical Agency of Ethiopia & World Bank. (2020). Socioeconomic Survey 2018-2019, Wave 4. Accessed October 12, 2020. https://www.worldbank.org/en/programs/lsms/initiatives/lsms-ISA#2. Addis Ababa, Ethiopia.

Cochrane, L., & Bekele, Y. W. (2018). Contextualizing narratives of economic growth and navigating problematic data: Economic trends in Ethiopia (1999–2017). *Economies*, 6(4), 64.

Cover, T., & Hart, P. (1967). Nearest neighbor pattern classification. *IEEE Transactions on Information Theory*, 13(1), 21–27.

CSA (Central Statistical Agency of Ethiopia). (2019). *Agricultural sample survey 2018/19 (2011 E.C.) Report on area and production of major crops*. Addis Ababa.

EIAR (Ethiopian Institute of Agricultural Research). (2019). Melkassa Agricultural Research Center: Sorghum research. http://www.eiar.gov.et/marc/index.php/anrl-research/crop-research.

Elmyhun, M., & Mekonen, M. (2016). Participatory varietal evaluation of open-pollinated maize in Western Amhara, North-west Ethiopia. *Journal of Crop Science and Biotechnology,* 19, 131–136.

Elven, S., & Krishnan, L. (2018). *Estimating historical CGIAR research investments*. Technical Note No. 5. Rome: Independent Science and Partnership Council. https://cas.cgiar.org/spia/publications/estimating-historical-cgiar-research-investments.

Ertiro, B.T., Zeleke, H., Friesen, D., Blummel, M., Twumasi-Afriyie, S. (2013). Relationship between the performance of parental inbred lines and hybrids for food-feed traits in maize (Zea mays L.) in Ethiopia. *Field Crops Research* 153, 86–93. https://doi.org/10.1016/j.fcr.2013.02.008

ESSP (Ethiopia Strategy Support Program). (2014). The impact of research on the Productive Safety Net Program (PSNP). ESSP Outcome Note 5. Washington, DC: International Food Policy Research Institute. http://essp.ifpri.info/files/2011/04/Outcome-Note_5_PSNP_v1-0.pdf.

FAO (Food and Agriculture Organization of the United Nations). (2013). *The state of Ethiopia's biodiversity for food and agriculture*. Rome: FAO.

FCA (Federal Cooperative Agency). (2016). *3rd national cooperatives exhibition, bazaar, and symposium*. Addis Ababa.

FDRE (Federal Democratic Republic of Ethiopia). (2014). Irrigation water users' association (IWUA) proclamation of Ethiopia: Proclamation No. 841/2014. Addis Ababa. https://chilot.me/wp-content/uploads/2018/12/Proclamation-No.-841-2014-Irrigation-Water-Users-Associations.pdf.

FDRE. (2019a). *Ethiopia national pulses strategy 2019–2024*. Addis Ababa.

FDRE. (2019b). Mimeo, Table-2C: Percentage distribution of GDP by economic activity at constant basic prices (%) (2008 EFY base year series). Addis Ababa: Planning and Development Commission.

Gebregziabher, G., Giordano, M. A., Langan, S., & Namara, R. E. (2014). Economic analysis of factors influencing adoption of motor pumps in Ethiopia. *Journal of Development and Agricultural Economics*, 6(12), 490–500.

Gebremedhin, B., Ahmed, M. M., & Ehui, S. K. (2003). Determinants of adoption of improved forage technologies in crop-livestock mixed systems: Evidence from the highlands of Ethiopia. *Tropical Grasslands*, 37, 262-273.

Gebremedhin, B., Jemaneh, S., Hoekstra, D. & Anandajayasekeram, P. (2012). A guide to market-oriented extension services with special reference to Ethiopia. Nairobi: International Livestock Research Institute (ILRI).

Getacher, T., Mesfin, A., & Gebre-Egziabher, G. (2013). Adoption and impacts of an irrigation technology: Evidence from household-level data in Tigray, Northern Ethiopia. *African Journal of Agricultural Research*, 8(38), 4766–4772.

Getachew, T., Haile, A., Wurzinger, M., Rischkowsky, B., Gizaw, S., Abebe, A., & Sölkner, J. (2016). Review of sheep crossbreeding based on exotic sires and among indigenous breeds in the tropics: An Ethiopian perspective. *African Journal of Agricultural Research*, 11(11), 901–911.

Gezahegn, A. (1999). *Economic analysis of innovation and adoption of vertisol technology: A study of smallholder mixed farming in the highlands of Ethiopia*. Stuttgart, Germany: Verlag Ulrich E. Grauer.

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, 114(1), 23–34.

Gizaw, S., Abera, M., Muluye, M., Hoekstra, D., Gebremedhin, B., & Tegegne, A. (2016). Smallholder dairy farming systems in the highlands of Ethiopia: System-specific constraints and intervention options. LIVES Working Paper 23. Nairobi, Kenya: International Livestock Research Institute (ILRI).

Gurmu, F., & Mekonen, S. (2017). Registration of a newly released sweet potato variety "Hawassa-09" for production in Ethiopia. *Agrotechnology*, 6(160), 2.

Haile, A., Wurzinger, M., Mueller, J., Mirkena, T., Duguma, G., Rekik, M. & Rischkowsky, B. A. (2019). Guidelines for setting up community-based small ruminant breeding programs. Beirut, Lebanon: ICARDA.

Haregeweyn, N., Tsunekawa, A., Tsubo, M., Meshesha, D., Adgo, E., Poesen, J., Schütt, B. (2016). Analyzing the hydrologic effects of region-wide land and water development interventions: a case study of the Upper Blue Nile basin. *Regional Environmental Change* 16, 951–966. https://doi.org/10.1007/s10113-015-0813-2.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). (n.d.). *ICRISAT and Ethiopia: Working with partners for prosperous semi-arid tropics*. Addis Ababa: ICRISAT-Ethiopia. http://www.icrisat.org/who-we-are/investors-partners/donor-flyers/Ethiopia-icrisat.pdf.

IMF (International Monetary Fund). (2020a). *The Federal Democratic Republic of Ethiopia*. IMF Country Report No. 20/29. Washington, DC: IMF.

IMF. (2020b). Policy responses to COVID-19. https://www.imf.org/en/Topics/imf-and-covid19/Policy-Responses-to-COVID-19.

Jaleta, M., Kassie, M., Marenya, P., Yirga, C., & Erenstein, O. (2018). Impact of improved maize adoption on household food security of maize producing smallholder farmers in Ethiopia. *Food Security*, 10(1), 81–93.

Jaleta, M., Tesfaye, K., Kilian, A., Yirga, C., Habte, E., Beyene, H. & Erenstein, O. (2020). Misidentification by farmers of the crop varieties they grow: Lessons from DNA fingerprinting of wheat in Ethiopia. *PloS One*, 15(7), e0235484.

Kassie, M., Zikhali, P., Pender, J., & Köhlin, G. (2010). The economics of sustainable land management practices in the Ethiopian highlands. *Journal of Agricultural Economics*, 61(3), 605–627.

Kassie, M., Köhlin, G., Bluffstone, R., & Holden, S. (2011). Are soil conservation technologies "win-win?" A case study of Anjeni in the north-western Ethiopian highlands. In *Natural Resources Forum,* 35(2), 89–99.

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., Mekuria, M. (2012). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change* 80, 525–540.

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P., & Erenstein, O. (2015). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy*, 42, 400–411.

Katungi, E., Farrow, A., Mutuoki, T., Gebeyehu, S., Karanja, D., Alamayehu, F. & Buruchara, R. (2010). *Improving common bean productivity: An analysis of socioeconomic factors in Ethiopia and eastern Kenya*. Baseline report: Tropical Legumes II. Cali, Colombia: International Center for Tropical Agriculture (CIAT).

Kitonga, K., Sartie, A. M., Hanson, J., Teufel, N., Jones, C. S., Jamora, N. & Smale, M.. (2019). Tracing the benefits of ILRI germplasm distributions: *Medicago sativa, Sesbania sesban* and *Pennisetum purpureum*. Genebank Impacts Working Paper No. 8. CGIAR Genebank Platform, ILRI, and the Crop Trust. Nairobi, Kenya.

Kebebe, E. G. (2015). Understanding factors affecting technology adoption in smallholder livestock production systems in Ethiopia: The role of farm resources and the enabling environment. PhD thesis, Wageningen University, Wageningen, Netherlands.

Kilian, A., Wenzl, P., Huttner, E., Carling, J., Xia, L., Blois, H., Caig, V., Heller-Uszynska, K., Jaccoud, D., Hopper, C., et al. (2012). Diversity arrays technology: A generic genome profiling technology on open platforms. *Methods in Molecular Biology,* 888, 67–89.

Kinfe, H., & Tesfaye, A. (2018). Yield performance and adoption of released sorghum varieties in Ethiopia. *Edelweiss Applied Science and Technology*, 2(1), 46–55.

Kosmowski, F., Stevenson, J., Campbell, J., Ambel, A., & Tsegay, A. H. (2017). On the ground or in the air? A methodological experiment on crop residue cover measurement in Ethiopia. *Environmental Management*, 60(4), 705–716.

Kosmowski, F., & Worku, T. (2018). Evaluation of a miniaturized NIR spectrometer for cultivar identification: The case of barley, chickpea, and sorghum in Ethiopia. *PLoS One,* 13 (3), e0193620.

Kosmowski, F., Aragaw, A., Kilian, A., Ambel, A., Ilukor, J., Yigezu, B. & Stevenson, J. (2019a). Varietal identification in household surveys: Results from three household-based methods against the benchmark of DNA fingerprinting in southern Ethiopia. *Experimental Agriculture*, 55(3), 371–385.

Kosmowski, F., Ilukor, J., Johnson, N., Sekabira, H., Stevenson, J., & Wambugu, S. (2019b). *A country-level approach for tracking the diffusion of agricultural innovations in developing countries*. Technical Note No. 7. Rome: Independent Science and Partnership Council.

Kosmowski, F., Abebe, A., & Ozkam, D. (2020a). Challenges and lessons for measuring soil metrics in household surveys. *Geoderma,* 375, 114500.

Kosmowski, F., Alemu, S., Mallia, P., Stevenson, J., & Macours, K. (2020b). Supplementary materials for report "Shining a Brighter Llight: Comprehensive Evidence on Adoption and Diffusion of CGIAR-Related Innovations in Ethiopia". Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor]. https://doi.org/10.3886/E124681.

Kretzschmar, T., Mbanjo, E. G. N., Magalit, G. A., Dwiyanti, M.S., Habib, M.A., Diaz, M.G., Hernandez, J., Huelgas, Z., Malabayabas, M.L., Das, S.K., et al. (2018). DNA fingerprinting at farm level maps rice biodiversity across Bangladesh and reveals regional varietal preferences. *Scientific Reports*, 8, 14920.

Le, D. P., Labarta, R. A., de Haan, S., Maredia, M., Becerra, L. A., Nhu, L., Ovalle, T., Nguyen, V., Pham, N, Nguyen, H., et al. (2019). Characterization of cassava production systems in Vietnam. Working Paper. CIAT Publication No. 480. Hanoi, Vietnam: International Center for Tropical Agriculture (CIAT).

Lempériere, P., Hagos, F., Lefore, N., Haileslassie, A., & Langan, S. (2014). Establishing and strengthening irrigation water users' associations (IWUAs) in Ethiopia: A manual for trainers. Colombo, Sri Lanka: International Water Management Institute (IWMI). doi: 10.5337/2014.232.

Liyama, M., Derero, A., Kelemu, K., Muthuri, C., Kinuthia, R., Ayenkulu, E., & Sinclair, F. L. (2017). Understanding patterns of tree adoption on farms in semi-arid and sub-humid Ethiopia. *Agroforestry Systems*, 91(2), 271–293.

Lewin-Koh, J.N., & Bivand, R. (2011). Maptools: Tools for reading and handling spatial objects. R Package Version 0.8-10. http://cran.r-project.org/web/packages/maptools/index.html.

Mahdi, E., Pichai, T., & Savitree, R. (2010). Factors influencing the adoption of improved sorghum varieties in Awbere district of Somali regional state, Ethiopia. *East African Journal of Sciences*, 4(1), 41–47.

Mahoo, H., Radeny, M. A., Kinyangi, J., & Cramer, L. (2013). Climate change vulnerability and risk assessment of agriculture and food security in Ethiopia: Which way forward? CCAFS Working Paper No. 59. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Marenya, P., Kassie, M., Jaleta, M., Rahut, D. B., & Erenstein, O. (2015). Adoption of conservation agriculture under alternative agricultural policy and market access indicators: Evidence from Eastern and Southern Africa. 29th International Conference of Agricultural Economists (ICAE). Milan, Italy.

Masresha, D., Legesse, B., Haji, J., & Zemedu, L. (2017). Determinants of the adoption of improved white haricot beans in East Shewa Zone, South-Eastern Ethiopia. *Journal of Development and Agricultural Economics*, 9(12), 355–372.

Mekonen, L. K., Minot, N., Warner, J., & Abate, G. T. (2019). *Performance of direct seed marketing pilot program in Ethiopia: Lessons for scaling-up*. Ethiopia Strategy Support Program Working Paper 132. Washington, DC: International Food Policy Research Institute.

Mekuriaw, A., Heinimann, A., Zeleke, G., & Hurni, H. (2018). Factors influencing the adoption of physical soil and water conservation practices in the Ethiopian highlands. *International Soil and Water Conservation Research,* 6(1), 23–30.

Merrey, D. J., & Lefore, N. (2018). *How to support effective and inclusive irrigation water users' associations: A guide for practitioner*s. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE).

MoA (Ministry of Agriculture). (2013). *Crop variety register*. Issue No. 16. Addis Ababa: Ethiopian Ministry of Agriculture, Plant Variety Release, Protection and Seed Quality Control Directorate.

MoA. (2015a). *Agricultural growth program ll (AGP II): Program design document*. Addis Ababa: Ministry of Agriculture.

MoA. (2015b). *Productive Safety Net Program (PSNP IV) annual work plan and budget for 2015/16 (2008 EFY)*. Addis Ababa: Ministry of Agriculture.

MoA and ATA (Agricultural Transformation Agency). (2014). Seed system development strategy: Vision, systemic challenges, and prioritized interventions. Addis Ababa: Ministry of Agriculture and Agricultural Transformation Agency.

Moller, L. C. (2015). *Ethiopia's great run: The growth acceleration and how to pace it*. Washington, DC: World Bank.

Monyo, E. S., & Varshney, R. K. (2016). *Seven seasons of learning and engaging smallholder farmers in the drought-prone areas of sub-Saharan Africa and South Asia through Tropical Legumes, 2007–2014*. Patancheru, India: International Crops Research Institute for the Semi-Arid Tropics.

NBE (National Bank of Ethiopia). (2019). *National Bank of Ethiopia annual report 2017/18*. https://nbebank.com/wp-content/uploads/pdf/annualbulletin/Annual%20Report%202017-2018/Annual-report-2017-2018.pdf.

Phalan, B., Rodrigues, A. S. L., Balmford, A., Green, R. E., & Ewers R. M. (2007). Comment on "Resource-conserving agriculture increases yields in developing countries." *Environmental Science and Technology*, 41, 1054–1055.

PIM (CGIAR Research Program on Policies, Institutions, and Markets). (2017). *Strengthening resilience of rural households through improved social protection*. PIM Outcome Note. Washington, DC: International Food Policy Research Institute. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/131428.

PIM. (2019). *Annual report 2018: CGIAR Research Program on Policies, Institutions, and Markets (PIM)*. Washington, DC: International Food Policy Research Institute. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/133320.

Poets, A., Silverstein, K., Pardey, P., Hearne, S. & Stevenson, J. (2020). *DNA fingerprinting for crop varietal identification: Fit-for-purpose protocols, their costs and analytical Implications*. Rome: SPIA.

Purushothaman, R., Upadhyaya, H. D., Gaur, P. M., Gowda, C. L. L., & Krishnamurthy, L. (2014). Kabuli and desi chickpeas differ in their requirement for reproductive duration. *Field Crops Research*, 163, 24–31.

Randolph, T. (2018). CGIAR Research Program on Livestock. Poster prepared for the 8th Multi Stakeholder Partnership (MSP) meeting of the Global Agenda for Sustainable Livestock, Ulaanbaatar, Mongolia, June 11–15.

Richards, M., Sapkota, T., Stirling, C., Thierfelder, C., Verhulst, N., Friedrich, T., Kienzle, J. (2014). Conservation agriculture: Implementation guidance for policymakers and investors. Climate-Smart Agriculture Practice Brief. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen.

Rutherford, A. S. (2008). Broad bed maker technology package innovations in Ethiopian farming systems: An ex-post impact assessment. Nairobi: International Livestock Research Institute.

Rutherford, A., Odero , A., & Kruska R. (2001). *The role of the broad bed maker plough in Ethiopian farming systems: An ex-post impact assessment study*. ILRI Impact Assessment Series 7. Nairobi: International Livestock Research Institute.

Shapiro, B. I., Gebru, G., Desta, S., Negassa, A., Negussie, K., Aboset, G., & Mechal, H. (2015). Ethiopia Livestock Master Plan: Roadmaps for growth and transformation. Nairobi, Kenya: ILRI.

Shiferaw, A. (2017). *Productive capacity and economic growth in Ethiopia*. New YorK: United Nations, Department of Economics and Social Affairs.

Sisay, D. T., Verhees, F. J., & Van Trijp, H. C. (2017). Seed producer cooperatives in the Ethiopian seed sector and their role in seed supply improvement: A review. *Journal of Crop Improvement,* 31(3), 323–355.

SPIA (CGIAR Standing Panel on Impact Assessment) (2020) *SPIA's approach to impact assessment for CGIAR*. Technical Note No. 8. Rome: SPIA.

Staal, S. J., Baltenweck, I., Waithaka, M.M., de Wolff, T., & Njoroge L. (2002). Location and uptake: Integrated household and GIS analysis of technology adoption and land use, with application to smallholder dairy farms in Kenya. *Agricultural Economics,* 27, 295–315.

Stevenson, J. R., Serraj, R., & Cassman, K. G. (2014). Response to comment on "Evaluating conservation agriculture for small-scale farmers in Sub-Saharan Africa and South Asia." *Agriculture, Ecosystems and Environment*, 196, 112–113.

Stevenson, J., Vanlauwe, B., Macours, K., Johnson, N., Krishnan, L., Place, F., & Vlek, P. (2019). Farmer adoption of plot- and farm-level natural resource management practices: Between rhetoric and reality. *Global Food Security*, 20, 101–104.

Suri, T. (2011). Selection and comparative advantage in technology adoption. *Econometrica*, 79, 159-209.

Tamru, S. (2020). Transformation in the dairy sector. Presentation given at the webinar "Improving Evidence for Better Policy Making in Ethiopia's Livestock Sector," organized by the International Food Policy Research Institute, June 24. https://www.slideshare.net/essp2/improving-evidence-for-better-policy-making-in-ethiopias-livestock-sector.

Teklewold, H., Kassie, M., Shiferaw, B., & Köhlin, G. (2013). Cropping system diversification, conservation tillage, and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use, and demand for labor. *Ecological Economics*, 93, 85–93.

Tesfaye, A., Mamo, T., Getahun, W., Fikadu, T., Alemu, T., Bediye, S., & Solomon, T. (2016). Adoption analysis of smallholder dairy production technologies in Oromiya region. Addis Ababa: Ethiopian Institute of Agricultural Research.

Teshome, A., de Graaff, J., & Kassie, M. (2016). Household-level determinants of soil and water conservation adoption phases: Evidence from North-Western Ethiopian highlands. *Environmental Management*, 57(3), 620–636.

Thornton, P. K., & Herrero, M. (2014). Climate change adaptation in mixed crop-livestock systems in developing countries. *Global Food Security*, 3(2), 99–107.

Thornton, P. K. et al. (2018). A qualitative evaluation of CSA options in mixed crop-livestock systems in developing countries. In Lipper, L., McCarthy, N., Zilberman, D., Asfaw, S., & Branca, G., (eds.), *Climate-smart agriculture*. Natural Resource Management and Policy, vol. 52. Cham, Switzerland: Springer.

Tsadik, E. T., & Tamir, S. Z. (2015). Characterization of the adoption of village poultry technology package elements, chicken breeds and forms in the Central Oromia Region, Ethiopia. *Journal of Economics and Sustainable Development*, 6(13).

Tsige, T., Shiferaw, T., Fekadu, W., Lakew, B., Gezahegn, S., Taye, K., Mekasa, W., Haile, A., & Ahmed, S. (2019).

Registration of two food barley (*Hordeum vulgare L.*) varieties (HB 1965 and HB 1966) for the highlands of Ethiopia. *Ethiopian Journal of Science and Technology*, 10 (1): 17–27.

UNDP (United Nations Development Programme). (2018). Ethiopia's progress towards eradicating poverty. Addis Ababa.

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., Nziguheba, G., Schut, M., Van Asten, P. (2014). Sustainable intensification and the African smallholder farmer. *Current Opinion on Environmental Sustainability* 8, 15–22. https://doi.org/10.1016/j.cosust.2014.06.001.

Varma Penmetsa, R., et al. (2016). Multiple post-domestication origins of kabuli chickpea through allelic variation in a diversification-associated transcription factor. *New Phytologist*, 211, 1440–1451.

Vavilov, N. I. (1992). *Origin and geography of cultivated plants*. Cambridge, UK: Cambridge University Press.

Verkaart, S., Mausch, K., Claessens, L., & Giller, K. E. (2019). A recipe for success? Learning from the rapid adoption of improved chickpea varieties in Ethiopia. *International Journal of Agricultural Sustainability*, 17(1), 34–48.

Walker, T., Alene, A., Ndjeunga, J., Labarta, R., Yigezu, Y., Diagne, A., Andrade, R., Muthoni Andriatsitohaina, R., De Groote, H., Mausch, K., et al. (2014). Measuring the effectiveness of crop improvement research in Sub-Saharan Africa from the perspectives of varietal output, adoption, and change: 20 crops, 30 countries, and 1150 cultivars in farmers' fields. Report of the Standing Panel on Impact Assessment (SPIA). Rome: CGIAR Independent Science and Partnership Council (ISPC) Secretariat.

WFP (World Food Programme). (2019). *Comprehensive food security and vulnerability analysis (CFSVA)*. Addis Ababa: World Food Program Ethiopia Office and Central Statistical Agency of Ethiopia. https://reliefweb.int/sites/reliefweb.int/files/resources/wfp_ethiopia_cfsva_report_june_2019.pdf.

Wineman, A., Njagi, T., Anderson, C. L., Reynolds, T. W., Alia, D. Y., Wainaina, P., & Ayieko, M. W. (2020). A case of mistaken identity? measuring rates of improved seed adoption in Tanzania using DNA fingerprinting. *Journal of Agricultural Economics,* 71(3), 719–741. doi:10.1111/1477-9552.12368.

WOCAT (World Overview of Conservation Approaches and Technologies). (2020). Global Database on Sustainable Land Management. Accessed June 3, 2020. https://qcat.wocat.net/en/wocat/.

World Bank. (2013). *Ethiopia's Productive Safety Net Program (PSNP) integrating disaster and climate risk management: Case study*. Washington, DC: World Bank.

World Bank. (2015). *Ethiopia poverty assessment 2014*. Washington, DC: World Bank.

World Bank. (2016). *Priorities for ending extreme poverty and promoting shared prosperity*. Report No. 100592-ET. Washington, DC: World Bank.

World Bank. (2019). World Bank Open Data. Data retrieved September 2019. https://data.worldbank.org/.

World Bank. (2020a). *Ethiopia poverty assessment: Harnessing continued growth for accelerated poverty reduction*. Washington, DC: World Bank.

World Bank. (2020b). Living Standards Measurement Study–Integrated Surveys on Agriculture. https://www.worldbank.org/en/programs/lsms/initiatives/lsms-ISA.

World Bank. (2020c). Living Standards Measurement Study: The Center for Development Data (C4D2). https://www.worldbank.org/en/programs/lsms/C4D2.

Wossen, T., Tessema, G., Abdoulaye, T., Rabbi, I., Olanrewaju, A., Alene, A., & Manyong, V. (2017). *The cassava monitoring survey in Nigeria: Final report*. Ibadan, Nigeria: International Institute of Tropical Agriculture.

Wubeneh, N. G., & Sanders, J. H. (2006). Farm-level adoption of sorghum technologies in Tigray, Ethiopia. *Agricultural Systems*, 91(1–2), 122–134.

Yigezu, Y. A., Yirga, C., & Aw-Hassan, A. (2015). Varietal output and adoption in barley, chickpea, faba bean, field pea and lentil in Ethiopia, Eritrea and Sudan. In Walker, T. S., & Alwang, J. (eds.), *Crop improvement, adoption and impact of improved varieties in food crops in Sub-Saharan Africa*. Wallingford, UK: CGIAR and CABI.

Yirga, C., Bekele, A., & Kassie, M. (2017). Adoption and diffusion of sustainable intensification practices for maize-legume production in Ethiopia: A panel data analysis. Addis Ababa: Ethiopian Institute of Agricultural Research. ISBN 978-99944-66-46-7.

Zeng, D., Alwang, J., Norton, G. W., Shiferaw, B., Jaleta, M., & Yirga, C. (2015). Ex post impacts of improved maize varieties on poverty in rural Ethiopia. *Agricultural Economics*, 46(4), 515–526.

Cattle in the Upper Ghibe Valley, Ethiopia.
Credit: ILRI/S. Mann

Appendices

Appendix A. Questions/Protocols Used to Measure CGIAR-Related Innovations in the ESS

Chickpea

12c. What do the chickpea <u>flowers</u> look like?

1

2

3 = Do not know

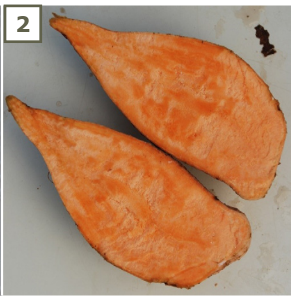
Response 1 (white flower) = kabuli type; Response 2 (purple flower) = desi type

Orange-fleshed sweet potato

17. What does the sweet potato <u>flesh</u> look like?

1

2



18. What does the sweet potato <u>skin</u> look like?

1

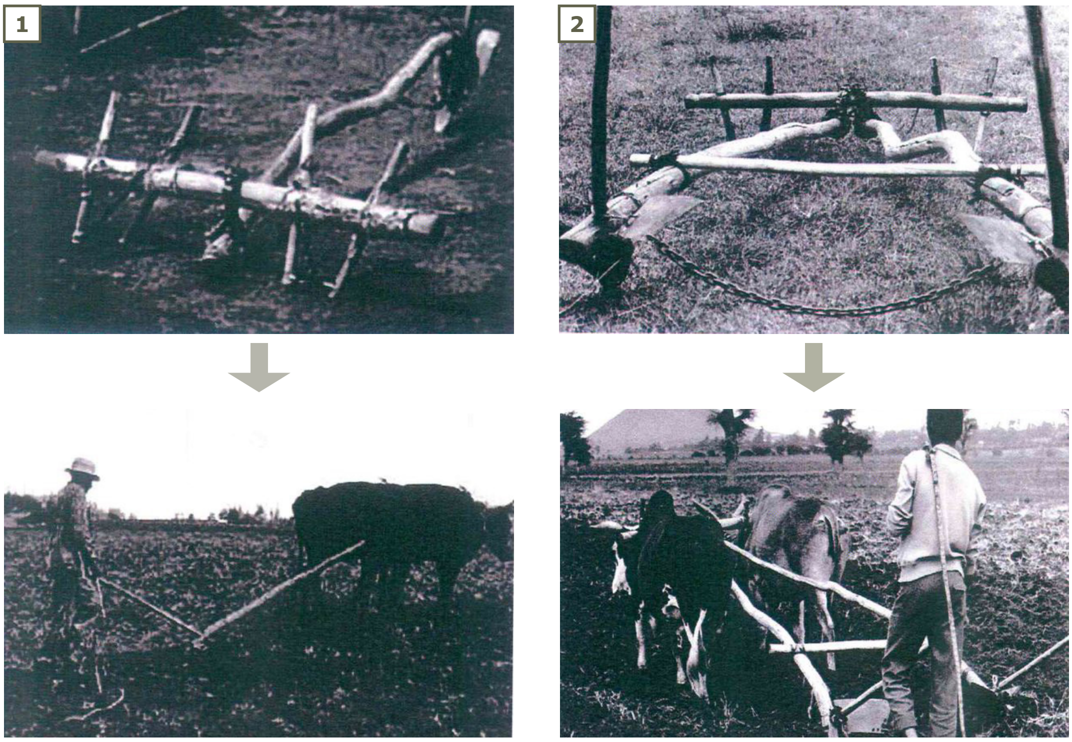
2

Q17 Response 2 = OFSP

Q17 Response 1 AND Q18 Response 2 = Awassa 83

Chickpea

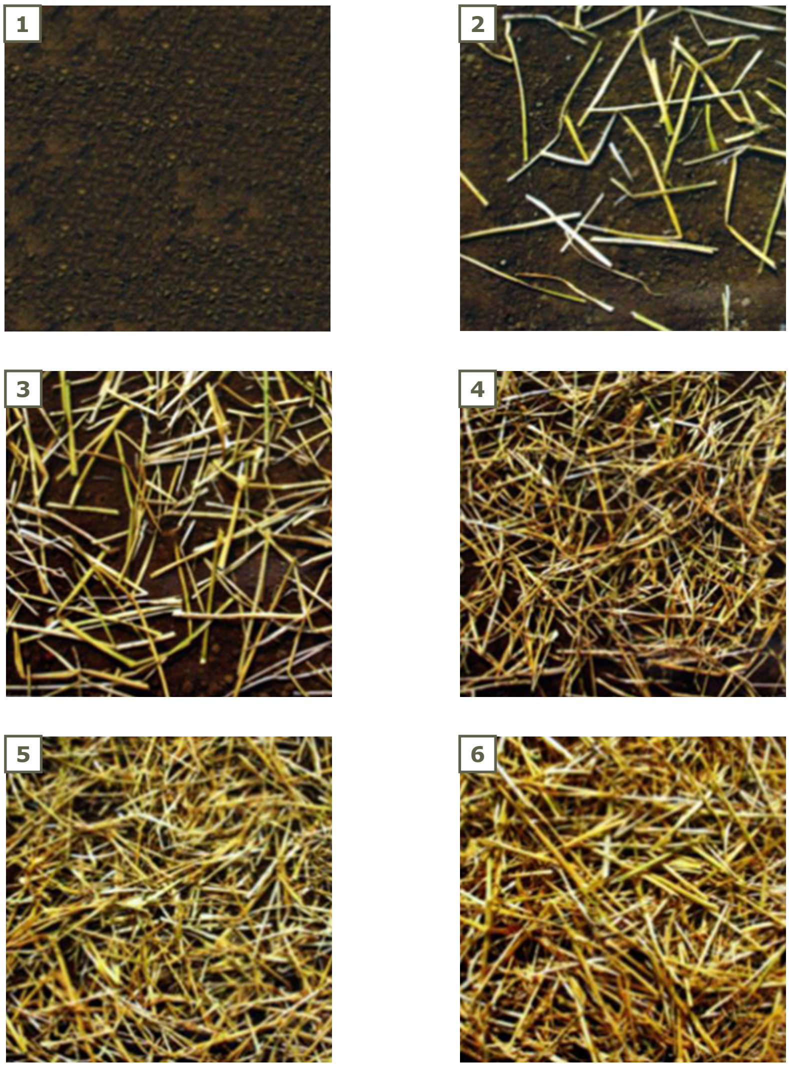
What did you use to plough the land for [FIELD]?



Response 2 = Broad Bed Maker

Crop residue cover

"After planting of this agricultural season, what did the [FIELD] look like?"



1 = 0% coverage; 2 = 10%; 3 = 30%, 4 = 50%; 5 = 70%; 6 = 90%.
30% and above denotes "crop residue cover."

Table 21: Overview of questions used in the ESS to measure adoption

Innovation	Questionnaire position *	Question/protocol
Crossbred animals	Post-planting, sect. 8.1, questions 1 & 3	Livestock keepers were firstly asked "How many [LIVESTOCK TYPE] does the holder currently keep (both his own and from other households)?" followed by the question "How many of [LIVESTOCK NAME] is crossed with an exotic breed?"
Use of artificial inseminations services	Post-planting, sect. 8.3, quest. 2	The question asked "What has been the main controlled mating or breeding strategy used by this holder for [LIVESTOCK TYPE] in the past 12 months?'. Artificial insemination was among the set of possible answers.
Feed & forage	Post-planting, sect. 8.3, quest. 16	"Has this holder used improved food for [LIVESTOCK TYPE] in the past 12 months?" and "what type of improved food for [LIVESTOCK TYPE] has this holder used in the past 12 months?". Elephant grass, Gaya, Sasbaniya, Oats, Lablab and alfalfa figured among the categories of responses
Orange-fleshed sweet potato (OFSP)**	Post-planting, sect. 4, quest. 25	Sweet potato growers were asked, "What does the chickpea flowers look like?" using the visual-aid protocol available below.
Chickpea desi and kabuli types**	Post-planting, sect. 4, quest. 12c	Chickpea growers were asked, "What does the chickpea flowers look like?" using the visual-aid protocol available below.
Self-reported improved varieties	Post-planting, sect. 5, questions 1a and 1b	What is the seed type used on [FIELD]?
River diversion, motorized pumps, treadle pumps**	Post-planting, sect. 3, quest. 20	What is the method of irrigation used on [FIELD]?
Soil and water conservation (SWC) practices	Post-planting, sect. 3, quest. 40	"Do you use any method to maintain or sustain as well as increase soil fertility on the field?" The SWC method used, asked as a follow-up question included terracing, water catchments, afforestation, and plow along the contour.
Broad bed maker**	Post-planting, sect. 3, quest. 35a	What did you use to plow the land for [FIELD]?
Conservation agriculture**	Post-planting, sect. 3, questions 34, 36 and 42	The three components of Conservation agriculture (CA) were computed using this set of questions: i) Minimum (< 2) and zero tillage were categorized using the question "How many times was [FIELD] tilled in this agricultural season?" ii) A visual-aid (shown below) was used to identify fields with a crop residue cover > 30 %, using the question "After planting of this agricultural season, what did the [FIELD] look like?" iii) Crop rotation was measured using the question "During the last three years, have you planted a legume on this [FIELD]?"
Tree seed centers	Post-planting, sect. 3, quest. 3b	What crop(s) is planted on [FIELD] in this current agricultural season?
Productive Safety Net Program (PSNP)	Household, sect. 4, quest. 45	In the past 12 months has [NAME] been employed as temporary labour by PSNP?
Water users associations	Community, sect. 6, quest. 10	Is there an irrigation scheme in this community?

* Both ESS 2015/16 and 2018/19 unless specified

** Indicates newly introduced questions or categories

Appendix B. Improved Varietal Adoption Estimates for Other Crops

Table 22: National adoption estimates of improved varietal adoption in ESS4, based on farmers' self-reported data

	EA-level		Household-level	
	Obs.	%	Obs.	%
Faba beans	264	2.9	342	2.6
Red kidney bean	264	2.0	197	4.6
Chickpea	264	0.0	90	0.0
Groundnut	264	0.1	138	0.6
Lentils	264	0.0	87	0
Finger millet	264	0.8	198	1.7
Rice	264	0.6	55	5.1
Potatoes	264	3.3	115	13.3
Sweet potatoes	264	1.0	142	1.5

EA-level refers to the percentage of EAs in the sample with at least one household adopting. Household-level refers to the percentage of households that adopt on at least one plot. Number of observations for household level estimates refers to the number of observations with households growing the specific crop. The adoption rate is calculated as a share of those households.

Appendix C. Origins and Traits of Improved Varieties Released in Ethiopia

Table 23: Barley improved varieties released by the national agricultural research system of Ethiopia, 1974–2019

Variety	Year of release	Type	Pedigree	**Source of pedigree data** (in addition to National Variety Registry)	Breeder / maintainer
IAR/H/485	1975	Food Barley	Pure line selection from local landrace		EIAR
Beka	1976	Malt Barley	Introduced by EIAR		Holetta ARC
Holker	1979	Malt Barley	EIAR cross - Holetta mixed/Kenya		Holetta ARC
Ahor 880/61	1980	Food Barley			EIAR
HB-42	1984	Food Barley	EIAR cross - IAR-H-81 /comp29/ / comp14-20/coast		EIAR
Ardu 1260-B	1986	Food Barley	Pure line selection from local landrace		EIAR
HB-120	1994	Malt Barley	EIAR cross - EH11/F3A.A.A.L/Beka		Holetta ARC
Shege	1995	Food Barley	Pure line selection from local landrace		EIAR
Abay	1998	Food Barley	Pure line selection from local landrace		Adet ARC
Misrach	1998	Food Barley			Debre Birhan ARC
Meserach	1998	Food Barley	Pure line selection from local landrace		Debre Birhan ARC
Dimtu	2001	Food barley	Pure line selection from local landrace		EIAR
HB-52	2001	Malt Barley	EIAR cross - Compound29/Beka		Holetta ARC
Charie	2003	Food Barley			Debre Birhan ARC
Mulu	2003	Food Barley	Pure line selection from local landrace		Adet ARC
Shedho	2003	Food Barley	Pure line selection from local landrace		Sirinka ARC
Mezezo	2004	Food Barley	Pure line selection from local landrace		Debre Birhan ARC
Trit	2004	Food Barley	Pure line selection from local landrace		Sirinka ARC
Basso	2004	Food Barley / Dual	Pure line selection from local landrace		Debre Birhan ARC
Setegn	2004	Food Barley	Pure line selection from local landrace		Adet ARC
HB-1533	2004	Malt Barley	ICARDA line	Personal com.	Holetta ARC
Harbu	2004	Food Barley	Pure line selection from local landrace		Sinana ARC
Dinsho	2004	Food barley	Pure line selection from local landrace		Sinana ARC

Variety	**Year of release**	**Type**	**Pedigree**	**Source of pedigree data** (in addition to National Variety Registry)	**Breeder / maintainer**
Estayish	2004	Food Barley	Pure line selection from local landrace		Sirinka ARC
SHIRE	2005	Food Barley	Pure line selection from local landrace		EIAR
BIFTU	2005	Food Barley	Pure line selection from local landrace		Sinana ARC
Dafo	2005	Food barley	Pure line selection from local landrace		Sinana ARC
Yedogit	2005	Food Barley	ICARDA line	Personal com.	Sirinka ARC
HB-1307	2006	Food Barley	EIAR Cross - Awra Gebs (N.Ethiopia) /IBON 93/91		Holetta ARC
CDC selection	2006	Malt Barley	Introduced by EIAR		Holetta ARC
Misccal-21	2006	Malt Barley / Dual	ICARDA line	Publication	Holetta ARC
Haruna Nijo	2006	Malt Barley	ICARDA line	Personal com.	Kulumsa ARC
Desta	2006	Food barley	ICARDA line	Publication	Kulumsa ARC
Bentu	2006	Food Barley	ICARDA line	Publication	Kulumsa ARC
TILLA	2007	Food Barley	ICARDA line	Publication	Adet ARC
GABULA	2007	Food Barley	Pure line selection from local landrace		Awassa ARC
GUTA	2007	Food Barley	Pure line selection from local landrace		Sinana ARC
AGEGNEHU	2007	Food Barley	Pure line selection from local landrace		Sirinka ARC
Firegebse	2010	Food Barley			Adet ARC
EH 1293	2010	Malt Barley	EIAR cross - EH738/F2-6H-36-2/ IBON 93/91		Kulumsa ARC
Diribe	2010	Food Barley	ICARDA line	Publication	Holetta ARC
Bekoji-1	2010	Malt Barley			Holetta ARC
EH 1847	2011	Malt Barley			Holetta ARC
Sabini	2011	Malt Barley			Holetta ARC
Bahati	2011	Malt Barley			Holetta ARC
FELAMIT	2011	Food Barley			Mekelle University
Abdane	2011	Food Barley			Sinana ARC
EH-1493	2012	Food Barley			Holetta ARC
Cross 41/98	2012	Food Barley			Holetta ARC
IBON 174/03	2012	Malt Barley	ICARDA line	Publication	Holetta ARC
Gobe	2012	Food Barley			Kulumsa ARC
Hriti	2012	Food Barley			Mekelle University
Fetina	2012	Food Barley			Mekelle University

Variety	**Year of release**	**Type**	**Pedigree**	**Source of pedigree data** (in addition to National Variety Registry)	**Breeder / maintainer**
Walker	2012	Food Barley			Fedis ARC
Golden Eye	2012	Food Barley			Fedis ARC
Aquila	2012	Food Barley			Fedis ARC
Traveller	2013	Malt Barley			Holetta ARC
Grace	2013	Malt Barley			Holetta ARC
Fanaka	2015	Malt Barley			Holetta ARC
HB-1964	2016	Malt Barley	ICARDA line	Publication	Holetta ARC
HB-1963	2016	Malt Barley	ICARDA line	Publication	Holetta ARC
Illala-02	2016	Food Barley			Mekelle ARC
Illala-01	2016	Food Barley			Mekelle ARC
Wolelay	2016	Food Barley			Mekelle University
Adena	2016	Food Barley			Mekelle University
Robera	2016	Food Barley			Sinana ARC
Singitan	2016	Malt Barley	ICARDA line	Personal com.	Sinana ARC
HB-1965	2017	Food Barley	ICARDA line	Publication	Holetta ARC
Explorer	2017	Malt Barley			Holetta ARC
HB-1966	2017	Food Barley	ICARDA line	Publication	Holetta ARC
Hegere	2018	Food Barley			Debre Birhan ARC

Note: Varieties are from the National Variety Registry of the MoA; varieties released before 1990 are greyed. The origin/pedigree of varieties was identified with the National Variety Registry of MOA, available publications, and personal communications with CGIAR and EIAR scientists.

Table 24: Chickpea improved varieties released by the national agricultural research system of Ethiopia, 1974–2019

Variety	Year of release	Type	Pedigree	Breeder / maintainer
DZ-10-4	1974	Desi	Pure line selection from local landrace	Debre Zeit ARC
Dube	1978	Desi	Pure line selection from local landrace	Debre Zeit ARC
Mariye	1985	Desi	ICARDA line	Debre Zeit ARC
Worku	1994	Desi	ICARDA line	Debre Zeit ARC
Akaki	1995	Desi	ICARDA line	Debre Zeit ARC
Arerti	2000	Kabuli	ICRISAT line	Debre Zeit ARC
Shasho	2000	Kabuli	ICRISAT line	Debre Zeit ARC
Chefe	2004	Kabuli	ICRISAT line	Debre Zeit ARC
Habru	2004	Kabuli	ICRISAT line	Debre Zeit ARC
EJERE	2005	Kabuli	ICRISAT line	Debre Zeit ARC
Teji	2005	Kabuli	ICRISAT line	Debre Zeit ARC
Kutaye	2005	Desi	ICARDA line	Sirinka ARC
Yelbey	2006	Kabuli	ICRISAT line	Sirinka ARC
Fetenech	2006	Desi	ICARDA line	Sirinka ARC
Mastewal	2006	Desi	ICARDA line	Debre Birhan ARC
Natoli	2007	Desi	ICARDA line	Debre Zeit ARC
ACOS Dubie	2009	Kabuli	ICRISAT line	Debre Zeit ARC
Minjar	2010	Desi	ICARDA line	Debre Zeit ARC
Kasech	2011	Kabuli	ICRISAT line	Sirinka ARC
Akuri	2011	Kabuli	ICRISAT line	Sirinka ARC
Kobo	2012	Kabuli	ICRISAT line	Sirinka ARC/ ARARI
Dalota	2013	Desi	ICARDA line	Debre Zeit ARC
Teketay	2013	Desi	ICARDA line	Debre Zeit ARC
Dimtu	2016	Desi	ICARDA line	Debre Zeit ARC
Hora	2016	Kabuli	ICRISAT line	Debre Zeit ARC
Dhera	2016	Kabuli	ICRISAT line	Debre Zeit ARC
Koka	2019	Kabuli	ICRISAT line	-
Geletu	2019	Desi	ICARDA line	Debre Zeit ARC

Note: Varieties are from the National Variety Registry of the MoA; varieties released before 1990 are greyed. The origin/pedigree of varieties was identified with the National Variety Registry of MOA, available publications, and personal communications with CGIAR and EIAR scientists.

Table 25: Maize improved varieties released by the national agricultural research system of Ethiopia, 1973–2019

Variety	Year of release	Type	Pedigree	Source of pedigree data (in addition to National Variety Registry)	Breeder / maintainer
A-511	1973	Hybrid			Awassa ARC
Alemaya Composite	1973	Hybrid			Haramaya University
Katumani	1974	OPV			Bako ARC
Abo-Bako	1986	Hybrid	IITA line		IITA/EIAR
BH 140	1988	Hybrid	CIMMYT line	Publication	Bako ARC
Gutto	1988	OPV	CIMMYT line	Publication	Bako ARC
BH 660	1993	Hybrid	CIMMYT line	Publication	Bako ARC
Kuleni	1995	Hybrid	CIMMYT line	Publication	Bako ARC
BH540	1995	Hybrid			Bako ARC
Jabi	1995	Hybrid	Pioneer Hi-Bred		Pioneer
Tesfa(ACV6)	1996	OPV			Awassa College of Agriculture
Fetene (ACV3)	1996	OPV			Awassa College of Agriculture
Rare-1	1998	Hybrid			Haramaya University
Gibe Comp-1*	2001	OPV	CIMMYT line	Publication	Bako ARC
Gambela Comp1	2001	OPV	IITA line	Publication	EIAR
Melkassa-1	2001	Hybrid	CIMMYT line	Publication	Melkassa ARC
Tabor (30-H83)	2001	Hybrid	Pioneer Hi-Bred		Pioneer
Shindi (phb-30G-97)	2001	OPV	Pioneer Hi-Bred		Pioneer
BH-670	2002	OPV	EIAR		Bako ARC
BH-QP-542	2002	OPV, QPM	CIMMYT line	Publication	Bako ARC
BH-541	2002	Hybrid	CIMMYT line	Publication	Bako ARC
Melkassa -2	2004	OPV, DTMZ	CIMMYT line	Publication	Melkassa ARC
Mekassa-3	2004	OPV	CIMMYT line	Publication	Melkassa ARC
Hora	2005	OPV	CIMMYT line	Publication	Ambo ARC
AMH-800 (Arganne)	2005	Hybrid	CIMMYT line	Publication	Ambo ARC
BH-543	2005	Hybrid	CIMMYT line	Publication	Bako ARC
Toga	2005	Hybrid			ESE
SC715	2005	OPV			SEED-Co
SC713	2005	Hybrid			SEED-Co
BH-544	2006	OPV	CIMMYT line	Publication	Bako ARC
Melkassa-4	2006	OPV, DTMZ	CIMMYT line	Personal com.	Melkassa ARC
Welel	2006	OPV	Pioneer Hi-Bred		Pioneer
Shone	2006	Hybrid	Pioneer Hi-Bred		Pioneer
Aba raya	2006	OPV			SEED-Co
BHQPY-545	2008	Hybrid, QPM	CIMMYT line	Publication	Bako ARC
Morka	2008	OPV	EIAR		EIAR
AMH-850 (Wenchi)	2008	Hybrid	CIMMYT line	Publication	Ambo ARC

Variety	Year of release	Type	Pedigree	Source of pedigree data (in addition to National Variety Registry)	Breeder / maintainer
Melkassa-7	2008	Hybrid	CIMMYT line	Publication	Melkassa ARC
Melkassa-6Q	2008	Hybrid, DTMZ and QPM	CIMMYT line	Publication	Melkassa ARC
Mekassa-5	2008	Hybrid	CIMMYT line	Publication	Melkassa ARC
Agar	2008	Hybrid	Pioneer Hi-Bred		Pioneer
AMH-851 (Jibat)	2009	Hybrid	CIMMYT line	Publication	Ambo ARC
Gibe-2	2011	Hybrid, DTMZ	CIMMYT line	Publication	Bako ARC
BH 661	2011	Hybrid, DTMZ	CIMMYT line	Publication	Bako ARC
AMH760Q	2012	Hybrid, QPM	CIMMYT line	Publication	APRC/EIAR
Hawassa-1	2012	Hybrid	CIMMYT line		ESE
MHQ138	2012	Hybrid, QPM	CIMMYT line	Publication	Melkassa ARC
MH130	2012	Hybrid, DTMZ	CIMMYT line	Publication	Melkassa ARC
Limmu	2012	Hybrid	Pioneer Hi-Bred		Pioneer
BH547	2013	Hybrid, DTMZ	CIMMYT line	Publication	Bako ARC
BH546	2013	Hybrid, DTMZ	CIMMYT line	Publication	Bako ARC
MH140	2013	Hybrid, DTMZ	CIMMYT line	Publication	Melkassa ARC
Melkasa-1Q	2013	Hybrid, DTMZ and QPM	CIMMYT line	Publication	Melkassa ARC
SPRH1	2015	Hybrid	CIMMYT line	Publication	Bako ARC
SBRH1	2015	Hybrid	CIMMYT line	Publication	Bako ARC
BHQP548	2015	OPV, QPM	CIMMYT line		Bako ARC
Damote	2015	Hybrid	Pioneer Hi-Bred		Pioneer
AMH853	2016	Hybrid	CIMMYT line	Publication	Ambo ARC
AMH852Q	2016	OPV, QPM	CIMMYT line	Publication	Ambo ARC
Kortu (P2809W)	2017	Hybrid	Pioneer Hi-Bred		Pioneer

Note: Varieties are from the National Variety Registry of the MoA; varieties released before 1990 are greyed. The origin/pedigree of varieties was identified with the National Variety Registry of MOA, available publications, and personal communications with CGIAR and EIAR scientists.

* Contradicting information exists regarding the pedigree of this variety.

Table 26: Sorghum improved varieties released by the national agricultural research system of Ethiopia, 1970–2019

Variety	Year of release	Type	Pedigree	Source of pedigree data (in addition to National Variety Registry)	Breeder / maintainer
AI-70	1970	OPV	Selection from landraces		Haramaya University
76T1# 21	1976	OPV	ICRISAT line	Publication	Melkassa ARC
76T1# 23	1976	OPV	ICRISAT line	Publication	Melkassa ARC
Gambella 1107	1976	OPV	ICRISAT line	Publication	Melkassa ARC
Melkamash 79	1979	OPV	ICRISAT line	Publication	Melkassa ARC
IS 9302	1981	OPV	Selection from landraces		Melkassa ARC
Dinkimash	1986	OPV	ICRISAT line	Publication	Melkassa ARC
Kobomash 76	1986	OPV	ICRISAT line	Publication	Melkassa ARC
Seredo	1986	OPV			Melkassa ARC
Birmash	1989	OPV			Melkassa ARC
Baji	1996	OPV			Melkassa ARC
Chiro	1996	OPV			Melkassa ARC
Meko-1	1998	OPV	ICRISAT line	Publication	Melkassa ARC
Abshir*	2000	OPV	Purdue University / ICRISAT	Personal com.	Melkassa ARC
Gubye*	2000	OPV	Purdue University / ICRISAT	Personal com.	Melkassa ARC
Muyra-1	2000	OPV			Haramaya University
Muyra-2	2000	OPV			Haramaya University
Sartu/Aba-Melko	2001	OPV			Jimma University
Birhan*	2002	OPV	Purdue University / ICRISAT	Personal com.	Sirinka ARC
Teshale	2002	OPV	ICRISAT line	Publication	Melkassa ARC
Yeju	2002	OPV	ICRISAT line	Publication	Sirinka ARC
Abuare	2003	OPV	ICRISAT line	Personal com.	Sirinka ARC
Chelenko	2005	OPV			Melkassa ARC
Hormat	2005	OPV	ICRISAT line	Publication	Sirinka ARC
Dano	2006	OPV			Bako ARC
Lalo	2006	OPV			Bako ARC
EMAHOY	2007	OPV			Pawe ARC
Gedo	2007	OPV	ICRISAT line	Personal com.	Sirinka ARC
GEREMEW	2007	OPV			Melkassa ARC
GIRANA-1*	2007	OPV	ICRISAT line	Publication	Sirinka ARC
Macia	2007	OPV	ICRISAT line	Publication	Melkassa ARC
Misikir	2007	OPV			Sirinka ARC
Raya	2007	OPV			Sirinka ARC
Red Swazi	2007	OPV	ICRISAT line	Publication	Melkassa ARC
ESH-1	2009	Hybrid	ICRISAT line	Publication	Melkassa ARC
ESH-2	2009	Hybrid	ICRISAT line	Publication	Melkassa ARC
Melkam	2009	OPV	ICRISAT line	Publication	Melkassa ARC

Variety	Year of release	Type	Pedigree	Source of pedigree data (in addition to National Variety Registry)	Breeder / maintainer
Chare	2011	OPV			Debre Birhan ARC
Dagem	2011	OPV			Melkassa ARC
Mesay	2011	OPV	ICRISAT line	Personal com.	SARC/ARARI
Dekeba	2012	OPV	ICRISAT line	Publication	Melkassa ARC
Chemeda	2013	OPV			Bako ARC
Gemedi	2013	OPV			Bako ARC
PAC 537	2013	Hybrid			Advanta Seed
ESH-3	2014	Hybrid	ICRISAT line	Publication	Melkassa ARC
Adukara	2015	OPV			Melkassa ARC
Assosa-1	2015	OPV			Assosa ARC
Dibaba	2015	OPV			Melkassa ARC
Fendisha-1	2015	OPV			Haramaya University
97AN Progeny	2016	OPV			Melkassa ARC
Argity	2016	OPV	ICRISAT line	Personal com.	Melkassa ARC
ESH-4	2016	Hybrid	Purdue University	Personal com.	Melkassa ARC
Alene	2017	OPV			Sirinka ARC
ESH-5	2018	Hybrid	Purdue University	Personal com.	Melkassa ARC
Mentebteb	2018	OPV	ICRISAT line	Personal com.	Melkassa ARC

Note: Varieties are from the National Variety Registry of the MoA; varieties released before 1990 are greyed. The origin/pedigree of varieties was identified with the National Variety Registry of MOA, available publications and personal communications with CGIAR and EIAR scientists.

* Contradicting information exists regarding the pedigree of this variety.

Table 27: Sweet Potato improved varieties released by the national agricultural research system of Ethiopia, 1987–2019

Variety	Year of release	Type	Pedigree	Breeder / maintainer
Koka 12	1987	Pale orange	CIP line	Awassa ARC
Koka 6	1987	Cream	CIP line	Awassa ARC
Guntutie	1997	OFSP	CIP line	Awassa ARC
Awassa-83*	1997	White	CIP line	Awassa ARC
Dubo	1997	White	Selection from landraces	Awassa ARC
Falaha	1997	White	Selection from landraces	Awassa ARC
Kudadie	1997	Cream	Selection from landraces	Awassa ARC
Damota	1997	Cream	Selection from landraces	Adet ARC
Bareda	1997	White	Selection from landraces	Awassa ARC
Belela	2002	Cream	Selection from landraces	Awassa ARC
Beletech	2004	White	CIP line	Awassa ARC
Temesgen	2004	White	Selection from landraces	Awassa ARC
Kero	2005	OFSP	CIP line	Awassa ARC
Tulla	2005	OFSP	CIP line	Awassa ARC
Kulfo	2005	OFSP	CIP line	Awassa ARC
Ordollo	2005	White	Selection from landraces	Awassa ARC
Dimitu	2005	White	Selection from landraces	Bako ARC
Balo	2006	White	CIP line	Baco ARC
Adu	2007	Cream	CIP line	Haramaya University
Berkume	2007	White	Selection from landraces	Haramaya University
Jari	2008	Yellow	CIP line	Sirinka ARC
Birtukanie	2008	OFSP	CIP line	Sirinka ARC
Ma'e	2010	White	CIP line	Werer ARC
Tola	2012	White	Selection from landraces	Bako ARC
Hawassa-09 (TIS-8250-1)	2017	Cream	CIP line	Awassa ARC
Alamura	2019	OFSP	CIP line	Awassa ARC
Dilla	2019	OFSP	CIP line	Awassa ARC
Kabode	2019	OFSP	CIP line	Awassa ARC
Ogan-Sagan	-	-	Selection from landraces	Ministry of Agriculture

Note: Varieties are from the National Variety Registry of the MoA; varieties released before 1990 are greyed. The origin/pedigree of varieties was identified with the National Variety Registry of MOA, available publications, and personal communications with CGIAR and EIAR scientists.

* Contradicting information exists regarding the pedigree of this variety.

Appendix D. Improved Varieties Included in the Reference Libraries for DNA Fingerprinting

Barley

Abay, Abdane, Adena, Agegnehu, Ardu 1260 B, Bahati, Basso (4731-7), Beka, Bekoji-1, Bentu, Biftu, Charie, Cross 41/98, Dafo, Deribe, Dimtu, Dinsho (Wadago-4), EH-1493, EH-1847, Estaysh, Explorer, Fatima, Felamit, Fetina, Firegebse, Gobe, Grace, Guta, Harbu, HB-1307, HB-1533, HB-1963, HB-1964, HB-1965, HB-1966, HB-52, Hegere, Henricke, HKBL 1512-5 (Fanaka), Holker, Hriti, IBON 174-03, Illala-01, Illala-02, Meserach, Mezezo (4748-16), Misccal-21 (Kiflu-B), Misrach, Mulu, Planate, Robera, Sabini, Setegn, Shedho, Shege, Singitan, Tilla, Tirit, Traveller, Wolelay, and Yedogit.

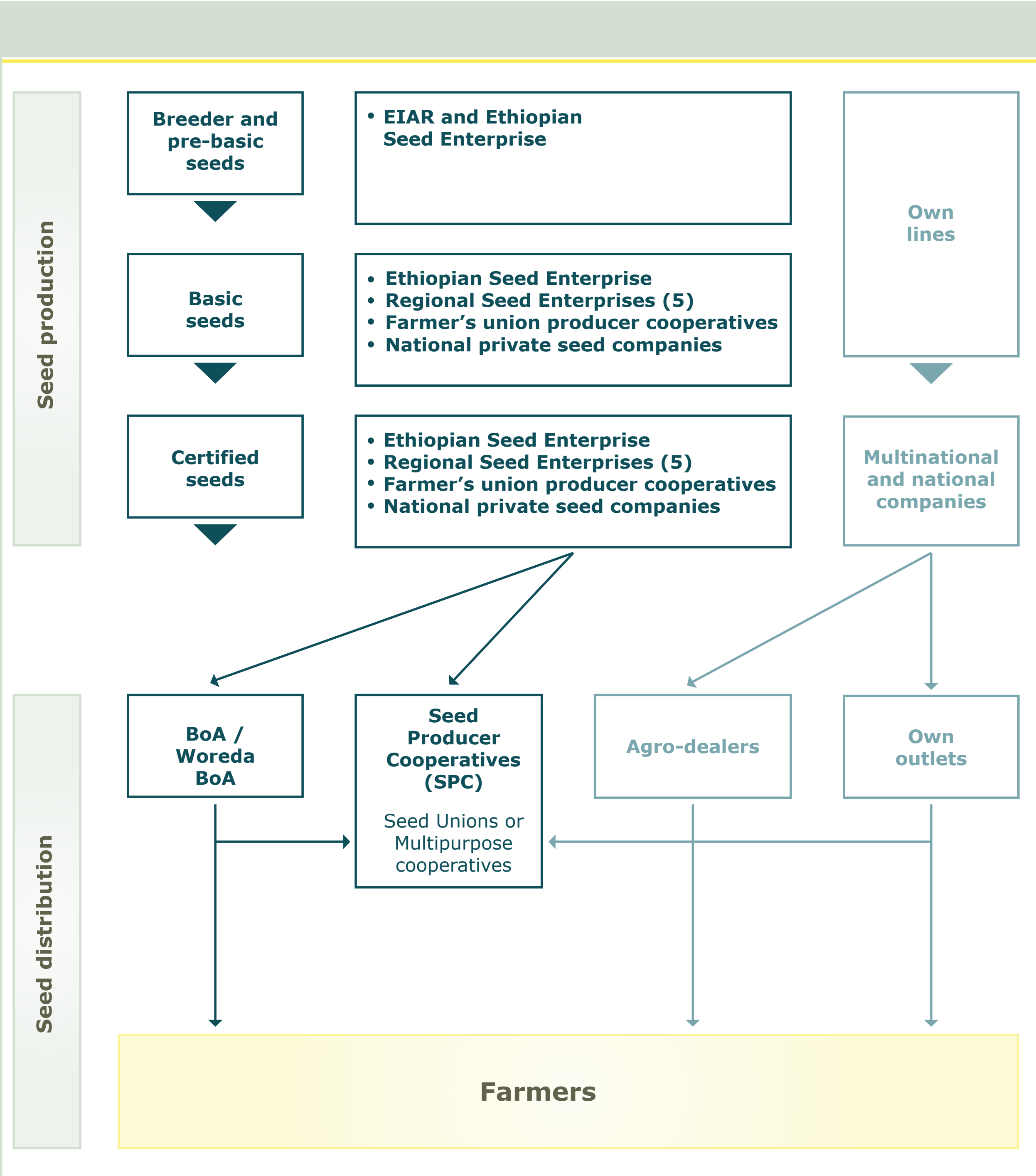
Maize

A-511, Aba raya, Abo-Bako, Agar, Alemaya Composite, AMH760Q, AMH-800 (Arganne), AMH-850 (Wenchi), AMH-851 (Jibat), AMH852Q, AMH853, BH 140, BH 660, BH 661, BH540, BH-541, BH-543, BH-544, BH546, BH547, BH-670, BH-QP-542, BHQP548, BHQPY-545, Damote, Fetene (ACV3), Gambela Comp1, Gibe Comp-1, Gibe-2 , Gutto, Hawassa-1, Hora, Jabi, Jibat, Katumani, Kortu (P2809W), Kuleni, Limmu, Mekassa-3, Mekassa-5, Melkasa-1Q, Melkassa -2, Melkassa-1, Melkassa-4, Melkassa-6Q, Melkassa-7, MH130, MHQ138, MH140, Morka, Rare-1, SBRH1, SC713, SC715, Shindi (phb-30G-97), Shone, SPRH1, Tabor (30-H83), Tesfa (ACV6), Toga, and Welel.

Sorghum

76TI#23, ABSHIR, Adukara, AI-70, Alene, Assosa-1, Birhan, Chare, Chemeda, Dano, Dekeba, ESH-1, Fendisha-1, Gambella 1107, Gemedi, Girana-1, Gubiye, Hormat, Lalo, Macia, MEKO-1, Melkam, Mesay, MISKIR, Muyra-1, Muyra-2, Raya, Teshale, and Yeju.

Appendix E. Overview of the Formal Seed Production and Distribution System in Ethiopia



Sources: MoA & ATA (2014); Atilaw & Korbu (2011); Sisay et al. (2017)

Note: Some SPCs also produce certified seeds on their own; some regional seed enterprises also rely on SPCs to produce certified seeds (not reflected in the scheme).

Appendix F. Adoption Rates from ESS3 (2015/16)

Table 28: Adoption rates at enumeration area (EA) and household levels (%) in ESS3 (2015/16)

	% of rural EAs	% of households with innovation (among households defined in next column)	Conditions applied	Estimated number of households
	(1)	(2)	(3)	(4)
Animal agriculture				
Artificial insemination use	12.5	1.9	Animal-keeping households	277,785
Crossbred large ruminant	30.9	6	Animal-keeping households	872,030
Crossbred small ruminant	11.8	1.3	Animal-keeping households	193,344
Crossbred poultry	25.3	4.1	Animal-keeping households	615,080
Forages	4.2	1.1	Animal-keeping households	158,667
Crop germplasm improvement				
Chickpea kabuli varieties	16.3	4.7	Crop-cultivating households[a]	677,591
Orange-fleshed sweet potato varieties	9.5	1.6	Crop-cultivating households[a]	235,758
Awassa-83 sweet potato varieties	8.4	2.7	Crop-cultivating households[a]	372,219
Natural resource management				
River diversion	18.3	1.6	Crop-cultivating households[a]	664,176
Motorized pumps	8.7	1.3	Crop-cultivating households[a]	201,482
SWC practices	89.1	64.2	Households with cultivated, pasture, fallow, or forest land[a]	9,415,780
Broad bed maker	4.5	0.4	Crop-cultivating households[a]	64,814
Conservation agriculture (min. tillage)	27.5	5.2	Households with cultivated, pasture, fallow, or forest land[a]	758,656
Conservation agriculture (zero tillage)	0	0	Households with cultivated, pasture, fallow, or forest land[a]	0
Mango	29.4	10.7	Crop-cultivating households[a]	1,565,247
Papaya	18.4	4.5	Crop-cultivating households[a]	665,968
Avocado	23	10.3	Crop-cultivating households[a]	1,451,518
Policy influences				
Productive Safety Net Program (PNSP)	27.9	8.5	Rural households	1,238,384

Note: All estimates are based on ESS3. All estimates use sampling weights to calculate the shares of EAs and households. Estimates in column 2 are calculated as shares over the populations defined in the "conditions applied" column. N.A. = not applicable.

[a] Where crops include both seasonal and permanent crops.

Appendix G. Animal Agriculture Innovations in Urban Areas

Table 29: Summary of adoption rates for animal agriculture innovations in urban areas in ESS4 (2018/19) at both enumeration area (EA) and household levels (in %)

Innovations	Conditions applied	EAs	Households
Large ruminant crossbreed	Animal-owning households	26.0	9.0
Small ruminant crossbreed	Animal-owning households	10.4	4.0
Poultry crossbreed	Animal-owning households	35.0	12.0

Appendix H: Plot-Level Correlates of Adoption of Natural Resource Management Practices

Table 30: Plot-level variables on land preparation and input use correlated with adoption of soil and water conservation practices and conservation agriculture

	SWC practices	Conservation agriculture (minimum tillage)	Conservation agriculture (zero tillage)
Plot with permanent crop	-0.17***	-0.23***	-0.23***
Urea use on plot	0.14***	-0.16***	-0.22***
Use of DAP on plot	0.05***	-0.05**	-0.07***
Use of NPS on plot	0.09***	-0.18***	-0.18***
Use of other chemical fertilizer on plot	0.03***	n.s	-0.02***
Use of manure on plot	n.s	n.s	n.s
Improved crop used	0.06***	-0.08***	-0.12***
Field preparation: Animal	0.17***	-0.33***	-0.46***
Incidence of pesticide use	0.03***	n.s	n.s
Incidence of herbicide use	0.04***	n.s	-0.09***
Incidence of fungicide use	n.s	-0.01***	-0.01***

Note: Each cell is a coefficient estimate from a separate regression of the row variable on the column variable. For statistically significant relationships, the magnitude of the difference is indicated. Green shows a positive relationship while red demonstrates a negative relationship.

*** $p < 0.01$, ** $p < 0.05$, n.s = non-significant.

Appendix I: Summary of Methods Experiments

Obtaining reliable estimates of adoption and diffusion rates should be a priority, and methodological validation is among SPIA's mandates (Stevenson et al., 2019; SPIA, 2020). Several experiments have been conducted in recent years in Ethiopia to advance evidence on survey methods and data collection standards.

Varietal identification

Accurate varietal identification was the topic of two studies. The first assessed sweet potato varietal identification in southern Ethiopia using three household-based methods against the benchmark of DNA fingerprinting: (1) elicitation from farmers with basic questions for the most widely planted variety; (2) farmer elicitation on five sweet potato phenotypic attributes by showing a visual-aid protocol; and (3) enumerator recording observations on five sweet potato phenotypic attributes using a visual-aid protocol and visiting the field.

Results reported in Kosmowski et al. (2019a) indicate that 20% of farmers identified a variety as improved when in fact it was local, and 19% identified a variety as local when it was improved. The variety names given by farmers delivered inconsistent and inaccurate varietal identities. Visual-aid protocols employed in methods 2 and 3 were better than those in method 1 but greatly underestimated the adoption estimates given by the DNA fingerprinting method. Overall, these results suggest that estimating the adoption of improved varieties with methods based on farmer self-reporting is questionable and point to the need for wider use of DNA fingerprinting in adoption and impact assessments. The OFSP visual-aid protocol that could deliver estimates with higher accuracy than farmers' self-elicitation was subsequently used in ESS3 and ESS4 and well as in the Malawi and Uganda LSMS surveys.

Kosmowski & Worku (2018) investigated the feasibility of using visible/near infrared (NIR) hyperspectral data collected with a miniaturized NIR spectrometer to identify cultivars of barley, chickpea, and sorghum in the context of Ethiopia. A total of 2,650 grains of barley, chickpea, and sorghum cultivars were scanned using the SCIO, a recently released miniaturized NIR spectrometer. Predictive multiclass models of 24 barley cultivars, 19 chickpea cultivars, and 10 sorghum cultivars delivered an accuracy of 89%, 96%, and 87% on the hold-out sample. The support vector machine (SVM) and partial least squares discriminant analysis (PLS-DA) algorithms consistently outperformed other algorithms. Several cultivars believed to be widely adopted in Ethiopia were identified with perfect accuracy. These results demonstrated that miniaturized NIR spectrometers represent a low-cost, rapid, and viable tool for varietal identification, with potential application for adoption surveys, field-scale agronomic studies, socioeconomic impact assessments, and value chain quality control.

While breeder seeds were used for this experiment, ongoing research is exploiting DNA data obtained from field samples of barley, maize, sorghum, and wheat to further study the accuracy of the SCIO device.

Crop residue cover measurement

Maintaining permanent coverage of the soil using crop residues is an important and commonly recommended practice in conservation agriculture, and measuring this practice is an essential step for capturing conservation agriculture adoption. Different data collection methods can be implemented to capture field-level crop residue coverage, each with its implications for survey budget, implementation speed, and respondent and interviewer burden (Kosmowski et al., 2017).

The accuracy of six methods of crop residue coverage measurement is compared against a benchmark, the line-transect method. These alternative methods include (1) interviewee (respondent) estimation; (2) enumerator estimation visiting the field; (3) interviewee with visual-aid without visiting the field; (4) enumerator with visual-aid visiting the field; (5) field pictures collected with a drone and analyzed with image-processing methods; and (6) satellite picture of the field analyzed with remote-sensing methods. Results show that survey-based methods tend to underestimate field residue cover. When quantitative data on the cover are needed, the best estimates are provided by visual-aid protocols. For categorical analysis (i.e., > 30% cover or not), visual-aid protocols and remote-sensing methods perform equally well. Results deliver a ranking of measurement options that can inform survey practitioners and researchers. Following this experiment, the crop residue visual-aid protocol was used in ESS3 and ESS4.

Soil metrics measurements: Soil texture, soil pH, and soil organic C

The fourth line of work has investigated soil metrics, an important outcome expected to be impacted by several agricultural innovations. Kosmowski et al. (2020a) first explore soil data requirements for a set of objectives that include identifying a soil constraint, improving recommendation domain studies, and capturing soil metrics as covariates, or as outcomes. The study then exposes the lessons learned from a methodological experiment in rural Ethiopia, where different approaches—farmers' self-elicitation and miniaturized spectrometers—are compared against laboratory benchmarks for a set of soil parameters: soil texture, soil pH, and soil organic C. Except for soil particle sizes, we find that soil parameters captured through farmers' elicitation do not converge with objective metrics. Miniaturized spectrometers such as the Tellspec can provide reasonably accurate data on the identification of soil constraints—soil acidity, low organic C, or sandy soils. Approximate quantitative predictions can also be delivered for soil pH ($R2 = 0.72$) and organic C ($R2 = 0.60$). The additional costs of plot sampling and analysis are in the range of \$19–\$23 per sample, with the additional percentage of plots with correct data equivalent to 10% for the identification of sandy soils, 75% for low organic C, and 89% for acidic soils.

Appendix J. Georeferenced Data on CGIAR-Related Projects

Table 31: Overview of georeferenced location collected and retrieved for CGIAR-related areas of activity

Innovation	N (project-level data)	N (GPS retrieved)
Animal agriculture		
Large ruminant crossbreeds	144	134
Small ruminant crossbreeds	27*	40
Poultry crossbreeds	23	21
Crop germplasm improvements		
DTMZ varieties	41	35
Improved sorghum varieties	4	3
NuME varieties	35	33
OFSP	87	82
Public-private partnership for barley seed dissemination	62	58
Natural resource management		
Avocado trees	4*	5
Conservation agriculture	63	41
Soil and water conservation	21	6
Total	**511**	**458**

Note: Project-level data were obtained using project documents, communications and interviews with scientists.
* Project-level data include zones from which all *woredas* were retrieved

Table 32: Correlation between distance to CGIAR projects and adoption of innovations

	N (*woredas*-projects)	< 25 km	< 50 km	< 75 km	< 100 km	< 125 km	< 150 km
Animal agriculture							
Large ruminant crossbreeds	134	0.15	0.09	0.03	-0.04	0.02	-0.05
Poultry crossbreeds	21	0.06	-0.04	-0.02	-0.09	-0.03	-0.02
Crop germplasm improvements							
Barley varieties	58	-0.10	-0.24***	-0.21**	-0.19	-0.25**	-0.24
DTMZ varieties	35	-0.08	-0.05	-0.13	-0.13	-0.03	-0.01
OFSP varieties		-0.09	0.13	-0.01	-0.09	-0.10	-0.12
Natural resource management							
Soil and water conservation practices	6	-0.01	-0.01	0.09	0.11	0.11	0.02
CA (minimum tillage)	41	-0.02	0.02	0.08	0.03	0.01	0.01
CA (zero tillage)	41	-0.06	-0.09	0.11	-0.07	-0.11	0.06
Avocado trees	5	0.15**	0.14**	0.13	0.18**	0.18**	0.19**

Note: Table shows correlation of adoption of innovations (rows) against distance to georeferenced locations at different cutoffs (columns). Coefficient estimates for each tested distance are provided and highlighted when statistically significant (*** p < 0.01, ** p < 0.05). Excluding innovations with less than 1% adoption rates, or less than 5 *woredas* with project data. N

Appendix K: Disaggregated Adoption Rates for Less-Populated Regions

Table 33: Summary adoption rates by region at the EA and household levels for the regions that are aggregated as "other regions" in table 15

Innovation	Afar		Benishangul Gumuz		Dire Dawa		Gambella		Harar	
	EAs	HHs	EAs	HHs	EAs	HHs	EAs	HHs	EAs	HHs
Animal agriculture										
Artificial insemination use	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Large ruminant crossbreed	0.5	0.1	10.9	1.3	0.0	0.0	0.0	0.0	18.7	3.4
Small ruminant crossbreed	0.0	0.0	0.0	0.0	10.9	1.0	0.0	0.0	0.0	0.0
Poultry crossbreed	3.8	0.7	27.1	5.7	62.4	18.4	41.4	12.5	10.3	1.8
Forages	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5	0.7
Crop germplasm improvements										
OFSP varieties	0.0	0.0	16.6	5.8	10.5	1.2	0.0	0.0	13.3	1.4
Awassa-83 sweet potato varieties	0.0	0.0	10.9	1.6	19.6	4.2	4.3	0.5	4.6	0.5
Natural resource management										
River diversion	16.9	49.3	26.3	9.7	38.3	25.6	0.0	0.0	17.7	6.5
Motorized pump	13.4	12.6	0.0	0.0	10.6	1.2	13.6	1.1	47.3	17.3
SWC practices	27.1	66.7	93.1	79.9	81.1	89.4	21.2	8.3	100.0	91.8
Conservation agriculture (minimum tillage)	0.0	0.0	51.6	17.5	39.8	19.8	12.3	2.2	7.3	0.7
Conservation agriculture (zero tillage)	0.0	0.0	16.2	1.6	9.3	7.2	8.6	1.0	0.0	0.0
Mango trees	0.0	0.0	72.9	51.3	20.0	3.2	58.7	18.5	62.1	37.3
Papaya trees	0.0	0.0	49.7	17.9	30.2	9.2	58.4	15.6	49.5	8.8
Avocado trees	0.0	0.0	33.6	5.3	0.0	0.0	29.5	16.3	12.7	1.3
Policy influences										
Productive Safety Net Program (PNSP)	75.0	22.7	7.7	2.7	74.4	9.6	13.6	1.3	35.6	3.9
Water users associations	37.4	-	65.6	-	58.5	-	24.8	-	60.6	-

Note: Somali region not included given too few observations.

Appendix L. Correlates of Households by Maize Variety Classification Status

Table 34: Correlates of classification status (see notes below)

	CGIAR germplasm						
	True positive	True negative	False positive	False negative	p-value_1	p-value_2	p-value_3
HH-head years of education completed	2.299	1.885	1.368	1.636	0.097*	0.072*	0.584
	0.406	0.389	0.317	0.234	.	.	.
Farmsize (ha)	1.286	0.936	1.479	1.144	0.225	0.275	0.063*
	0.138	0.084	0.111	0.074	.	.	.
Total annual consumption (BIRR) - winsorize	62,016.662	45,191.123	45,444.619	41,512.054	0.003***	0.005***	0.466
	4,790.679	4,380.383	3,293.801	2,508.502	.	.	.
Nominal annual consumption per adult equivalent (BIRR)	14,753.563	12,376.843	11,376.540	11,240.797	0.055*	0.063*	0.497
	1,509.079	1,425.846	985.978	877.560	.	.	.
Bottom 1 consumption quintile	0.150	0.325	0.286	0.388	0.007***	0.038**	0.361
	0.037	0.057	0.054	0.039	.	.	.
Bottom 1–2 (<40%) consumption quintiles	0.337	0.604	0.527	0.644	0.007***	0.021**	0.583
Plot prepared by tractor	0.016	0.000	0.007	0.002	0.309	0.409	0.171
	0.010	0.000	0.005	0.001	.	.	.
Plot prepared by animal	0.489	0.520	0.705	0.643	0.003***	0.008***	0.100
	0.059	0.065	0.054	0.037	.	.	.
Plot prepared by digging by hand	0.493	0.480	0.279	0.355	0.004***	0.009***	0.096*
	0.060	0.065	0.054	0.037	.	.	.
Plot area: GPS imputed with SR	0.135	0.109	0.211	0.091	0.434	0.006***	0.269
	0.014	0.014	0.024	0.009	.	.	.
Plot under extension program	0.690	0.219	0.588	0.225	0.015**	0.202	0.929
	0.056	0.049	0.058	0.033	.	.	.
Plot is irrigated	0.020	0.090	0.000	0.010	0.032**	0.212	0.048**
	0.016	0.039	0.000	0.010	.	.	.
Incidence of urea use	0.623	0.212	0.672	0.143	0.040**	0.548	0.203
	0.058	0.048	0.057	0.027	.	.	.

	CGIAR germplasm						
	True positive	True negative	False positive	False negative	p-value_1	p-value_2	p-value_3
Incidence of DAP use	0.289	0.098	0.085	0.099	0.006***	0.002***	0.985
	0.055	0.039	0.035	0.023	.	.	.
Incidence of NPS use	0.489	0.089	0.571	0.082	0.263	0.318	0.849
	0.059	0.033	0.058	0.022	.	.	.
Incidence of other chemical fertilizers use	0.003	0.004	0.039	0.015	0.028**	0.048**	0.310
	0.003	0.004	0.018	0.009	.	.	.
Incidence of manure use	0.298	0.463	0.308	0.448	0.598	0.901	0.846
	0.053	0.063	0.052	0.040	.	.	.
Incidence of hired labor use	0.278	0.153	0.247	0.198	0.850	0.660	0.410
	0.051	0.045	0.049	0.032	.	.	.
Plot prevented from soil erosion	0.790	0.594	0.685	0.728	0.917	0.163	0.059*
	0.049	0.061	0.057	0.036	.	.	.
Parcel granted by local leaders	0.259	0.297	0.305	0.420	0.039**	0.527	0.077*
	0.050	0.057	0.053	0.039	.	.	.
Parcel acquired as gift/inherited	0.628	0.652	0.457	0.434	0.000***	0.033**	0.002***
	0.055	0.059	0.058	0.040	.	.	.
Parcel rented	0.000	0.000	0.042	0.032	0.002***	0.045**	0.017**
	0.000	0.000	0.021	0.013	.	.	.
Parcel shared crop	0.094	0.026	0.152	0.052	0.393	0.288	0.321
	0.031	0.019	0.045	0.019	.	.	.
Parcel purchased	0.019	0.025	0.000	0.041	0.784	0.159	0.499
	0.014	0.017	0.000	0.016	.	.	.
Soil quality: Good	0.396	0.526	0.481	0.391	0.635	0.297	0.073*
	0.057	0.063	0.058	0.040	.	.	.
Soil quality: Fair	0.578	0.414	0.486	0.521	0.980	0.259	0.150
	0.058	0.062	0.058	0.040	.	.	.
Soil quality: Poor	0.026	0.060	0.033	0.088	0.234	0.770	0.475
	0.017	0.032	0.019	0.022	.	.	.
Soil type: Leptosol	0.145	0.123	0.145	0.094	0.516	0.997	0.530
	0.041	0.040	0.037	0.022	.	.	.
Soil type: Cambisol	0.021	0.004	0.033	0.007	0.839	0.714	0.568
	0.021	0.004	0.023	0.006	.	.	.
Soil type: Vertisol	0.529	0.493	0.434	0.338	0.010**	0.255	0.037**
	0.059	0.063	0.058	0.039	.	.	.
Soil type: Luvisol	0.163	0.148	0.258	0.200	0.129	0.160	0.374
	0.044	0.050	0.051	0.032	.	.	.
Soil type: Mixed type	0.142	0.218	0.129	0.322	0.078*	0.819	0.109
	0.041	0.053	0.038	0.037	.	.	.

	CGIAR germplasm						
	True positive	**True negative**	**False positive**	**False negative**	**p-value_1**	**p-value_2**	**p-value_3**
Major source of hybrid seeds in the community: Government	0.368	0.558	0.172	0.356	0.003***	0.008***	0.007***
	0.058	0.064	0.045	0.038	.	.	.
Major source of hybrid seeds in the community: Private dealer	0.001	0.000	0.109	0.031	0.001***	0.010**	0.024**
	0.000	0.000	0.042	0.014	.	.	.
Major source of hybrid seeds in the community: Union	0.631	0.442	0.702	0.554	0.301	0.379	0.141
	0.058	0.064	0.056	0.040	.	.	.
Major source of hybrid seeds in the community: Other	0.001	0.000	0.017	0.058	0.003***	0.334	0.004***
	0.000	0.000	0.017	0.020	.	.	.
Distance to the major urban center (KM) - winsorized	49.580	61.967	53.517	69.504	0.100*	0.650	0.352
	4.333	6.731	7.495	4.507	.	.	.
Distance to the nearest large weekly market (KM) - winsorized	4.240	2.463	1.946	3.946	0.739	0.049**	0.046**
	1.085	0.524	0.399	0.523	.	.	.
Distance to the nearest place where there is SACCO (Km) - winsorized	18.719	20.118	6.412	12.275	0.032**	0.003***	0.327
	3.981	7.677	0.950	2.268	.	.	.

Note: Point estimates are weighted sample means. Standard errors are reported below. Stars represent level of statistical significance of t-test/chi-squared test of difference in means.

P-value_1 = Difference between True (positive & negative) vs. False (positive & negative)

P-value_2 = Difference between True positive vs. False positive

P-value_3 = Difference between True negative vs. False negative

The table compares correlates for four categories of household constructed from a combination of self-reported data on adoption of improved maize varieties (positive or negative) and DNA fingerprinting data on adoption of improved maize varieties (true if self-report is confirmed, false if not).

*** $p < 0.01$, ** $p < 0.05$, * $p<0.1$

"Correct classifiers" versus "Misclassifiers": p-value_1 in Table 34

(i.e., "true positives and true negatives" versus "false positives and false negatives")

Looking at the characteristics of maize-growing households, farmers who correctly identified the variety grown (whether improved or not improved) belong to households with a more educated household head vis-à-vis those who misclassified. This group of "correct classifiers" exhibits a higher annual consumption both in total and per capita terms, with an annual total average between true positives and true negatives of US$1,640 against US$1,232 for the false positives and false negatives. The correct classifier households reside in communities closer to a major urban center, while there is no statistically significant difference in terms of connection to the markets for the misclassifier group. However, the correct classifier group (of true positives and true negatives) are on average in communities with a lower incidence of SACCO beneficiaries, which, given the wealthier status could be linked to less need for credit. Farmers who correctly specified the varieties grown, on average, reside more in communities where the government is the main source of hybrid seeds (37% and 56%, for true positive and true negative, respectively) in comparison with the other group (17% and 36%, false positive and false negative). In terms of plot characteristics, plots where varieties were correctly identified are more likely to be irrigated, benefit from extension services, and exhibit a higher incidence of fertilizer use, such as urea and DAP. No significant difference is found in self-reported soil quality or type between the two groups. Moreover, plots in which varieties were correctly identified are more likely to be owned rather than rented.

True positive vs. False positive: p-value 2 in Table 34

Farmers who reported growing improved maize varieties when indeed it is improved (true positive) are again, more educated and wealthier than farmers who misclassify the varieties as improved (false positive). Conversely, false positives are more correlated to residing in communities closer to large weekly markets and SACCO informal loan schemes. Communities where the major source of hybrid seeds is the government are more common in the case of true positive (36.7%) in comparison with false negatives (17.2%), while the opposite is true for private dealers, and no statistically significant difference is observed in the case of unions.

Although plots where improved maize varieties are grown are on average smaller than plots with non-improved varieties (0.135 ha and 0.211 ha, respectively), the two groups do not show any statistical difference in terms of plot input management, such as incidence of irrigation or urea and NPS fertilizers, suggesting that farmers' management behavior covaries with their beliefs about varietal status. There is also no statistical difference between the groups in terms of other self-reported plot characteristics, such as soil type and quality.

True negative vs. False negative: p-value 3 in Table 34

When comparing farmers who incorrectly believe they are growing non-improved maize varieties (false negative), with farmers who know they truly are not growing improved maize (true negative), we do not observe statistically significant differences in terms of consumption levels. However, false negatives exhibit larger farm size when compared with true negative, which is also reflected in differences in land preparation methods used, the incidence of irrigation, and the use of soil erosion prevention methods. Differences arise also on parcel acquisition methods, with higher shares of parcels granted by local leaders in the case of false negative, while a higher percentage of true negative plots were inherited. Soil quality by self-assessment is reported to be slightly worse in the case of false negatives compared with true negative, who also exhibit higher percentages of Vertisol soil type. Larger shares of true negative respondents live in communities where the majority of hybrid seed is the government, are more likely to be in a major urban center, and, on average, live closer to large weekly markets than their counterparts.

Robustness of correlations

Most of the correlations outlined in the preceding sections also hold when considering stricter definitions of "improved" maize varieties: varieties with CGIAR-derived germplasm and purity level above 95% and varieties with CGIAR-derived germplasm released between 2010 and 2020. The only exception is that we no longer observe differences in consumption levels between the correct classifiers and misclassifiers when imposing a 95% minimum purity level.

Appendix M: Misclassification Results for Sorghum and Barley Varieties

Sorghum

In the case of sorghum, the vast majority of the plot samples are correctly classified as non-improved (98.3%). However, only 11 plots are cultivated with CGIAR-related germplasm varieties out of a total of 368 plots; thus there is limited variation. The reference library for sorghum varieties in these analyses is restricted to those varieties for which EIAR still maintains breeder's seed and for which seed is still produced. However, these should be considered interim results and interpreted with caution until we have been able to incorporate further reference samples from ICRISAT's Nairobi breeding program (this process having only recently been initiated).

The data exhibit limited variation both in terms of purity level and in year of release of varieties: all the CGIAR-related germplasm sorghum varieties were released in the past decade (2010–20) and have a purity level between 70 and 90% with no changes in farmers' reporting by these two parameters.

Table 35: Misclassification rate of adoption status of CGIAR-derived sorghum varieties at plot level

DNA fingerprinting results: CGIAR-related germplasm?	Self-reporting			
	Improved	Not improved	Total	N
Yes	0.07%	0.87%	**0.94%**	11
No	0.79%	98.3%	**99.1%**	357
Total	**0.86%**	**99.1%**	**100%**	**368**

Table 36: Rates of misclassification of varietal status for farmers adopting CGIAR-related sorghum germplasm when the definition of adopter of an improved variety additionally incorporates a minimum threshold for genetic purity

CGIAR-related germplasm AND Purity level threshold imposed of:	Self-reported data (classification status)			Implied adoption rate under combined conditions	Samples not meeting combined conditions
	Improved (true positive)	Not improved (false negative)	N		
Above 70%	0.07%	0.87%	11	**0.94%**	357
Above 90%	0.07%	0.00%	2	**0.07%**	366
Above 95%	0.07%	0.00%	2	0.07%	366

Table 37: Rates of misclassification of varietal status for farmers adopting CGIAR-related sorghum germplasm when definition of adopter of an improved variety additionally incorporates a maximum limit for varietal age

CGIAR-related germplasm AND year of release being:	Self-reporting (classification status)			Implied adoption rate under combined conditions	Samples not meeting combined conditions
	Improved (true positive)	Not improved (false negative)	N		
After 1990	0.07%	0.87%	11	**0.94%**	357
After 2000	0.07%	0.87%	11	**0.94%**	357
After 2010	0.00%	0.00%	0	0.00%	368

Barley

The adoption rate of barley varieties derived from CGIAR germplasm is estimated to be 18%, but only a single farmer (0.42% of the sample of 249) correctly reports it as such (true positive). The vast majority of the sample (76.8%) correctly report non-improved varieties (true negatives).

Table 38: Misclassification rate of adoption status of CGIAR-derived barley varieties at plot level

DNA fingerprinting results: CGIAR-related germplasm?	Self-reporting			
	Improved	Not improved	Total	N
Yes	0.42%	17.3%	**17.7%**	29
No	5.48%	76.8%	**82.3%**	220
Total	**5.9%**	**94.1%**	**100%**	**249**

The self-reported data from farmers about whether they are growing an improved barley variety show a pattern whereby distance to markets, asphalt as a main access road, and female share of family labor over 50 percent are all negatively correlated with adoption status (first column in Table 39). When replaced with DNA fingerprinting data identifying improved varieties from samples in farmers' fields (second column in Table 39), two of these three relationships no longer hold—asphalt as a main access road is the exception in still being negatively correlated. In addition, the household being in the bottom two quintiles in terms of annual consumption becomes negatively correlated, and annual consumption per capita and the productive asset index become positively correlated with adoption.

Table 39: Impact of misclassification on which variables are correlated with adoption of improved barley varieties

	Self-reported data	DNA fingerprinting data
Total parcels size	n.s.	n.s
Distance to market (km)	-4.68***	n.s
Asphalt as a main access road	-0.13***	-0.15***
Livestock manager is female	n.s.	-
Female share of family labor is > 50%	-0.05**	n.s
Annual consumption per capita (ETB)	n.s.	4.87**
Bottom 40% annual consumption	n.s.	-0.28***
Productive asset index	n.s.	0.39**
Annual off-farm income (ETB)		n.s
Age of household head		n.s

*** $p < 0.01$, ** $p < 0.05$, n.s = non-significant.

Note: Each cell is a coefficient estimate from a separate regression of the row variable on the column variable. For statistically significant relationships, the magnitude of the difference is indicated. Green shows a positive relationship while red demonstrates a negative relationship.

By increasing the level of purity, as shown in Table 40, a share of false negatives drops out to become true negatives. Tightening the definition to include year of release does little to change the misclassification—most of the false negative cases actually cultivate CGIAR-related varieties released after 2010.

Table 40: Rates of misclassification of varietal status for farmers adopting CGIAR-related barley germplasm when the definition of adopter of an improved variety additionally incorporates a minimum threshold for genetic purity

CGIAR-related germplasm AND Purity level threshold imposed of:	Self-reported data (classification status)			Implied adoption rate under combined conditions	Samples not meeting combined conditions
	Improved (true positive)	Not improved (false negative)	N		
Above 70%	0.42%	17.3%	29	17.7%	220
Above 90%	0.42%	15.1%	26	15.5%	223
Above 95%	0.42%	10.6%	18	11.0%	231

Table 41: Rates of misclassification of varietal status for farmers adopting CGIAR-related barley germplasm when definition of adopter of an improved variety additionally incorporates a maximum limit for varietal age

CGIAR-related germplasm AND year of release being:	Self-reported data (classification status)			Implied adoption rate under combined conditions	Samples not meeting combined conditions
	Improved (true positive)	Not improved (false negative)	N		
After 1990	0.42%	17.3%	29	17.7%	220
After 2000	0.42%	17.3%	29	17.7%	220
After 2010	0.42%	14.2%	25	14.6%	224

Standing
Panel on
Impact
Assessment

CGIAR Advisory Services – SPIA

Via dei Tre Denari, 472/a, 00054 Maccarese (Fiumicino), Italy

email: spia@cgiar.org

url: https://cas.cgiar.org/spia