Fertilizer and Soil Fertility Potential in Ethiopia

Constraints and opportunities for enhancing the system

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The authors would like to thank the McKinsey & Company team for their analytical support and assistance.
### I. Executive Summary

This document is a summary report of the soil fertility and fertilizer value chain diagnostic work—one of eight reports across the agricultural system facilitated by the Bill & Melinda Gates Foundation (BMGF) and undertaken at the request of H.E. Prime Minister Meles Zenawi. Over 70 stakeholders, ranging from smallholder farmers and local Development Agents to the private sector and the Ministry of Agriculture and Rural Development contributed to the report’s findings and recommendations.

This report reaffirms the need for significant improvements soil fertility and fertilizer application that take into account Ethiopia’s varied agro-ecologies, soil, and climate. These steps are critical to achieve the aspirations of higher crop yields contained in the sectoral strategies of the Government of Ethiopia (GOE) and its development partners. Since the early 1990s, Ethiopia has achieved marked improvements in the distribution of agricultural inputs through programs such as the Participatory and Training Extension System (PADETES) and the work of Sasakawa Global 2000. While GOE’s strategies have contributed significantly to increased yields, a significant proportion of production growth has come from increased land under cultivation.

Given forecast population growth of over 2 percent p.a. to 2030, and the increasing scarcity of cultivable lands in high-potential areas, Ethiopia must consider approaches to improve future outputs by considerable enhancement in crop yields. These activities should incorporate a forward-looking strategy that complements enhanced soil fertility interventions with the effective use of chemical fertilizers.

#### SOIL FERTILITY CHALLENGES IN ETHIOPIA

Ethiopia faces a wide set of issues in soil fertility that require approaches that include, but go beyond, the application of chemical fertilizers – the only practice applied at scale, to date. Core constraints include: topsoil erosion (some sources list Ethiopia among the most severely erosion-affected countries in the world, along with Lesotho and Haiti; rates estimated at 10-13 mm p.a. on average); acidity-affected soils covering over 40 percent of the country; significantly depleted organic matter due to widespread use of biomass and dung as fuel; depleted macro and micro-nutrients, and; depletion of soil physical properties, and salinity.

The report prioritizes five areas where significant improvements in on-farm practice will yield substantial production gains, supplemented by use of appropriate fertilizers:

- Severe organic matter depletion, driven by competing uses for crop residues and manure as livestock feed and fuel. The use of dung as fuel instead of soil amendment is estimated to reduce Ethiopia’s agricultural GDP by 7 percent.
- Severe topsoil erosion of ~10-13 mm p.a. or 137t/ha/year, driven by the limited use of basic practices and benefits, e.g. minimum tillage and soil and water conservation and minimum tillage.

- Limited intercropping: while crop rotation and fallowing have implementation challenges related to food security and small size of land holdings, intercropping does not face these same challenges, yet current use is nearly non-existent.

- Lack of local specific fertilizer recommendation per commodity and limited guidance to farmers on possible integration of fertilizer with other soil and water management practices.

- Limited use of integrated, locally tailored solutions; required enablers (e.g. robust, simple plant and soil diagnostic tools) are not widely available outside research projects.

These interventions are constrained by lack of up-to-date data; many interventions depend on major national soil surveys dating to the 1980s (FAO) and macronutrient studies from the 1950s-60s. In addition to the lack of actionable, relevant data, the weak linkages between research and extension inhibit the adaption and adoption of these practices by smallholder farmers.

Specific to fertilizer, there are a set of value-chain constraints:

- Chemical fertilizer faces significant constraints in low availability of credit, and limited reach of distribution networks in contexts where appropriate application can enhance yields

- Bio-fertilizer currently only offers increased nitrogen (N) supply when rhizobium inoccula are used to enhance biological N fixation of legumes. The use of rhizobium inoccula is constrained by low demand, due to lack of awareness and understanding of the product, and limited production capacity. Extensive testing of benefits to identify appropriate products is needed—research efforts are currently limited. All other forms of bio-fertilizers would require thorough evaluation prior to commercialization.

**INTEGRATED SOIL FERTILITY MANAGEMENT – A MODEL FOR MULTIPLE INTERVENTIONS**

Given this set of constraints, focusing on interventions separately does not work: despite a fivefold increase in fertilizer application, national cereal yields have only increased 10 percent since the 1980s, and relative benefits of chemical fertilizer application have decreased over time. Further, the set of interventions required varies greatly by Ethiopia’s diverse agro-ecologies.

The report advocates for integrated soil fertility management (ISFM) as a framework for tackling multiple issues and accounting for varied local needs, using a range of interventions sequenced over time and tailored to the local situation. Examples from Ethiopia and other countries in sub-Saharan Africa and East Asia demonstrate this approach have more agronomic and economic impact than, for example, a focus on chemical fertilizer alone.
RECOMMENDATIONS

The report identifies six priority areas for action to improve soil fertility:

1. **Implement soil fertility solutions appropriate to Ethiopia’s extremely diverse agroecology and varied local soil fertility needs through ISFM:** increase awareness and use of integrated and locally-tailored solutions through an iterative research-pilot-rollout model. This would avoid the productivity-limited scenario under single, blanket interventions. Efforts could be managed by a national ISFM taskforce (in MoARD) who would oversee the national ISFM program, and draw on the resources and expertise of a national consortium or “learning alliance” to include a broader range of stakeholders from different sectors.

2. **Make effective use of organic carbon resources** by increasing the amount of manure and crop residues produced and used as organic nutrient sources. This is central to achieving the long-term need for increased biomass production for food and soil fertility, and hence sustainably higher productivity, needed to break the poverty cycle. Specific actions include local supply of affordable fuel alternatives, increased fuel efficiency of major fuel-consuming household devices, availability of local, affordable feed and forage, and the scale-up of existing efforts to promote compost preparation and application. At the same time, it is recognized that the availability of crop residues is constrained by low yield and biomass production. Integrated soil fertility management including effective fertilizer use are key to high yield.

3. **Mitigate severe topsoil erosion in cultivated highlands** through interventions at the individual farm level as well as through large-scale community and regional projects in targeted areas. Suggested actions include soil and water conservation measures, scale-up best practices (e.g. Tigray conservation program), and link implementation with provision of other inputs or enablers like fertilizer or credit, inter alia.

4. **Reduce constraints on value chains for chemical and bio-fertilizers** (rhizobium inoccula for legumes) by improving distribution channels and reach, increasing supply of fertilizer credit, encouraging institutions to better tailor credit products to end-user needs (e.g. long-term payback and based on input packages rather than single inputs), and evaluating rhizobium inoccula to enhance nitrogen fixation of legumes and helping initiate demand, supply and distribution where needed. Opportunities exist to engage with international initiatives to evaluate other bio-fertilizers across a wide range of environments.

5. **Create a central repository of national and local soil data, and effective knowledge dissemination channels to ensure this information provides the fact base for actions to improve soil health.** Activities include establishing a strategy at a national level; linking in with large-scale, cutting edge international soil mapping projects to obtain baseline data;
simplifying data and implications for maximum end-user impact; redefining and streamlining institutional responsibilities and links

6. **Link major soil fertility efforts to relevant international projects and experts** to maximize relevance of projects already underway and ensure transfer of applicable knowledge and experiences.

**IMPLEMENTATION**

The program of activities outlined above has potential to enable a wide range of interventions in the agricultural system to achieve their productive potential. These are critical for small producers to drive gains in food security and growth, and set Ethiopia on a path to achieve PASDEP II production targets. Implementation will require the prioritization and sequencing of recommendations, along with the integration of activities with a broader range of agricultural interventions.

The approach will require resources that GOE will likely have to mobilize beyond its own, identifying new resources and using existing resources more effectively. The recommendations outlined in this report and in the other sub-sector diagnostic reports are not an explicit roadmap of the activities the BMGF is best positioned to solely resource; they reflect a set of findings to support MoARD and all donors in the planning and implementing strategies to accelerate growth and food security in the context of Ethiopia’s nationally stated objective to achieve middle-income status by 2025.
A preliminary view of the potential timing of major activities is shown below:

<table>
<thead>
<tr>
<th>Short to medium term (1-2 years)</th>
<th>Long term (3-5 years)</th>
</tr>
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<tbody>
<tr>
<td><strong>Create national ISFM program</strong></td>
<td>Scale up ISFM projects and continue rollout</td>
</tr>
<tr>
<td>• Create an ISFM taskforce and a Learning Alliance to manage program</td>
<td>• Ensure ongoing feedback/links with research system</td>
</tr>
<tr>
<td>• Identify and enable distribution of simple, robust, locally usable soil diagnostic tools</td>
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<tr>
<td>• Initiate first wave of ISFM project sites</td>
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<tr>
<td><strong>Mitigate organic matter depletion</strong></td>
<td></td>
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<tr>
<td>• Initiate household and community fuel wood projects</td>
<td>• Consider commercialization of industrial by-products for fuel</td>
</tr>
<tr>
<td>• Roll out/increase penetration of fuel-efficient stoves</td>
<td>• Identify other fuel-saving devices and facilitate rollout</td>
</tr>
<tr>
<td>• Continue existing efforts to promote compost preparation and application</td>
<td>• Scale up extension compost efforts</td>
</tr>
<tr>
<td><strong>Mitigate topsoil erosion</strong></td>
<td></td>
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<tr>
<td>• Implement minimum requirement soil and water conservation (SWC) measures on all cultivated land in all regions</td>
<td></td>
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<tr>
<td>• Identify examples of successful, sustainable community-level SWC projects and roll out</td>
<td></td>
</tr>
<tr>
<td><strong>Reduce fertilizer value chain constraints</strong></td>
<td></td>
</tr>
<tr>
<td>• Increase supply of fertilizer credit</td>
<td>• Invest in improved infrastructure (roads, port?)</td>
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<tr>
<td>• Encourage better tailoring of credit products to end-user needs</td>
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<tr>
<td>• Evaluate bio-fertilizer opportunity</td>
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<tr>
<td><strong>Create and maintain a soil health fact base</strong></td>
<td></td>
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<tr>
<td>• Establish national soil data agenda and strategic plan</td>
<td>• Consider increasing soil status testing capacity in regions</td>
</tr>
<tr>
<td>• Link in with large-scale, cutting-edge international projects and leverage to obtain baseline data for new national database</td>
<td>• Ongoing: link all major soil fertility efforts to relevant international projects and experts</td>
</tr>
<tr>
<td>• Redefine institutional responsibilities and links</td>
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</table>
II Acknowledgments

Since the soil fertility and fertilizer sector diagnostic was initiated in November 2009 at the request of H.E. Prime Minister Meles Zenawi, over one hundred collaborators have generously participated in the process, from smallholder farmers and rural Development Agents to research institutes and the Ministry of Agriculture and Rural Development.

The Ministry of Agriculture and Rural Development provided guidance and leadership throughout. We are particularly grateful to H.E. Minister Ato Tefera, State Minister Dr. Adera Deressa, State Minister Bashir Abullahi, State Minister Mitiku Kassa, State Minister Yakob Yalla and their colleagues in the federal Ministry, regional Bureaus of Agriculture and Rural Development, and the woreda and kebele-level offices. Dr. Solomon Assefa, Director General of the Ethiopian Institute for Agricultural Research, and his colleagues at EIAR also provided invaluable input.

A panel of Ethiopian experts including Seme Debela, Solomon Bekure, Teferi Amakeltech, Yeshi Babunuki, Berhande Gebrikidan, Tesfai Kumsa and Gete Zeleke have provided ongoing guidance.

We would also like to provide special thanks to Eyasu Elias, Marco Quinones, Eleni Gabre-Madhin, Derek Byerlee, and Tsedeke Abate.

Beyond the local, regional, and federal governments, a broad number of Ethiopian institutes, research organizations, NGOs, private sector partners, and others engaged with teams of researchers in developing the content and recommendations from this work. These include: Addis Ababa University, Agricultural Research Institutes in Amhara, SNNP, Tigray, and Oromia, Bahir Dar University, Ethiopian Commodities Exchange, Ethiopian Institute for Agricultural Research, Ethiopian Seed Enterprise, Haramaya University, and Jimma University.

Many donors and global experts were also engaged directly in the process. The CGIAR representations in Addis Ababa provided generous use of facilities for consultant teams and expert leadership in the diagnostic areas, with particular thanks to the International Food Policy Research Institute, the International Water Management Institute, and the International Livestock Research Institute. We would also like to recognize the many institutions and donor agencies who contributed: the Alliance for a Green Revolution in Africa, ACDI-VOCA, African Development Bank, CARE, Catholic Relief Services, Center for International Agricultural in the Tropics, Center for International Forestry Research, CIMMYT, the Royal Dutch Embassy, the Food and Agriculture Organization, GTZ, International Development Enterprises, IPMS, Iowa State University, Michigan State University, Natural Resources Institute, Oxfam, Oxford University, PanVac, Sasakawa Africa Association, SNV, Islamic Relief, JICA, Save the Children, Technoserve, Tamrat, University of Texas A&M, Tufts University, UN OCHA, University of Minnesota, USAID, Wageningen University, Washington University, World Bank, and the World Food Program.
III Acronyms

ADD Agricultural Development Department
ADLI Agricultural Development Led Industrialization
AEZ Agro-ecological Zone
AGRA Alliance for a Green Revolution in Africa
AHI African Highlands Initiative
ATVETs Agricultural Technical Vocational Education and Training
BNF Biological Nitrogen Fixation
CSA Central Statistics Authority
DA Development Agent
EHRS Ethiopian Highlands Reclamation Study
EIAR Ethiopian Institute of Agricultural Research
EPID Extension and Project Implementation Department
EPA Environment Protection Authority
FAO Food and Agriculture Organization
FDRE Federal Democratic Republic of Ethiopia
FFW Food for Work
FYM Farmyard Manure
HPP High Potential perennial Zone
HPC High Potential Cereal Zone
ICRAF World Agroforestry Center
IFDC International Fertilizer Development Center
IFPRI International Food Policy Research Institute
IPNM Integrated Plant Nutrient Management
ISFM Integrated Soil Fertility Management
LER Land Equivalent Ratio
LGP Length of Growing Period
LPC Low Potential Cereal Zone
LUPRD Land Use Planning and Rural Development
MoA Ministry of Agriculture
MoARD Ministry of Agriculture and Rural Development
NUE Nutrient Use Efficiency
NFIU National fertilizer Inputs Unit
<table>
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<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tr>
<td>PADETES</td>
<td>Participatory Demonstration and Training Extension System</td>
</tr>
<tr>
<td>PASDEP</td>
<td>Plan for Accelerated and Sustained Development to End Poverty</td>
</tr>
<tr>
<td>RARI</td>
<td>Regional Agricultural Research Institute</td>
</tr>
<tr>
<td>REFLAC</td>
<td>Research, Extension and Farmers Linkage Advisory Council</td>
</tr>
<tr>
<td>SG</td>
<td>Sasakawa Global</td>
</tr>
<tr>
<td>SNNPR</td>
<td>Southern Nations Nationalities and Peoples Region</td>
</tr>
<tr>
<td>SSA</td>
<td>Sub-Saharan Africa</td>
</tr>
<tr>
<td>SWC</td>
<td>Soil and Water Conservation</td>
</tr>
<tr>
<td>TSBF-CIAT</td>
<td>Tropical Soil Biology and Fertility program of the International Center for Tropical Agriculture</td>
</tr>
<tr>
<td>UAAIE</td>
<td>Upper Awash Agro Industry</td>
</tr>
<tr>
<td>VCR</td>
<td>Value Cost Ratio</td>
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<td>WFP</td>
<td>World Food Program</td>
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IV Background

Agriculture is the core driver for Ethiopia’s growth and long-term food security. The stakes are high: 15 to 17 percent of the Government of Ethiopia’s (GOE) expenditures are committed to the sector\textsuperscript{viii}, agriculture directly supports 85 percent of the population’s livelihoods\textsuperscript{ix}, 43 percent of Gross Domestic Product (GDP)\textsuperscript{x}, and over 80 percent of export value\textsuperscript{xi}.

Ethiopia’s agricultural sector has witnessed consistent growth since 2003: maize production has expanded at six percent per annum, and the aggregate export value across all commodities has grown at nine percent per annum\textsuperscript{xii}, underpinning an eight percent annual growth rate in GDP\textsuperscript{xiii}. Public investment has expanded access to productive inputs, such as hybrid maize seed and fertilizer\textsuperscript{1}. Concerted government spending in extension has also established over 8,500 Farmer Training Centers (FTCs) and trained 63,000 Development Agents (DAs) from 2002 – 2008\textsuperscript{2}.

However, the sector continues to face a set of constraints that restrict further and accelerated growth. Markets are underdeveloped, federal and regional level public and private sector partners lack capacities to implement, some gender imbalances continue to be unaddressed, safety nets account for a large proportion of agricultural spending, irrigation potential remains underdeveloped, shortages of improved inputs hinder growth, and key areas of the enabling environment require improvement. Most importantly five to seven million Ethiopian’s remain chronically food insecure\textsuperscript{xiv}.

At the request of the Government of Ethiopia (GOE), in 2009, the Bill & Melinda Gates Foundation (BMGF) agreed to undertake diagnostic reviews of Ethiopia’s seed system, irrigation, extension, agricultural finance, soil fertility/fertilizer and markets value-chains for maize, livestock, and pulses\textsuperscript{3}. Jointly, these sub-sector diagnostics inform a separate holistic report with systems-level recommendations across agriculture. This systems-level work captures common themes from the more siloed diagnostics and identifies priority areas to drive food security and growth. The integrated, summary report also provides an implementation strategy for a program to accelerate agricultural development in Ethiopia.

The development of these reports has been led by senior fellows with the International Food Policy Research Institute (IFPRI), the Ethiopian Institute for Agricultural Research (EIAR), the International Livestock Research Institute (ILRI), the International Water Management Institute (IWMI), and the Association of Ethiopian Microfinance Institutions (AEMFI). Throughout their work, these sector experts worked closely with technical experts at the Ministry of Agriculture.

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1 Refer to the seeds and soil fertility diagnostic reports for more details
2 Refer to the extension diagnostic report for more details
3 Final reports and recommendations from the individual sub-sector diagnostics are completed and available for review. Contingent on the approval of GOE, the Foundation anticipates working with MoARD and IFPRI to facilitate the publication of the reports.
and Rural Development (MoARD) as well as other local stakeholders and local and international content experts.

The findings of the sub-sector diagnostics and the system-wide report are a complement to national GOE strategies, namely PASDEP II, along with corollary projects financed by GOE and its development partners. The purpose of the work is to support GOE to help accelerate the achievement of PASDEP II’s goals for sustainable growth, food security, and a pathway to middle-income status by 2025.
V Methodology of Diagnostic Work

In close consultation with the Ministry of Agriculture and Rural Development (MoARD), a team of local and global experts, coordinated by International Food Policy Research Institute (IFPRI), undertook the fertilizer and soil fertility diagnostic in Ethiopia from January 2010 to March 2010. Over 70 stakeholders, including many small-scale farmers, were consulted as part of the process at the kebele, woreda, regional, and federal level. An independent Ethiopian expert panel, local and international researchers, development partners, local institutions, NGOs, and other actors also provided input into this work. These discussions culminated in a wide ranging stakeholder convening held in June 2010, where the team’s preliminary findings and recommendations were presented and discussed. This final report reflects the input of all local partners and stakeholders currently operating in soil fertility/fertilizer in Ethiopia.

This sectoral analysis, similar to the diagnostic work in other sub-sectors of Ethiopia’s agricultural system facilitated by the BMGF at the request of the Prime Minister, consisted of a rigorous multi-step process, described below:

- **Extensive review of the relevant literature** – soil fertility research in Ethiopia is extremely fragmented. The team conducted an exhaustive review of the existing reports, which provided a baseline understanding and starting point for the team’s work. A listing of the various reports consulted is contained in Appendix 1 (References)

- **In-depth key informant interviews** – over 70 stakeholders, including BoARD and woreda government staff, research institutes, academic institutes, soil laboratories, other soil experts, cooperatives, unions, farmers, development partners, and others participated in interviews. The interviews brought context to and surfaced constraints identified in the literature review; they also provided a soundboard to validate findings and recommendations

- **Multi-stakeholder convenings** – convenings were held toward the end of the study to present, test and further refine the team’s initial findings and recommendations. Convenings were attended by regional and federal government officials, private sector representatives, as well as national and international research organizations

- **Synthesis and validation with expert panels** – As a final review of the recommendations and findings, three separate expert panels were consulted during the review process: an independent Ethiopian content expert panel; an international content expert group; and a high-level advisory group for cross-sectoral and broad development issues. Input was provided by these panels in an iterative process, consisting of meetings and direct comments into documents, held over a multi-month period. During this period, the team also continued to receive feedback from MoARD leadership.
The methods sought to combine academic rigor with a participatory, forward-looking, and actionable process with the stakeholders in Ethiopia who, at the end of the day, are the protagonists who will be affected by and take leadership in the implementation of the findings and recommendations of this work. It also sought to interact directly with the farmers, particularly women, who are not only the primary beneficiaries of the work, but the final link in the chain in implementing recommended interventions. The incorporation of a farmer perspective ensures that recommendations are demand driven, catering to the needs of the clients of this work.
1. Ethiopia’s Soil Fertility Situation

Agriculture in Ethiopia has long been a priority and focus of national policy, such as Agricultural Development Led Industrialization (ADLI), and various large-scale programs, such as the Plan for Accelerated and Sustained Development to End Poverty (PASDEP). Close to 10 percent of the country’s land area is currently under crop cultivation, and the sector employs about 85 percent of the population, generates over 46 percent of GDP and 80 percent of export earnings, and has a significant role to play in improving food security in the near- to mid-term. It is no surprise then, that it is widely agreed that Ethiopia has both the potential and the need to achieve better crop yields, particularly for food security.\textsuperscript{xv}

This report examines the case for improving soil fertility in terms of its potential contribution to higher crop yields for Ethiopia, gives an overview of the current status of Ethiopia’s soil, then considers various soil fertility interventions, positive progress to date in implementing these as well as prospects for improvement.

1.1 OVERVIEW OF FARMING SYSTEMS AND YIELD POTENTIAL

At a high level 5 major farming system zones were identified by FAO in 1986 and provide a useful, if extremely simplified introductory context. Ethiopia is classified into as many as 34 agro-ecological zones\textsuperscript{xvi}, with highly varied soil types and fertility status, climate, rainfall, altitude, topography, crop growing period, and the like. The FAO summary version is shown in Figure 1 and described below:

- **High potential perennial (HPP) zone**: areas in the south and western highlands with mean annual rainfall of 2000 mm; production focused on coffee, enset, fruits, cereals, root crops, and spices. Includes Sidamo, Gamo Gofa, Kafa, Illubabor and west Wellega

- **High potential cereal (HPC) zone**: areas in the north-central and south-eastern highlands with mean annual rainfall of 1200 mm; production focused on cereals, livestock and mixed farming. Includes Gojjam, South Gonder, south Wello, east Wellega and the Arsi-Bale

- **Low potential cereal (LPC) zone**: areas in the north-eastern highlands, typically identified as “drought-prone highlands”, with average annual rainfall of 600-700 mm p.a. Output is focused on cereals, livestock, pulses and oil crops. Areas include North Gonder, Tigray, north-east Shewa and east Hararghe and the Rift Valley areas

- **Low agricultural potential zone**: areas with poor soils, low rainfall and short growing period but good access to international markets; production is export-oriented with focus on crops such as sesame, banana, citrus, frankincense, and gum Arabica. Areas include Humera and Metema
- **Livestock zone:** pastoral and agro-pastoral lowland areas with low and variable rainfall, covering the majority of Afar and Somali Regional States, Borena and Karrayu in Oromiya State, south Omo in SNNPRS).

**Figure 1: Farming system zones of Ethiopia**

![Zonation to Farming Systems and Potentials](image)

Data source: Raw data from FAO 1996


### 1.2 ETHIOPIA’S CROP YIELD POTENTIAL

Since the early 1990s Ethiopia has achieved significant improvements in inputs through programs such as PADETES and Sasakawa Global 2000: irrigation and improved seed coverage of area under crop have nearly doubled, growing six to seven percent p.a., and fertilizer application has grown at three percent p.a.\(^{xvii}\) This input growth has led to some yield improvements, but production growth has come largely from increased land under cultivation. Total cereal production has grown at six percent p.a. and production per capita at three percent, but yields per hectare at just 0.5 percent p.a.\(^{xviii}\).
While production and yield growth in the past five years have accelerated (CSA reported six percent p.a. yield growth and 12 percent p.a. total production growth from 2004/5 to 2007/8\textsuperscript{xix}), given forecast population growth of over two percent p.a. to 2030\textsuperscript{xx}, and that additional cultivable land in the highlands is now scarce, Ethiopia faces strong incentives to increase future output by improving crop yields. Bringing additional land under crop will help but productivity increases are also needed.

Various studies highlight the significantly increased crop yield potential due to interaction between combined inputs and practices, over and above the effects of separate or stand-alone inputs. For example, Dercon et al. (2009) estimate that for Ethiopia this interaction effect could almost double the crop yield benefits of improved inputs and practices implemented separately.

Studies show the use of chemical fertilizers in Ethiopia have contributed to crop yield growth to date\textsuperscript{xxi}, although there is potential for further improvement: for example, fertilizer is applied by less than 45 percent of farmers, on about 40 percent of area under crop, and most likely at below-optimal dosage levels\textsuperscript{xxii}. While application rates are higher than the average for sub-Saharan Africa,\textsuperscript{xxiii} there is evidence to suggest that fertilizer applied in Ethiopia is not as effective as potential suggests. For example, the nutrient use efficiency (NUE = kg yield per kg nutrient) of maize in Ethiopia is 9 to 17 kg of grain per kg of applied N, while in Kenya and Tanzania equivalent NUEs range from 7 to 36 and 18 to 43\textsuperscript{xxiv}.

\textit{Table 1: Input use on cereal crops 1997–08 to 2007–08}

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<tbody>
<tr>
<td><strong>Fertilizer applied area (% total area cultivated)</strong></td>
<td>39.0</td>
<td>42.8</td>
<td>32.3</td>
</tr>
<tr>
<td><strong>Fertilizer application (kg/ha, total cultivated area)</strong></td>
<td>45</td>
<td>30</td>
<td>37</td>
</tr>
<tr>
<td><strong>Fertilizer application (kg/ha, fertilizer applied area)</strong></td>
<td>116</td>
<td>100</td>
<td>115</td>
</tr>
<tr>
<td><strong>Improved seed coverage (% of crop area)</strong></td>
<td>4.7</td>
<td>3.5</td>
<td>2.4</td>
</tr>
<tr>
<td><strong>Pesticide coverage (% of crop area)</strong></td>
<td>20.8</td>
<td>10.8</td>
<td>12.0</td>
</tr>
<tr>
<td><strong>Irrigated crop area (% of crop area)</strong></td>
<td>1.1</td>
<td>1.3</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Extension package coverage (% of crop area)</strong></td>
<td>14.5</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

NA = Data not available

\textbf{SOURCE:} Dercon and Hill (2009)

These differences are not only driven by the amount of chemical fertilizer applied—equally if not more significant factors include agro-ecology, soil fertility and physical management practices, and the resulting interactions between chemical and physical soil properties.\textsuperscript{xxv}
Likewise, comparisons with chemical fertilizer’s contribution towards India’s Green Revolution need to be considered in light of the fact that Ethiopia’s cultivated highlands are experiencing some of the most severe soil erosion rates in the worldxxvi—conditions very different to India’s conserved rice fields.

Accordingly, this picture of limited chemical fertilizer effectiveness needs to be considered in the context of declining fertility of cultivated soils overall. Numerous research efforts examine the extent of this trend and name a range of potential contributing factors, such as: reduced use of fallowing and highly cereal-dominated production, complete removal of crop residues from farm lands, low levels of fertilizer application, the use of animal manure as a source of fuel in place of soil fertility, and the absence of appropriate soil and water conservation practices.xxvii

In summary, while peer comparisons are useful to understand the global picture, peer benchmarking does not account for Ethiopia’s unique and highly varied landscape, soil and climate—hence yield and fertilizer application targets need to be based on agro-ecology. And while these agro-ecology based targets are not yet well-defined, it is clear that soil fertility is a necessary component in achieving them.

1.3 SOIL FERTILITY KNOWLEDGE AND RESEARCH

Data on soil fertility in Ethiopia is largely out-of-date at the national level, and very locally-specific, fragmented and difficult-to-access at the local level—meaning it would take significant time and effort to obtain an actionable view of the current soil status:

- There is no centralized source of soil data or soil research, although early-stage efforts are underway through the Ethiopian Institute of Agricultural Research (EIAR) and the National Soil Laboratory. Regional Research Institutes and national and regional soil laboratories exist, have seen progress in terms of resources and output, and are currently carrying out research on various areas of soil and water management, fertilizer recommendations, management of problematic soils and other relevant areas. However much of this knowledge is specific to particular areas selected for study and currently cannot be compiled, compared, or accessed at a national level to enable policymakers and other stakeholders to draw conclusions on the status of soil in Ethiopia and its implications for food production. Moreover, there is potential for more networking of soil scientists across Ethiopia and internationally, to ensure access to the latest literature to guide research, and to avoid reinventing the wheel

- The last major surveys of macronutrient status across the country were conducted in the 1950s-60s, first at the Alemaya College of Agriculturexxviii, then through the Institute of Agricultural Research at Holetta, Werer and Bako research centers. These studies did identify major soil problems such as erosion and inadequate water conservation, drainage and irrigation; however the most comprehensive findings of these studies were on macronutrient
levels. Since FAO studies from the 1980s, no further major soil mapping or surveys have been carried out at a national level

- Current fertilizer recommendations deal with N and P dosage only, are at least 15 years old, and are largely standardized for the country—they are specified for major crop groups, but do not take into account agro-ecological variation. Recommendations of liming acid soils are particularly lacking. Regional calibration efforts are underway through MoARD and EIAR’s regional centers, currently expected to be complete by mid-2011.

As a result the major soil fertility issues are currently only understood at a high level. More research needs to be carried out at a granular, actionable level (e.g. down to kebele or village level). Key metrics required include soil physical characteristics, pH, organic matter content, topsoil thickness, macro and micro-nutrient levels, and salinity levels.

What limited data is available suggests that the current outlook is far from positive:

- Even in 1986, 24 percent of Ethiopia’s soil faced moderate to very severe fertility constraints, affecting key farming regions. This has more than likely worsened after 24 years with little soil fertility management (such as use of fertilizer or manure, or good practices like fallowing or crop rotation), high rates of soil erosion, and high population growth and increasing population density in the highlands.

- Topsoil loss on agricultural land is estimated at 10mm p.a.; under agricultural conditions this yearly loss typically takes 200 years to replenish. Some sources list Ethiopia as one of the most severely erosion-affected countries in the world, along with Lesotho and Haiti.
2. Major Soil Fertility Issues in Ethiopia

Ethiopia faces a wider set of issues in soil fertility beyond chemical fertilizer use, which has historically been the major focus for extension workers, researchers, policymakers and donors. If left unchecked, this wider set of issues will limit future output and growth in agriculture across the country—and in some areas they already limit the effectiveness of chemical fertilizer. These chemical, physical and biological issues interact and include loss of organic matter, macronutrient, and micronutrient depletion; topsoil erosion; acidity; salinity; and deterioration of other soil physical properties. In addition Ethiopia has soil types with inherent characteristics which can be problematic for crop production and need special management. A summary of the issues is provided here:

- **Organic matter depletion:** depletion or lack of replenishment of matter usually derived from plant, animal and microbial bodies in all stages of decay (organic carbon and other nutrients). Critical to ensuring long-term soil fertility: provides balanced medium for water and nutrients for growth
  - **Causes:** not returning animal dung, crop residues to soil, and excessive tillage, among others. Major drivers of this behavior in Ethiopia include low availability of biomass overall due to low productivity, and competing uses for this biomass (dung used as fuel and crop residues used as feed)
  - **Severity** has not been measured at a national level, but the burning of dung as fuel instead of application as manure is estimated to reduce Ethiopia’s agricultural GDP by seven percent. A 2005 study in Bale highlands found organic Carbon levels in cultivated land of 2.5 percent - well-below ratings defined by Walkely and Black in 1984 (less than four percent is “Low”, four to ten percent is medium). This compares to levels of 12.7 percent in virgin forest, 7.3 percent in virgin grass and 4.4 percent in fallow land. These levels have been attributed to intensive cultivation and improper land use management. Similarly Tegenu et al. (2009) found in north-west Ethiopia organic matter content was seven percent in forest areas and 2.5 percent in cultivated areas
  - Organic matter depletion and nutrient depletion often occur together in the same area (example shown in Table 2)
Table 2: Soil pH, Organic Carbon and Total Nitrogen by Area

<table>
<thead>
<tr>
<th>Area</th>
<th>pH</th>
<th>Organic Carbon %</th>
<th>Total Nitrogen %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melkassa</td>
<td>7.0 - 8.2</td>
<td>0.8 - 1.5</td>
<td>0.1 - 0.15</td>
</tr>
<tr>
<td>Miesso</td>
<td>7.3 - 7.8</td>
<td>0.7 - 0.9</td>
<td>0.04 - 0.1</td>
</tr>
<tr>
<td>Arsi Negelle</td>
<td>6.5 - 7.9</td>
<td>1.3 - 2.1</td>
<td>0.1 - 0.2</td>
</tr>
<tr>
<td>Wolenchiti</td>
<td>7.5 - 8.5</td>
<td>0.8 - 2.0</td>
<td>0.1 - 2.2</td>
</tr>
<tr>
<td>UAAIE</td>
<td>8.2 - 8.5</td>
<td>&gt;1</td>
<td>2.1 - 2.4</td>
</tr>
<tr>
<td>Adami Tulu</td>
<td>&gt; 7.3</td>
<td>0.8 - 1.7</td>
<td>0.1 - 0.15</td>
</tr>
</tbody>
</table>

SOURCE: MARC (2007)

- Macronutrient depletion: loss of Nitrates (N), Phosphates (P) and Potash (K) from the soil in available form for plants. Results in stunted growth and low crop yields
  - Causes: farming without replenishing nutrients over time, and/or chemical imbalance issues (e.g. acidity, salinity leading to fixation)—often driven by continuous cropping of cereals, removal of crop residues, leaching, low levels of fertilizer usage and unbalanced application of nutrients. In addition, inadequate runoff management can lead to leaching especially for N and K
  - Data on severity is very outdated: the most recent national study of macronutrient levels was in 1990 by Stoorvogel and Smaling, and indicated balances of -41kg/ha N, -6kg/ha P and -26kg/ha K in cultivated highland areas (see Table 3)

Table 3: National Average Macronutrient Balances by Country

<table>
<thead>
<tr>
<th>Country</th>
<th>Nitrogen (kg/ha) 1982-84</th>
<th>2000 projected 1982-84</th>
<th>Phosphorus (kg/ha) 1982-84</th>
<th>2000 projected 1982-84</th>
<th>Potassium (kg/ha) 1982-84</th>
<th>2000 projected 1982-84</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethiopia</td>
<td>-41</td>
<td>-47</td>
<td>-6</td>
<td>-7</td>
<td>-26</td>
<td>-32</td>
</tr>
<tr>
<td>Kenya</td>
<td>-42</td>
<td>-46</td>
<td>-3</td>
<td>-1</td>
<td>-29</td>
<td>-36</td>
</tr>
<tr>
<td>Malawi</td>
<td>-68</td>
<td>-67</td>
<td>-10</td>
<td>-10</td>
<td>-44</td>
<td>-48</td>
</tr>
<tr>
<td>Ruwanda</td>
<td>-54</td>
<td>-60</td>
<td>-9</td>
<td>-11</td>
<td>-47</td>
<td>-61</td>
</tr>
<tr>
<td>Tanzania</td>
<td>-27</td>
<td>-32</td>
<td>-4</td>
<td>-5</td>
<td>-18</td>
<td>-21</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>-31</td>
<td>-27</td>
<td>-2</td>
<td>2</td>
<td>-22</td>
<td>-26</td>
</tr>
</tbody>
</table>

SOURCE: Stoorvogel and Smaling (1990)
Field-level studies in the southern Ethiopian highlands by Eyasu (2002) reported N levels of -102 kg/ha. Similarly, Amare et al. (2006) reported N, P and K balances in the central highlands showing N levels of up to -72 kg/ha in the study area, with highest nutrient depletion at foot slopes in Dega, and at the mid-slopes in Woina Dega (see Appendix 2, Annex 1).

- The age of this data combined with low overall (but extremely varied) fertilizer application rates suggests the issue has most likely worsened significantly, and that nutrient balances are extremely varied from one area to the next and even at different altitudes within one area.

- **Micronutrient depletion:** Loss of nutrients required in small amounts for plant growth including Fe, Mn, Zn, Cu, B, Mo and Cl. If levels of these nutrients are too low, this can lead to poor plant growth; reduced uptake and fixation of nutrients (e.g. P in cell roots); inhibited cell division, respiration, nitrogen mobilization and glucose phosphorylation; and inefficient water use by plants. If micronutrients are present in large amounts, these can become toxic and also limit growth.

- **Causes** include farming without replenishing (including focusing only on high analysis fertilizers), although balances are related to soil pH (acidity issue), salinity, soil moisture content, and organic matter.

- **Severity:** Zn and Cu were found to be deficient in 65 percent and 89 percent of soil samples collected across the country, respectively. Similarly, in a separate study, over 75 percent of Vertisol, Cambisol and Fluvisol soil samples analyzed were also reported to be Zn-deficient.

- **Topsoil erosion:** the loss of fertile topsoil—meaning the base on which inputs applied and crops grown is increasingly depleted and thinly-spread. This leads to reduced water-holding capacity of soil (making it more susceptible to extreme conditions, e.g. drought) and limited crop emergence, growth, yield and rooting depth, which in turn contributes to a vicious cycle of increased rate of loss of organic matter.

- **Caused** by a combination of cultivation of slopes with poor management, high rainfall and inappropriate drainage (water erosion), and significant loss of vegetation cover (deforestation, overstocking, overgrazing).

- **Severity:** Average annual loss on agricultural land of 137 t/ha/year, or an annual soil depth loss of 10-13 mm. Under agricultural conditions 10 mm lost topsoil takes approximately 200 years to replenish. Some sources list Ethiopia as one of the most severely erosion-affected countries in the world.

- **Acidity:** where soil pH is lower than optimal (5.5 and below) and reduces the solubility of nutrients needed for growth. Conditions also usually lead to Al and Mn toxicity plus deficiency in N, P, K, Mg, Ca and various micronutrients. This has multiple implications for
plant growth and other soil fertility issues: can lead to lack of or reduced response to Ammonium Phosphate and Urea fertilizers, stunted root and plant growth due to nutrient deficiency (yields frequently reduced by 50 percent and can be reduced to 0), increased incidence of disease, and toxicity (e.g. for Mn: black spots and streaks on leaves)

- **Causes:** Acidification occurs with other conditions including eroded topsoil and depleted organic matter, depleted nutrients, alternating drought stress and high rainfall. In moisture-stressed areas, acidification can also be caused by continuous application of acid-forming fertilizers. Approximately 80 percent of acidic soils are expected to derive from Nitisols

- **Severity:** A 1989 study by Schlede found 41 percent of land in Ethiopia is likely to be affected by soil acidity: 13 percent is strongly acidic (pH < 4.5) and 28 percent is moderately to weakly acidic (pH 4.5-5.5). Areas well-known to be severely affected by soil acidity include Ghimbi, Nedjo, Hosanna, Sodo, Chencha, Hagere-Mariam, Endibir and Awi Zone of the Amahara regional state

- Despite these high-level statistics the situation is not well-understood in detail at the local level, or with more up-to-date estimates of severity

- **Salinity:** Excessive accumulation of certain ions and salts impacts levels of other nutrients, limits the availability of water and disrupts the osmotic tension of soil, and can result in some excess accumulation of specific ions (B, Cl, Fl, Li, Na) and/or salts (e.g. HCO3-, CO32-). This leads to stunted plant growth

- **Causes:** can be a side effect of pH imbalance (acidity problem), e.g. for each unit increase in pH, Fe levels decrease a thousand fold, and Mn, Cu and Zn decrease a hundredfold. Otherwise salinity tends to occur in the presence of conditions such as shallow ground water tables, inefficient irrigation practices and poor drainage (man-made or natural), natural saline seeps, and high evaporation surface moisture or insufficient annual rainfall leading to leaching of salts from plant rooting zone

- **Severity:** salt-affected soils in Ethiopia cover at least 11 m ha—nearly 10 percent of total land, although most of this is in low-lying areas. However given this data is from 1980s it is likely to underestimate current status

- **Inherently problematic soils:** Reddy and Kidane (1993) found crop production constraints in dry land areas covering close to half of total arable land mainly centre on moisture and nutrient stress, salinization and soil surface crusting. Overall, soils in these areas are known either to have highly degraded structural stability, or to be in the process of degradation due to largely-inappropriate land management combined with their natural tendency to surface seal leading to low infiltration and high erosion. As a result, typically nutrient levels and moisture storage capacities are low, and salinity and limited crop productivity are common.
Vertisols are one such known “problematic soil” type, covering 12.6 million ha (10.3 percent of the country), with 7.6 million ha of this in the highlands and a large proportion in agricultural areas—though in the late 1980s, only 24 percent of the total Vertisols area in the highlands was under crop production. Numerous soil fertility issues have been reported in Vertisols that also occur on other types of soil but are exaggerated due to inherent soil properties and lack of adequate management practices—these include salinity issues, macro and micronutrient deficiencies, and very low efficiency of applied nitrogen fertilizers due to the tendency of Vertisols to become waterlogged.
3. Overview of Soil Fertility Interventions

Multiple interventions are needed to address these soil fertility issues—including, but not limited to, chemical and organic nutrient sources. Positive steps have been made in many areas by MoARD and EIAR, and achievements in the scale-up of chemical fertilizer use are especially noteworthy. Main soil fertility interventions possible include:

- **Organic nutrient sources**: animal waste and crop residues applied to soil in the form of manure, untreated crop residues, and/or compost. Impact is broad—it improves organic carbon and nutrient levels, nutrient retention, reduced topsoil erosion, and mitigated acidity and salinity; and effects are long-lasting (more than 2 seasons); local materials are low-cost. Recent efforts have increased focus on compost but manure use remains extremely low.

- **Chemical fertilizer**: synthetic concentrated macronutrients (N, P and/or K) applied to soil. These can have a large yield impact, but only under the right soil conditions and with adequate soil and water physical management—nutrients applied, for example, to acidic or saline soils can become fixated and hence unavailable; on depleted topsoil, nutrients can be leached away.
  - Application per hectare in Ethiopia has increased five times since the 1980s and is better than the sub-Saharan Africa average, but rates and coverage vary significantly, and focus on DAP and Urea means only N and P provided (not K).
  - Currently a large portion of EIAR resources is focused on testing crop yield response to N and P fertilizers, and regional tailoring of DAP and Urea fertilizer recommendations, as these were the priorities identified from the Murphy studies in the 1950s-60s. Initial blanket recommendations were adjusted for major cereals and soil types in the early 1990s, but aside from selected exceptions (e.g. some woredas in Amhara region) efforts on regional tailoring still have some way to go.

- **Bio-fertilizer**: cultures of nutrient-releasing bacteria and fungi applied to seeds; organisms make nutrients available to plants from surrounding environment. The effective nutrient impact can vary and needs extensive on-site evaluation to ensure varieties are fit for use; in some cases they can provide robust results as effects are not hindered by acidic or saline conditions in the same way as chemical fertilizers. The most promising bio-fertilizer at present are Rhizobium inocula to enhance biological nitrogen fixation of legumes, but current production in Ethiopia is small. All other bio-fertilizers would require significant research prior to commercialization and opportunities exist to engage with international initiatives to evaluate other bio-fertilizers across a wide range of environments.

- **Intercropping, crop rotation and fallowing**: allowing for natural replenishment of soil nutrients by co-planting legumes with grains, alternating legumes and cereals on the same plot in consecutive seasons, or leaving portions of land periodically fallow. Nutrient level
increases through these techniques are less than with applied fertilizers, but can help reduce the need for supplements. Projects in other SSA countries (e.g. the World Agroforestry Center, ICRAF) with food security issues have found fallowing impractical, and intercropping a better balance of benefits and feasibility. Currently in Ethiopia most farmers practice some crop rotation, but effectively on two thirds of land\textsuperscript{6}; intercropping and fallowing are largely not used

- **Lime:** crushed rock (e.g. limestone, chalk) applied to soil to reduce acidity levels. Under acidic conditions, makes nutrients available to plants by balancing pH, and prevents acidity-related crop damage. A national acidity management project, including lime production and distribution, is underway through MoARD and EIAR but is in early stages

- **Physical land management techniques, erosion and moisture management:** includes on-farm soil preparations such as minimum tillage, mulching and tied ridging, as well as large-scale land management practices (e.g. terracing, soil/stone bund construction, use of grass/forage strips and other agro-forestation, watershed conservation, irrigation and drainage). Practices reduce topsoil erosion and also benefit all other major soil issues. Successful practices have been developed in food-insecure areas (e.g. Tigray) but are not well spread to the rest of the country

The exact set of issues and interactions present in any one area will vary significantly, but the diagram below (Figure 2) provides a generalized overview of the types and extent of complexity of the issues at hand in Ethiopia. It is clear, then, that soil fertility needs to be managed using multiple interventions given the complex, multiple and interacting issues at hand and multiple possible interventions. In addition, solutions need to be integrated, holistic and locally-tailored to have substantial and lasting impact. Some examples exist from experimental plots in Ethiopia where multiple interventions have been applied and resulted in greater crop yields—these are outlined in Section 5.3 (ISFM Framework and Examples).
**Figure 2: Soil Fertility Issues and Interventions in Ethiopia**

<table>
<thead>
<tr>
<th>Soil fertility issues</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macronutrient depletion</td>
<td>Organic matter depletion</td>
<td>Micronutrient depletion</td>
<td>Topsoil erosion</td>
<td>Acidity</td>
<td>Salinity</td>
<td></td>
</tr>
</tbody>
</table>

**Interventions**

1. Organic nutrient sources
2. Chemical fertilizer (DAP, Urea)
3. Biofertilizer
4. Crop rotation, fallowing, intercropping
5. Lime application
6. Tillage
7. Land management, soil and water conservation

- **Chemical fertilizer and organic matter (biomass) replacement are interdependent**
- **Generalized example shown: exact interdependencies will vary by location**

**SOURCE:** Expert interviews, team analysis
4. Ethiopia’s Soil Fertility Challenges

Ethiopia is trapped in a vicious cycle of poverty and over-taxation of land resources—described as “the misuse of natural resources caused by need”\textsuperscript{lii} and “an unsustainable, exploitative sequence… linked to a lack of choice due to poverty rather than neglect”\textsuperscript{liii}. In the increasingly densely-populated highlands, a growing number of low-income smallholders depend heavily on soil nutrients for food and biomass for energy, meaning that everything produced from the soil is used as far as possible and very little remains to re-invest in soil replenishment or inputs for the following year. This cycle of poor on-farm practices and low yields and income, leading to low re-investment, and again poor on-farm practices can only be broken with large-scale structural change that dramatically increases smallholders’ ability to invest in and implement packages of technologies and inputs over a 3-5 year horizon, achieve production and economic surplus, then use this to build capital and invest in continued high output.

As part of breaking the poverty cycle, overcoming the challenges relating to on-farm practices is necessary, though not sufficient. We have identified four major areas where on-farm practices need major change across Ethiopia:

- **Severe organic matter depletion:**
  - Long-term field experiments in sub-Saharan Africa have shown mineral fertilizer use without recycling of organic materials can result in higher yields compared to an untreated control\textsuperscript{liv} (as shown in Figure 3). Recycling of organic materials, however, leading to higher organic carbon levels results in significantly higher yields when mineral fertilizer is applied\textsuperscript{lv}
  - Organic matter depletion is driven by competing uses for crop residues and manure as livestock feed and fuel, respectively. Burning of dung cake and crop residues is common in Ethiopia due to a lack of widely-available and affordable fuel wood; dung cake has been reported to account for about 50 percent of households’ fuel supply, particularly in the north and central highland cereal zones,\textsuperscript{lv} and in some cases manure is used as a source of supplementary cash income as a result. Zinash and Seyoum (1989) reported that 63 percent of cereal straws are used for feed, 20 percent for fuel, 10 percent for construction and seven percent for bedding
  - The use of dung as fuel instead of fertilizer is estimated to reduce Ethiopia’s agricultural GDP by seven percent\textsuperscript{lvii}. Similarly for crop residues, some estimates suggest the nutrient contents of the crop residues used as feed are higher than the quantities applied as fertilizers\textsuperscript{lviii}—in other words, this lack of alternative fuel and feed sources is a significant constraint
Supply of both dung and crop residues is scarce to begin with: the average smallholder typically owns two or fewer cattle of the local variety that produce very little dung. Crop residues are limited given low yields overall, and for some crops this is exacerbated by off-farm processing (leaves and stems are removed at central processing facility rather than on-farm). Total crop residue production is given in Appendix 2, Annex 2.

Case Study: SG-2000 Conservation Agriculture Project – Successes from West Shewa, West Arsi and Sidama

In Ethiopia, farmers typically plough their land three to five times before planting using oxen-drawn local ploughs, and minimum tillage practices are not widespread. Recommendations as early as 1986 (FAO) suggested its importance, but until recently little experimental research was available to evaluate its potential significance in Ethiopia.

In 1998, SG-2000 initiated a conservation agriculture project including minimum tillage in selected maize-growing areas. Several years of observations from demonstration plots have shown significantly increased crop yields and farmer income under the conservation plots compared to conventionally-prepared plots. However, adoption is still limited, apparently largely due to lack of appropriate minimum tillage implements to facilitate seed-soil contact; the practice of free-range grazing on plots after harvest, limiting ease of implementation of conservation practices; and limited availability and affordability of pre-planting herbicides (leading to farmers reverting to further tillage to try to reduce uptake of weeds). Perhaps most significantly, though, minimum tillage adoption presents the larger challenge of altering habits and mind-sets that have been unchanged for generations.

SOURCE: Sasakawa, 2007
Severe topsoil erosion of ~10-13mm p.a. or 137t/ha/year, driven by the limited use of basic practices and benefits, e.g. minimum tillage and soil and water conservation.

- Erosion problems are perhaps not unexpected given Ethiopia’s varied, rugged topography and steep slopes, and removal of vegetation cover in areas in recent decades. In addition, the cereal-dominated crop production system with fine seed bed preparation provides only little ground cover during the erosive rainy season, resulting in high soil erosion rates.

- Overall this under-managed issue of severe erosion can be attributed to weak knowledge dissemination and limited enforcement of land management guidelines, rather than a lack of identified technologies and practices. For example the government-designed national conservation strategy launched in 1997 was comprehensive, covering management guidelines for soil, forest and water resources, but implementation through extension has proved difficult and has largely stalled (see case study on SG-2000 conservation agriculture project).

- The structural issue of overcrowding of fertile lands exacerbates this problem by creating disincentives to investment in long-term soil management through large-scale erosion management (e.g. agro-forestation, terracing), encouraging instead a focus on next year’s food supply from the limited available resources. Although exceptions exist in some moisture-stressed and food-insecure areas in the east and north, where government intervention in conservation has seen successful implementation of conservation practices, these successes have not yet been rolled out to other regions (see case study on Soil and Water Conservation Community Projects in Tigray).

**Case Study: Soil and Water Conservation Community Projects in Tigray**

In the 1970s and 1980s, conservation efforts in Tigray were limited, due to lack of economic or labor capacity to implement the necessary measures, and the short-term perspective of the farmers.

However, huge efforts were undertaken through government-led projects focusing on wide-spread implementation of conservation measures such as: construction of stone bunds to conserve both soil and runoff; rehabilitation of steep slopes, through e.g. agro-forestation, recovery of vegetation (vegetation strips) or better terracing; and “exclosure” development, i.e. areas set aside to allow regeneration of natural vegetation.

Today significant improvements can be noted. Sheet and rill erosion rates have decreased - average soil loss is estimated at around 68% of the 1975 rate. Groundwater recharge, vegetation cover and biomass production have increased, along with crop yields.

This success could be scaled up to many other highland areas, bringing significant productivity and environmental benefits.

SOURCE: Esser et al. (2002); Nyssen et al. (2007)
- **Limited intercropping and crop rotation:** though Ethiopia’s cropping systems are diverse, the proportion of legume coverage on average is far exceeded by that of cereals. Crop rotation, fallowing and green manuring are largely difficult to implement in densely-populated areas with small farm sizes, and even more so where food supply is insecure. However intercropping does not face these same challenges, yet current use is nearly non-existent. The benefits of intercropping and suggested optimal combinations of crops have been identified by research but have not been translated into widespread use.

- **Limited use of integrated, locally tailored solutions to tackle complexity of constraints:** the situation outlined above of multiple, interacting issues that vary widely by agro-ecology and within local areas, and the multiple interventions needed to manage these issues and achieve increased productivity, requires localized solution frameworks that draw on up-to-date knowledge of the soil status and priority issues, at both the national and farm level. Currently the integrated use of soil fertility interventions is in its early stages in Ethiopia, and the required enablers (e.g. robust, simple diagnostic tools available to local communities to identify soil problems and generate solutions) are largely not in place, outside specific research projects.

Another overarching constraint that will need to be overcome to break Ethiopia’s poverty cycle is the absence of up-to-date, comprehensive and actionable soil data. Almost all national-level recommendations and analysis depend on Murphy’s national macronutrient assessment from the 1950s-60s, and FAO studies from the 1980s. Much of this data is based only on N and P nutrient levels and yield response, with very little information available on other aspects of soil health (e.g. micronutrients, organic matter, physical properties). Likewise fertilizer recommendations are largely out-of-date (early 1990s), focused on N and P, and not regionally tailored, though selected woredas in Amhara have made positive first steps towards local calibration. Research and testing institutes and facilities exist under EIAR, Regional Agricultural Research Institutes (RARIs) and the Ministry of Agriculture and Rural Development (MoARD), although many of these face challenges in maintaining adequate skilled staff as well as equipment and chemicals. At a higher level there is no systematic effort underway to evaluate soil fertility at a granular level across the country and in a way aimed at supporting policymakers (e.g. soil fertility maps and databases). This lack of a basic fact base—up-to-date, localized data covering all aspects of soil health—is a major constraint to intervention effectiveness.

A third general constraint affecting soil fertility management in Ethiopia is the lack of effective links between research, extension, education and farmers—a fundamental enabler for transfer of knowledge and skills from theory into widespread practice. Improvements have been made through the creation of the Research, Extension and Farmers Linkage Advisory Council (REFLAC) as one forum for this type of knowledge transfer, however there remains significant room for improvement in coordinating stakeholders from research and higher learning institutions, governmental and non-governmental organizations, the private sector, regional and
international organizations at all levels. Research findings and conclusions largely remain within journals and not in the hands of extension workers or smallholder farmers.

Soil fertility knowledge dissemination is poor, with few farmers aware of what soil fertility issues are relevant to them. For example, some woreda workers interviewed on field visits were well aware of the importance of locally-tailored fertilizer dosages, but had no idea whether these will be developed or when and by whom. Likewise farmers and extension workers interviewed about acidity issues were aware of acidity as a problem generally, but were waiting to be told by government and research institutes about which specific farms were affected.

This default approach, of passively waiting for information to be passed down the chain, limits the ability of farmers and extension workers to identify relevant issues and their root causes, and hence develop fact-based action plans. A common result is that the soil fertility management techniques used in specific areas are based on tradition, which in some areas can be effective (e.g. soil and water conservation practices in Konso) but in many others is vastly inadequate.

In addition to the three cross-cutting issues described above, value chains for fertilizers face a number of constraints:

- **Chemical fertilizer** faces a number of potentially significant constraints; although these need framing in the overall context of whether more chemical fertilizer is optimal (current situation varies from one location to the next)—and in particular the impact of other soil fertility issues (e.g. acidity) on fertilizer effectiveness, and hence what economically optimal application levels could be
  
  - Currently about 69 percent of the area cropped with wheat is reportedly fertilized but rates applied are often less than half of those recommended
  
  - Fertilizer uptake and application is linked to credit access, which is currently severely limited—accordingly fertilizer credit availability is a limiting constraint to further fertilizer use. For smallholders, on average the economics of fertilizer use are attractive, but risk of negative cash flow is high; large farmers with significant commercialization can afford to bear this risk, but smallholders cannot
  
  - In addition, domestic distribution is a significant component of fertilizer cost. While the reach of road networks and cooperatives to most high-production areas has improved significantly in recent years, access to very remote areas is limited; accordingly fertilizer may be unaffordable, not available on-time or simply unavailable in these hard-to-reach areas

- **Bio-fertilizer** currently only offers increased nitrogen (N) supply when rhizobium inoccula are used to enhance biological N fixation of legumes. The use of rhizobium inoccula is constrained by low demand, due to lack of awareness and understanding of the product, and limited production capacity (currently only produced in Ethiopia by the National Soil Testing
Laboratory using research equipment—no commercialization). Research is currently preliminary with emphasis given to N-fixing rhizobia for legumes, and extensive research and evaluation is needed to determine appropriateness of application and potential scale for Ethiopia. All other forms of bio-fertilizers would require thorough evaluation prior to commercialization.
5. Integrated Soil Fertility Management (ISFM)

Further to the challenges identified above, the effectiveness of soil fertility interventions in Ethiopia has historically been constrained by the lack of an integrated and locally-tailored approach, despite apparent success in individual programs. Historical evidence in Ethiopia supports the conclusion that the focus on fertilizer to date has been impressive but regrettably has not led to a revolutionary change in yields. Despite a fivefold increase in fertilizer application, cereal yields have increased 10 percent\(^4\) since the 1980s (see Figure 4). In addition, the relative economic benefits of chemical fertilizer application have decreased over time, with value-cost ratios for major crops decreasing from around four in 1995 to marginally-attractive levels of approximately two today\(^{lxiv}\).

**Figure 4:** Ethiopia Annual Yield (t/ha) for Top 5 Cereals (Barley, Maize, Sorghum, Teff, Wheat) as affected by fertilizer application.


\(^{4}\) Based on trend
Table 4 details historical trends in soil fertility management approaches in sub-Saharan Africa. In recent years soil fertility management in Ethiopia has begun to shift towards a more integrated approach—examples of projects include but are not limited to the Wageningen-EIAR Integrated Nutrient Management project, MoARD/SG-2000 Conservation Agriculture plots, and AGRA-EIAR ISFM projects.

Table 4: **Overview of Soil Fertility Management Paradigms in Sub-Saharan Africa**

<table>
<thead>
<tr>
<th>Period</th>
<th>Paradigm</th>
<th>Role of fertilizer</th>
<th>Role of organic inputs</th>
<th>Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960s and 1970s</td>
<td>First External Input Paradigm</td>
<td>Use of fertilizer alone will improve and sustain yields.</td>
<td>Organic resources play a minimal role.</td>
<td>Limited success due to shortfalls in supply, infrastructure, policy and adoption.</td>
</tr>
<tr>
<td>1980s</td>
<td>Organic Input Paradigm</td>
<td>Fertilizer plays a minimal role in land quality maintenance</td>
<td>Organic resources are the main sources of nutrients and substrate.</td>
<td>Limited adoption as organic matter production requires excessive land and labor.</td>
</tr>
<tr>
<td>1990s</td>
<td>Sanchez’s Second Paradigm</td>
<td>Fertilizer use is essential to alleviate the main nutrient constraints.</td>
<td>Organic resources serve as an entry point offering functions other than nutrient release.</td>
<td>Difficulties to access organic resources hampered adoption (e.g. improved fallows).</td>
</tr>
<tr>
<td>2000s</td>
<td>Integrated soil fertility management</td>
<td>Fertilizer is a major entry point to increase yields and supply needed organic resources.</td>
<td>Access to organic resources has social and economic dimensions.</td>
<td>Ongoing</td>
</tr>
</tbody>
</table>

SOURCE: Vanlauwe et al. (2006)

5.1. **OVERVIEW OF ISFM**

ISFM can be defined as “the application of soil fertility management practices, and the knowledge to adapt these to local conditions, maximizing fertilizer and organic resource use efficiency and crop productivity. These practices necessarily include appropriate fertilizer and organic input management in combination with the utilization of improved germplasm.” Other aspects of soil fertility management can also be included in ISFM programs, such as soil and water conservation; timing and method of mineral fertilizer application; practices to improve availability, quality and storage of organic matter; and the maintenance and enhancement of beneficial soil organisms. In other words, ISFM is not defined in terms of set field practices, but
rather characterizes approaches combining available and locally-relevant technologies in a way that increases the agronomic efficiency of individual interventions. A conceptual framework is outlined in Figure 6, although it should be noted that by definition the exact sequencing and combination of interventions will need to vary by local area—hence this framework should not be considered as a prescriptive solution.

In addition, successful ISFM implementation at a large scale beyond individual experimental plots is crucially dependent on well-functioning knowledge dissemination channels from research to farmers, and an iterative process from research to planning and implementation, to allow tailoring of interventions and sequencing based on observed results.\textsuperscript{lxvi}

### 5.2 INTEGRATED AND LOCALLY-TAILORED SOLUTIONS

There is strong evidence to suggest that benefits from an integrated approach—incorporating multiple inputs and soil fertility interventions—are much greater than the benefits of the component parts. For a set of three treatments, NPK fertilizer, lime and manure, Bationo et al. (2006) found maize yield increased by 150 percent for fertilizer application alone, and with all treatments 184 percent. For a broader range of interventions, Dercon and Hill (2009) predict that for maize in Ethiopia, improved practices, fertilizer application and use of improved seed individually account for half of the yield improvement potential of the entire package—the remainder is due to interaction of these elements (see Figure 5).

\textit{Figure 5: Expected Yield Increase from Improved Inputs (Maize Example), percent}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure5.png}
\caption{Expected Yield Increase from Improved Inputs (Maize Example), percent}
\end{figure}

\textit{SOURCE:} Dercon and Hill (2009)
Soil fertility characteristics typically vary greatly by region, and Ethiopia is no exception with its extremely diverse agro-ecology. For example, measured nutrient and organic carbon levels within a single farm have been shown to vary by a factor of ten (Vanlauwe et al., 2009). Accordingly, sustainable soil fertility management options need to take into account the socio-economic and biophysical environments, natural resources available, characteristics of the farming household (e.g. income, size of family, size of farm and grazing land), other aspects of the farm system such as livestock, general farming practices and production objectives of a given area. A corollary is that adoption of soil fertility management practices is often more effective when local knowledge and practices are considered and built upon.

Furthermore, many mineral nutrients, although present in the soil and detected by soil lab analysis, may not be available to crops, as described above, because of immobilization due to pH levels and presence of other competing minerals Therefore, soil testing on pH and organic matter must be complemented with integrated soil fertility management at farm level and research recommendations tailored based on results.

The potential benefits of a locally-tailored approach are clear, but the real challenge is in implementing solutions at this level without resorting to expensive, extensive and complicated testing for every farm; accordingly having cheap but robust diagnostic tools available to local communities is fundamental to achieving effective locally-tailored solutions; these will be considered later in the recommendations section.

5.3. ISFM FRAMEWORK AND EXAMPLES

Integrated soil fertility management is a framework for tackling multiple issues and accounting for varied local needs, using a range of interventions. These can include techniques described above such as application of chemical and organic nutrient sources, and leaching control, minimum tillage, and integrate other inputs as well, such as improved seed, irrigation, and pest/disease control. The mix and extent of use of these techniques depends on local needs and agro-ecological variability, taking into account e.g. weather; weeds, pests and diseases present; inherent soil characteristics, market access/local availability of inputs, as well as relevant local knowledge and adoption potential. Interventions are typically sequenced over time, to allow gradual development of increasingly complex solutions and knowledge (Figure 6).
ISFM projects in Ethiopia and other SSA countries demonstrate the yield and economic benefits of this integrated, locally-tailored approach. Examples of partial ISFM experiments to date include:

- **Manure and fertilizer, Ethiopia, potato**: A combination of manure and 75 percent of fertilizer recommendation (and a similar combination of compost and fertilizer) led to 10 to 20 percent higher potato yields than for 100 percent fertilizer alone. VCR ratios were up to 0.36 points higher than for the fertilizer-only treatment.

- **Manure and fertilizer, Ethiopia, wheat**: significantly higher grain yields were obtained when both organic and inorganic nutrient sources were used, compared to inorganic fertilizers alone—this was especially relevant given the acidic conditions in the area (see Table 5 for results).
Table 5: Grain Yield Under Chemical N and P Fertilizers and Farmyard Manure (FYM)

<table>
<thead>
<tr>
<th>Treatment N/P/FYM (kg/ha)</th>
<th>Soil type</th>
<th>Medium (Dila) Grain yield (t/ha)</th>
<th>Poor soil (Dimile) Grain yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9/10/0</td>
<td>Medium (Dila)</td>
<td>2.63c</td>
<td>1.63c</td>
</tr>
<tr>
<td>9/10/8000</td>
<td>Poor soil (Dimile)</td>
<td>3.05b</td>
<td>2.15b</td>
</tr>
<tr>
<td>32/10/4000</td>
<td></td>
<td>3.27ab</td>
<td>2.29b</td>
</tr>
<tr>
<td>32/10/8000</td>
<td></td>
<td>3.44a</td>
<td>2.59a</td>
</tr>
<tr>
<td>64/20/0</td>
<td></td>
<td>3.46a</td>
<td>2.78a</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td></td>
<td>0.34</td>
<td>0.23</td>
</tr>
<tr>
<td>CV (%)</td>
<td></td>
<td>8.79</td>
<td>8.43</td>
</tr>
</tbody>
</table>

SOURCE: Getachew and Chilot (2009)

- **Tied ridging and fertilizer, Ethiopia:** Tied ridging increased maize yields without fertilizer by approximately 10 percent; with fertilizer this increase ranged from 15 percent to over 250 percent.\(^{lxv}\)

- **Intercropping maize or sorghum with haricot bean, Ethiopia:** on-farm experiments in the central Rift Valley in 1992-1993 showed intercropping two rows of maize or sorghum with one row of haricot bean gave the highest grain yield and land use efficiency, and helped suppress weed growth.\(^{lxvi}\)

- **Intercropping barley with faba bean, Ethiopia:** in west Shewa, intercropping increased land equivalent ratios by 5 to 23 percent over sole cropping; weed and disease pressures were also decreased.\(^{lxii}\)

- **Erosion management and fertilizer, Burkina Faso:** millet and sorghum yields increased from 400kg/ha in 1984-88 to 650kg/ha in 1996-2000 due to use of stone rows and grass strips for erosion control, along with fertilizer, manure and compost.\(^{lxiii}\)

- **Intercropping arrangements, western Kenya:** intercropping maize with groundnut and pigeon pea in a staggered-row arrangement led to higher maize yields, net returns, benefit-to-cost ratios and fertilizer agronomic efficiency. Within five years of development, 16 percent of households in the region had adopted it.\(^{lxiv}\)
6. Recommendations

Improving Ethiopia’s soil fertility will lead to increased crop productivity on its own, but is also fundamental to ensuring other agricultural productivity enhancing interventions are not wasted or under-realized. With input from MoARD, local experts and stakeholders, we have identified six priority areas for action to improve soil fertility:

1. **Implement soil fertility solutions appropriate to Ethiopia’s extremely diverse agro-ecology and varied local soil fertility needs through ISFM**

   Increase awareness and use of integrated and locally-tailored solutions through an iterative research-startup-rollout model. This would avoid the productivity-limited scenario under single, blanket interventions. Efforts could be managed by a national ISFM taskforce who would oversee the national ISFM program, who would draw on the resources and expertise of a national consortium or “learning alliance” involving close collaboration between participants from research, academia, extension, farmer groups, government, the private sector and NGOs.

   Specific actions include:

   - **Develop a national ISFM framework:** identify experts to form a national ISFM taskforce and develop appropriate technology options meeting farmers’ site-specific needs; connect with international research organizations and initiatives in the development of innovative knowledge products and diagnostic tools to develop, evaluate, and disseminate management options in consultation with stakeholders.

   - **Design projects and sequencing:** identify representative areas across Ethiopia—not only in “moisture sufficient” or “moisture stressed” areas—and plan for sequenced rollout to demonstration plots in each area; define consistent experimental setup and data collection processes

   - **Manage and own ongoing data collection and continuous improvement process:** take inputs from research centers and higher learning institutions, ensure feedback of experimental results back into research and extension; create and use iterative research process to use findings from each phase to adjust each subsequent phase and create a geo-spatial linkage to the database

   - **Guide regional research centers** to identify priority interventions and sequencing guidelines relevant to each kebele, and in parallel introduce ISFM component in ATVETs program to ensure DAs have basic training in ISFM concepts and tools. Prioritization of interventions, sequencing and planning framework should be driven and coordinated through the ISFM program and draw on national soil data (outlined below). Once interventions identified, use trained DAs to take woreda- or kebele-level priority actions and tailor to individual farms selected as part of start-up/scale-up program
- **Oversee execution of experimental startup program and rollout:** ideally link implementation to an existing program, e.g. Sasakawa conservation agriculture or SG-2000, SLMP and PSNP projects, to ensure integration with irrigation, seed etc. ISFM taskforce should determine level of collaboration required.

- **Identify and distribute basic diagnostic tools** as part of input packages in startup program. Commission short-term research project to develop and/or identify existing cheap, simple but robust diagnostic tools (like leaf color charts used for rice in Asia), and select relevant products for Ethiopia’s major agro-ecologies and farming systems supported with GIS/Remote Sensing products. Obtain funding if required and distribute with input packages. To ensure this ISFM program achieves sustainable impact on a large scale it is imperative these tools are in place and widely available, or results will be limited to experimental plots and the limited number of farmers able to have intensive support from research and extension.

As part of ISFM program implementation, selection of sites should consider an up-front basic segmentation process to ensure broad coverage of smallholders across the country and to maximize possibilities for iterative learning (implementation of program, feedback of data into research, leading to improvements for the next wave of rollout). This would need to take into account Ethiopia’s range of agro-ecological zones with different altitudes, soil conditions, climate, rainfall, growing period and the like; as well as farming systems and agricultural potential.

2. **Make effective use of organic carbon resources**

Make effective use of organic carbon resources by increasing the amount of manure and crop residues used as organic nutrient sources. Improving organic matter levels in the soil will enable chemical fertilizer to be more effective. This is central to achieving the kind of long-term increased biomass production for food and soil fertility, and hence sustainably higher productivity, needed to break the poverty cycle. Specific actions center on reducing competing needs for organic matter, by increasing the supply of substitutes and decreasing the competing needs themselves:

- **Increase supply of local, affordable fuel alternatives to substitute for manure** and hence make manure more available as fertilizer. Initiate a national program to ensure all kebeles have adequate local sources of fuel, other than manure, for basic household requirements. A national-level requirement for energy self-sufficiency levels could also allow regional governments to select the most appropriate approach for each region. Some examples of approaches:
  - **Household fuel wood projects:** ensure all farms within a region plant agro-forestry trees around homesteads and farm boundaries, to provide fuel wood, livestock feed and help reduce erosion.
Implementation should be through extension packages, and include assisted provision of seeds plus resources for capacity building and education. Funding of seedling production and development of extension packages would likely require partnership with NGOs/donors. Planting would be carried out by farmers; DAs would need to provide advice, education on benefits, and follow-up.

Tree/shrub varieties identified as non-detrimental to adjacent crops and as dual-purpose, for agro-forestry and forage (e.g. Acacia Abisinica, Gravilia, etc) should be prioritized for use, to avoid these plants competing with crops for resources. Table 6 provides an example of potential species for use, and observed benefits.

**Table 6: Intercropping Leguminous Shrubs with Alternative Uses as Fuel Wood and Animal Feed**

Studies at Melkassa examined benefits of intercropping various leguminous shrubs (Sesbania sesban, Cajanus cajan and Leucaena leucocepholaha) with food crops (sorghum and maize) to determine the adoption potential. Grain yields increased by up to 38 percent when shrubs were intercropped as alley crops compared to maize and sorghum planting alone. In addition, these legume trees (especially Sesbania sesban and Leucaena) produced high biomass yield which could be used for animal feed and fuel wood to free up other organic nutrient sources (dung and crop residues), or alternatively could themselves provide green manure and mulch.

**Grain yields of maize and sorghum under alley cropping with leguminous shrubs kg/ha**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Maize</th>
<th>Sorghum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole crop</td>
<td>4120</td>
<td>2416</td>
</tr>
<tr>
<td>Sesbania</td>
<td>4274</td>
<td>3337</td>
</tr>
<tr>
<td>Leucaena</td>
<td>4988</td>
<td>3026</td>
</tr>
<tr>
<td>Cajanus</td>
<td>4666</td>
<td>2611</td>
</tr>
<tr>
<td>Mean</td>
<td>4512</td>
<td>2847</td>
</tr>
</tbody>
</table>


Program design and rollout should ensure adequate and extensive input and feedback from women, given current responsibility for fuel and cooking typically rests with women. Implementation should focus on influencing household actions through women’s activities.

- **Community fuel wood projects**: develop community and regional large-scale fuel wood plantations, particularly in communal lands (hillsides, gulleys) not highly suited to...
agriculture. Examples already exist (e.g. in Tigray, East Gojam in Robe Gebeya) where community labor was successfully harnessed to implement projects; initiatives should be nationally coordinated and draw on successes from other regions to maximize knowledge transfer and effectiveness

– **Large-scale energy projects**: regional or state governments invest in e.g. solar, hydro power towards rural electrification. Efforts would have much longer-term impact and are likely to require interim measures such as fuel wood projects to tackle manure issue in the meantime

– **Commercialize industrial by-products for fuel**: encourage investment in/find partners to commercialize processing of industrial by-products into usable fuel, e.g. bricks. Unlikely to be sufficient as stand-alone efforts; could be considered as part of a wider intervention package

- **Increase fuel efficiency of major fuel-consuming household devices to reduce overall fuel requirements**: initial focus could be on smallholders’ cooking stoves, which in the longer term could extend to other devices. Fuel-efficient stoves, such as the “Gonze”, have reported energy savings of 66 percent compared to the three-stone stoves currently used. Efforts are already underway by the Ministry of Mines and Energy along with various NGOs and donors (e.g. GTZ) to distribute these at low cost (approximately US$20 each) these could be leveraged and up-scaled to reduce fuel requirements in parallel to the fuel substitutes program. Cost to farmers could be varied depending on situation, e.g. stoves effectively donated to lowest income groups; those with higher income could pay a nominal small fee. Extension and education of benefits is needed in parallel to ensure successful uptake; programs should center on women and their priorities

- **Increase availability of local, affordable feed sources to substitute for crop residues** and hence make more available as soil amendment. Focus initially on rollout of compulsory backyard agro-forestry and forage sources (as part of fuel wood program above) on all farms. This should be supported by extension efforts to improve the quality of crop residues used as feed such as soaking in urea, or supplementing with molasses, oilseed meals and leguminous fodder crops. This will reduce the quantities of crop residue required for feed and this means more residue will go back to the soil replenishing soil nutrients

- **Scale up and continue existing efforts to promote compost preparation and application**—key improvements are ensuring compost preparation instructions for farmers are simplified and better-communicated, and through the initiatives outlined above, ensuring that source material (i.e. manure, crop residues, plant matter) is available locally in greater quantities for this purpose. Furthermore, by implementing conservation agriculture practices such as minimum or zero till, cover crops or crop residue management as and where fits, farmers can do composting in situ while avoiding the burden of compost preparation as traditionally understood.
3. **Mitigate severe topsoil erosion in cultivated highlands**

Mitigate severe topsoil erosion in cultivated highlands through interventions at the individual farm level as well as through large-scale community and regional projects in targeted areas. Again adequate topsoil needs to be present as the medium for all other inputs (e.g. chemical fertilizer) and to enable increased crop yields—and is hence also central towards breaking the poverty cycle through increased biomass production and sustained higher crop productivity. Suggested actions include:

- **Implement minimum-requirement soil and water conservation (SWC) measures on all cultivated land in all regions** – primarily lands that need to be protected from soil erosion to achieve immediate and sustainable food security.
  - Remove the current broad dichotomy of private versus communal lands which discriminates external resource support for conserving cultivated lands by many government implemented projects (eg. PSNP, MERET, SUN and SLMP).
  - Consider splitting SWC implementation on cultivated land into two parts: 1) initial implementation which could be entitled to any available external support – could be full or partial support depending on slope level of degradation and 2) management of constructed SWC measures and making them productive should be purely the responsibility and obligation of the land user
  - Create simple communication guides covering required actions and benefits of various measures (in terms of crop productivity and income) to be provided with rollout. Roll out communications and implementation of priority actions, farm by farm, over a one to two year period: through DAs and/or student resources
  - Consider linking implementation with provision of other inputs or enablers such as fertilizer credit to increase likelihood of compliance with a simple principle of “no SWC, no fertilizer application”

- **Identify examples of successful, sustainable community-level SWC projects and roll out nationally.** Evaluate known projects harnessing community resources to implement large-scale SWC and watershed management measures, e.g. Tigray conservation program using farmers’ compulsory community service hours, WFP supported MERET Project, GTZ supported SUN project. Use learnings and successes along with local experts from these projects to design community SWC programs for national rollout; link program design to existing MoARD watershed management project; use regional and local government authority and resources to tailor and implement across the country. This can be linked to community fuel wood projects
- **Strengthen research support for soil and water conservation (SWC) efforts.** Appoint a SWC representative at each regional research centre or university; giving them responsibility to:
  - Identify the three to five top-priority SWC interventions relevant to each kebele in their jurisdiction, working with national soil data/research and ISFM taskforces outlined below
  - Carry out on-farm trials to ensure recommendations are practical and farmers are likely to implement; where found not practical, use trials to develop pragmatic alternatives. Implementation should consider involvement of women and balance of household responsibilities
  - Create simple communication guides covering required actions and benefits of various measures (in terms of crop productivity and income) to be provided with rollout. Roll out communications and implementation of priority actions, farm by farm, over a one to two year period: through DAs and/or student resources

4. **Reduce constraints on value chains for chemical and bio-fertilizers**

Reduce constraints on value chains for chemical and bio-fertilizers to ensure uptake and use of these interventions are not constrained:

- **Increase supply of fertilizer credit** by strengthening rural finance institutions, and channeling credit provision through existing financial institutions to increase system effectiveness. The use of cooperatives as a source of credit access has been problematic.  

- **Encourage increased tailoring of credit products to end-user needs:** initiate annual forum for next three years, run through MoARD with NGO partnership, to identify priority new agricultural credit products or product characteristics (e.g. longer time frame for payoffs, loans based on input packages rather than single inputs). Initially make participation compulsory from largest agricultural credit providers along with extension, local government, research and farmer focus groups; eventually aim for self-sustaining model

- **Improve distribution networks in the medium- to long-term,** by encouraging low-cost distribution providers, and investing in improved infrastructure enablers (roads and trucking capacity). The input distribution provider model could transition from current regulated model to a government-controlled tender process, in order to ensure farmers face low distribution costs. Input distributors (including cooperatives but could also include, for example, agro-dealer associations) would tender to regional governments for five-year contracts for the right to distribute fertilizer within that region, providing guarantees such as on-time delivery and keeping distribution costs within a pre-determined range.

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5 Please refer to the Agricultural Finance diagnostic for more details.
- **Evaluate bio-fertilizer opportunity and create value chain where needed**: initiate a national research project with multi-location testing to determine what types of bio-fertilizer could be effective in Ethiopia. Include extensive independent evaluation of benefits to ensure whether lab results for nutrient release are achievable in typical farm setting. Where benefits are worthwhile, evaluate and implement options for scaling up supply, including increasing current capacity through research labs, partnering research labs with NGOs or private sector, and/or encouraging commercialization of existing products through private enterprise. In parallel initiate efforts to raise awareness of product and benefits through on-farm demonstrations (e.g. over two years). Give highest priority to the development, evaluation, and delivery of Rhizobium inoccula for enhanced nitrogen fixation by grain legumes grown in cereal intercropping systems.

5. **Create a central repository of national and local soil data, and effective knowledge dissemination channels to ensure this information provides the fact base for actions to improve soil health.**

Efforts should be coordinated by a soil data and research taskforce, focused on data building, institutional links and knowledge dissemination. The data team should be integrated with the ISFM team under a common vision; the data team would focus on translating high-level soil mapping data into prioritized interventions by area and hence guide the ISFM experimental designs, and should then leverage data from experimental results. The data team should focus on improving soil fertility data relevance and availability, and maximizing efficiency of institutional activities relating to soil fertility, through the following activities:

- **Create a national soil database:**
  - **Establish a national soil data agenda and strategic plan**, to identify goals for priority analyses at national, regional and local levels, and allocate responsible parties to these areas (e.g. research centers, universities, soil laboratories, international organizations, private sector fertilizer companies etc). This would require a targeted, objective and comprehensive review of the current system overall—a coherent agenda is unlikely to evolve organically or through consensus-building. The coordinated action plan would include both delivery on and communication of the agreed research priorities, and dissemination of findings
  - **Establish principles of site specific ISFM recommendations by cropping system**: supported by on-farm research and existing research outputs (eg. Amhara region woreda based fertilizer recommendation) as well as on a simple soil and plant diagnostics, ISFM management options including fertilizer recommendations need to be developed and locally adapted in the context of the respective cropping system. Promotional materials need to be designed to meet the needs of farmers and extension agents.
– **Link in with large-scale, cutting-edge international soil mapping projects and leverage these to obtain baseline data for new national database** (e.g. African Soil Information Service). Efforts using cutting-edge technology and yielding digitized outputs will be crucial to maximizing future usability; if correctly managed, this data could lead to dramatically increased effectiveness of soil fertility interventions and therefore needs to be an ongoing priority. The role in Ethiopia for government, research bodies and extension should be to identify and work with relevant existing projects to ensure outputs are relevant and actionable, then ensure transfer of outputs to national database. The data and research taskforce should then own this data and manage updates on ongoing basis, as well as define update and knowledge management processes for future work.

– **Make use of legacy data where worthwhile:** evaluate resources required to make existing knowledge usable. Longer-term efforts could include taking an inventory of what exists and assessing quality, cataloguing according to some basic usability criteria (e.g. age of tests, what soil issues covered, interventions tested, location), and making data centrally available in Addis.

- **Simplify data for maximum end-user access:** The taskforce’s highest priority should be to use the data and diagnostic tools available to identify key domains where particular issues are likely to be significant, and use this information to influence large-scale decisions on interventions. Then as a medium-term priority once data is in place, taskforce should regularly synthesize and simplify major soil fertility issues and communicate these to extension and government to drive awareness. Needs to use relevant presentation formats (i.e. not research papers) ensuring translation to local languages where needed; should include both events/forums and written communication programs.

- **Redefine institutional responsibilities and links:** for all institutions (research, labs, universities, NGOs, government) involved in soil fertility data and management: codify current mandates/responsibilities, interaction process, and organization structures. Simplify and streamline these to minimize complexity of responsibilities and collaboration—and drive consolidation of institutions where needed. Give taskforce responsibility for allocating budget to these institutions, and ensure MoUs are in place to allow taskforce to act as centralized channel for funding and performance management. The taskforce could be linked to groups such as AGRA’s research consortia.

- **Consider increasing soil status testing capacity in regions:** harmonize soil and plant based approaches under the leadership of the national ISFM taskforce to arrive at widely-supported, consistent, robust and cost-effective strategies towards the development of nutrient management options; this may include programs/NGOs to build local diagnostic capacity e.g. through mobile labs and soil test kits for cooperatives/DAs, subsidized basic tests, e.g. pH and macronutrient levels, physical properties. Consider expanding larger regional testing labs by resourcing existing facilities to operational level (currently limited by shortage of skilled
labor and materials). The services and outputs provided by these labs need to be usable and actionable by local communities and associations; if not, the types of tests and outputs need to be modified, and/or the scale of these regional labs should be carefully considered.

6. Link major soil fertility efforts to relevant international projects and experts

Link major soil fertility efforts to relevant international projects and experts to maximize relevance of projects already underway and ensure transfer of applicable knowledge and experiences. Examples of potential partnerships include:

- General soil fertility management: CIAT-TSFB, evaluating various bio-fertilizers as part of an on-going multi-national initiative in Sub-Saharan Africa; expertise in ISFM pilots, cheap and simple diagnostic tools for use at the local level, developing localized fertilizer recommendations.

- Soil database and mapping: African Soil Information Service, on efforts already underway to produce spatially referenced soil data (nutrients, pH, physical characteristics) for sub-Saharan Africa including Ethiopia.

- ISFM projects and large-scale rollout:
  - AGRA: AGRA has multiple ISFM projects underway or starting in SSA countries, including 2 in Ethiopia, and has extensive experience in establishing consortia across research, extension, government, private sector etc.
  - Wageningen University (EKN-WUR project): on-farm ISFM pilot projects are already underway in partnership with EIAR and could provide useful initial learnings or a starting point for future efforts (2010-2011).
7. Implementation

The programme of activities outlined above will require significant resources. To achieve these objectives and implement the recommendations, the Government of Ethiopia will likely have to mobilize resources beyond its own, tapping into the financial resources and skills of Ethiopians as well as foreign individuals and institutions. This will require further development through discussion with the Ministry of Agriculture and other relevant stakeholders in order to develop detailed project plans that outline the activities required to begin implementation and hence mobilize resources against them. It will also be important to revisit current on-going projects such as PSNP, MERET and SLMP to incorporate the above key recommendations in their portfolio.

The recommendations will need to be prioritized, and a preliminary view of potential timing of major activities is shown here in Figure 7.

Figure 7: Implementation Modality

<table>
<thead>
<tr>
<th>Short to medium term (1-2 years)</th>
<th>Long term (3-5 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Create national ISFM program</strong></td>
<td>• Scale up ISFM projects and continue rollout</td>
</tr>
<tr>
<td></td>
<td>• Ensure ongoing feedback/links with research system</td>
</tr>
<tr>
<td><strong>Mitigate organic matter depletion</strong></td>
<td>• Invest in large-scale energy sources</td>
</tr>
<tr>
<td></td>
<td>• Consider commercialization of industrial by-products for fuel</td>
</tr>
<tr>
<td></td>
<td>• Identify other fuel-saving devices and facilitate rollout</td>
</tr>
<tr>
<td></td>
<td>• Scale up extension compost efforts</td>
</tr>
<tr>
<td><strong>Mitigate topsoil erosion</strong></td>
<td>• Implement more advanced SWC measures where initial efforts show success and high adoption; refocus/redesign efforts where not the case</td>
</tr>
<tr>
<td></td>
<td>• Implement minimumrequirement soil and water conservation (SWC) measures on all cultivated land in all regions</td>
</tr>
<tr>
<td></td>
<td>• Identify examples of successful, sustainable community-level SWC projects and roll out</td>
</tr>
<tr>
<td><strong>Reduce fertilizer value chain constraints</strong></td>
<td>• Improve distribution network reach</td>
</tr>
<tr>
<td></td>
<td>• Invest in improved infrastructure (roads, port?)</td>
</tr>
<tr>
<td><strong>Create and maintain a soil health fact base</strong></td>
<td>• Simplify data for maximum end-user access</td>
</tr>
<tr>
<td></td>
<td>• Consider increasing soil status testing capacity in regions</td>
</tr>
<tr>
<td></td>
<td>• Ongoing: link all major soil fertility efforts to relevant international projects and experts</td>
</tr>
</tbody>
</table>

- Create an ISFM taskforce and a Learning Alliance to manage program
- Identify and enable distribution of simple, robust, locally-useable soil diagnostic tools
- Initiate first wave of ISFM project sites
- Initiate household and community fuel wood projects
- Roll out/increase penetration of fuel-efficient stoves
- Continue existing efforts to promote compost preparation and application
- Increase supply of fertilizer credit
- Encourage better tailoring of credit products to end-user needs
- Evaluate bio-fertilizer opportunity
- Establish national soil data agenda and strategic plan
- Link in with large-scale, cutting-edge international projects and leverage to obtain baseline data for new national database
- Redefine institutional responsibilities and links
- Simplify data for maximum end-user access
- Consider increasing soil status testing capacity in regions
- Ongoing: link all major soil fertility efforts to relevant international projects and experts
8. Conclusion

8.1 OVERVIEW
The findings in this report demonstrate the importance of soil fertility as a significant contributor to the economic and social development of Ethiopia. GOE along with its development partners have made great strides toward improving availability of fertilizer and encouraging soil fertility interventions through the extension system. Realizing Ethiopia’s full productivity potential as a component of Ethiopia’s long-term food security and growth relies on clear direction and execution capacity from GOE and a wide number of stakeholders.

8.2 FIVE-YEAR SECTORAL VISION
To date Ethiopia has made notable progress in a number of areas within both agriculture and soil fertility management. In order to effect substantial, lasting change over the next five years, interventions and efforts need to be locally-tailored and integrated across inputs—for example, ensuring simultaneous rollout of soil fertility interventions with improved seed and irrigation, along with enablers such as finance and adequate extension and education. Accordingly the recommendations above for soil fertility and fertilizer should not be stand-alone projects, but rather need to form part of integrated efforts across the agriculture sector. As part of an integrated program to improve agriculture, Ethiopia has the possibility to grow this sector as well as the overall economy and improve food security and living standards for its millions of smallholder farmers.

8.3 THE WAY FORWARD
The recommendations outlined in this report and in the other sub-sector diagnostic reports are not an explicit roadmap of the activities the Bill & Melinda Gates Foundation is best positioned to solely resource; they reflect a set of findings to support MoARD and all donors in the planning and implementing strategies to accelerate growth and food security in the context of Ethiopia’s nationally stated objective to achieve middle-income status by 2025.

Accelerating the five-year vision contained in this report will undoubtedly require the effective use of significant human and financial resources. It will require a level of sequencing and coordination that has in the past been challenging to implement at a national-level, not only in Ethiopia, but in success cases globally, from Latin America to East Asia. To achieve these objectives, GOE will need to work closely with all its partners, ranging from the development community to the private sector. The recommendations contained in this report offer a preliminary view on the sequencing of various activities to address issues related to soil fertility and the fertilizer value chain.
The findings contained in this report are also complementary to a range of other findings across the diagnostic studies supported by the BMGF from April 2009 to April 2010. The vision for soil fertility relies on a set of factors contained in accompanying diagnostic reports, including a robust system of agricultural extension, a vibrant and efficient seed sector, and access by small-scale producers to irrigation. Additionally, a set of enabling factors will deepen the impact of these recommendations, including financial services, rural infrastructure, and information and communication technologies. At every stage of the value-chain gender must be prioritized, as women are often primarily responsible for planting, harvest, value-addition, and marketing.

Since each of these sectors is mutually dependent, the recommendations and sequencing of activities for soil fertility and fertilizer must be seen within the context of the overall recommendations provided in the holistic and integrated report. With soil fertility as a key enabler to drive Ethiopia’s growth and food security, these steps will be critical to accelerating the long-term vision of achieving middle-income status by 2025.
Appendix 1: References

See end notes for references from text.


FAO. 2001. Integrated soil fertility management for sustainable agriculture and food security. Case studies from four countries in Africa. FAO, Regional Office for Africa. ACCRA, Ghana.


## Appendix 2: Technical background

### Annex 1: Macronutrient balances in the Central European Highlands

<table>
<thead>
<tr>
<th>Altitude belts</th>
<th>Land use</th>
<th>Area (ha)</th>
<th>Partial balance</th>
<th>Full balance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Dega Elevation: 2500-3500m Temperature:11–16°C Enset based mixed farming system Soil type: Luvisols</td>
<td>Barley</td>
<td>5.7</td>
<td>-8</td>
<td>+27</td>
</tr>
<tr>
<td></td>
<td>Potato</td>
<td>1.84</td>
<td>-66</td>
<td>-13</td>
</tr>
<tr>
<td></td>
<td>Enset</td>
<td>0.73</td>
<td>+75</td>
<td>+5</td>
</tr>
<tr>
<td></td>
<td>Meadow/ grazing land</td>
<td>0.9</td>
<td>-61</td>
<td>-9</td>
</tr>
<tr>
<td></td>
<td>Fallow</td>
<td>6.64</td>
<td>0</td>
<td>+3</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>2.85</td>
<td>-50</td>
<td>-8</td>
</tr>
<tr>
<td></td>
<td>Meadow/ grazing land</td>
<td>1.13</td>
<td>-70</td>
<td>-11</td>
</tr>
<tr>
<td></td>
<td>Teff</td>
<td>2.66</td>
<td>-8</td>
<td>+10</td>
</tr>
<tr>
<td></td>
<td>Bean</td>
<td>0.17</td>
<td>-56</td>
<td>-8</td>
</tr>
<tr>
<td></td>
<td>Maize</td>
<td>1.28</td>
<td>+18</td>
<td>-8</td>
</tr>
<tr>
<td>Altitude belts</td>
<td>Landscape positions</td>
<td>Partial balances (N, P, K)</td>
<td>Full balances (N, P, K)</td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>----------------------</td>
<td>----------------------------</td>
<td>-------------------------</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>P</td>
<td>K</td>
</tr>
<tr>
<td>Dega</td>
<td>Upper slope</td>
<td>−10</td>
<td>+13</td>
<td>−32</td>
</tr>
<tr>
<td></td>
<td>Mid slope</td>
<td>−5</td>
<td>+6</td>
<td>−11</td>
</tr>
<tr>
<td></td>
<td>Foot slope</td>
<td>−62</td>
<td>−10</td>
<td>−66</td>
</tr>
<tr>
<td>Woina Dega</td>
<td>Upper slope</td>
<td>−3</td>
<td>−8</td>
<td>−48</td>
</tr>
<tr>
<td></td>
<td>Mid slope</td>
<td>−40</td>
<td>−7</td>
<td>−41</td>
</tr>
<tr>
<td></td>
<td>Foot slope</td>
<td>−19</td>
<td>+5</td>
<td>−30</td>
</tr>
</tbody>
</table>

Source: Amare et al. (2006)

**Annex 2: National estimate of crop residues produced per annum (based on grain yield of 2001/02)**

<table>
<thead>
<tr>
<th>Residue type</th>
<th>Conversion factor</th>
<th>Quantity (million tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tef</td>
<td>3.0</td>
<td>4.48</td>
</tr>
<tr>
<td>Maize</td>
<td>2.0</td>
<td>5.60</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.8</td>
<td>1.16</td>
</tr>
<tr>
<td>Barley</td>
<td>1.2</td>
<td>1.12</td>
</tr>
<tr>
<td>Sorghum</td>
<td>3.0</td>
<td>4.64</td>
</tr>
<tr>
<td>Millet</td>
<td>3.0</td>
<td>0.92</td>
</tr>
<tr>
<td>Oats</td>
<td>1.2</td>
<td>0.04</td>
</tr>
<tr>
<td>Rice</td>
<td>0.8</td>
<td>0.01</td>
</tr>
<tr>
<td>Pulse</td>
<td>1.0</td>
<td>1.02</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>18.99</strong></td>
</tr>
</tbody>
</table>

**Annex 3: Soil and water conservation measures implemented by the Ethiopian government between 1976 and 1988**

<table>
<thead>
<tr>
<th>Conservation measures</th>
<th>Area covered</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil and stone bunds on cultivated fields</td>
<td>800,000 km</td>
<td>Level earth works and stone lines on 350,000 ha crop land</td>
</tr>
<tr>
<td>Hill-side terraces and afforestation</td>
<td>600,000 km</td>
<td>Mostly in the northern highlands</td>
</tr>
<tr>
<td>Check dams on gullied lands</td>
<td>15,400 km</td>
<td>Includes gulley reclamation and plugging work</td>
</tr>
<tr>
<td>Area closures on communal areas (hill-sides)</td>
<td>410,000 ha</td>
<td>Area closures were meant for regeneration of natural vegetation, most common in Tigray</td>
</tr>
<tr>
<td>Tree planting on communal areas (woodlots)</td>
<td>465,000 ha of tree planting</td>
<td>500 million seedlings planted on community woodlots for conservation of communal lands</td>
</tr>
</tbody>
</table>


**Annex 4: Variation in soil fertility status**

**Table 1: Variation between agro-ecological zones and between plots within a farm**

<table>
<thead>
<tr>
<th>Agro-ecological zone</th>
<th>Status of soil fertility metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pH</td>
</tr>
<tr>
<td>Equatorial savanna</td>
<td>5.3</td>
</tr>
<tr>
<td>Guinea savanna</td>
<td>5.7</td>
</tr>
<tr>
<td>Sudan savanna</td>
<td>6.8</td>
</tr>
<tr>
<td><strong>Field within a farm</strong></td>
<td></td>
</tr>
<tr>
<td>Home garden</td>
<td>6.7-8.3</td>
</tr>
<tr>
<td>Village field</td>
<td>5.7-7.0</td>
</tr>
<tr>
<td>Bush field</td>
<td>5.7-6.2</td>
</tr>
</tbody>
</table>

Source: Sanginga and Woomer (2009)
Table 2: Variation in soil fertility status between contrasting fields of the same soil type (Nitisols, West Shewa, Ethiopia)

<table>
<thead>
<tr>
<th>Field type</th>
<th>pH</th>
<th>N (%)</th>
<th>P (ppm)</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>CEC meq/100g soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural field</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field near to home</td>
<td>5.50</td>
<td>0.24</td>
<td>17.93</td>
<td>2.20</td>
<td>12.76</td>
<td>2.63</td>
<td>29.80</td>
</tr>
<tr>
<td>Field far from home</td>
<td>4.60</td>
<td>0.16</td>
<td>8.40</td>
<td>1.41</td>
<td>8.95</td>
<td>1.76</td>
<td>19.51</td>
</tr>
</tbody>
</table>

Source: Getachew and Chilot (2007)

Annex 5: Fertilizer consumption by region and year

<table>
<thead>
<tr>
<th>Year</th>
<th>Quantities of fertilizer consumed by region (MT of DAP + Urea)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oromiya</td>
</tr>
<tr>
<td>2003</td>
<td>120,461</td>
</tr>
<tr>
<td>2004</td>
<td>146,823</td>
</tr>
<tr>
<td>2005</td>
<td>172,851</td>
</tr>
<tr>
<td>2006</td>
<td>170,575</td>
</tr>
<tr>
<td>2007</td>
<td>181,233</td>
</tr>
<tr>
<td>2008</td>
<td>171,801</td>
</tr>
<tr>
<td>2009</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>963,744</td>
</tr>
</tbody>
</table>

Source: Agricultural Inputs and Outputs Marketing Directorate (MoARD)
End Notes

i Dercon and Hill (1999); FAO

ii UN World Population Prospects

iii FAO Land Degradation Assessment, citing Young (1998)

iv SCRIP; Okigbo (1986)

v Zenebe (2007)

vi SCRIP

vii Vanlauwe et al. (2009)

viii World Bank PER (2008)

ix CIA (2009 est)

x Data from MoFED quoted in the Policy and Investment Framework (2010)

xi MoARD (as announced in March 2010); US Department of State (2010)

xii FAOstat (1998 to 2008)

xiii World Bank (2009)

xiv Expert interviews (2010)

xv Alemayehu (2008)

xvi Multiple expert interviews with senior researchers at EIAR gave this number as 34; other estimates range from 5 by USDA to 18 by Tesema (2006, citing MoA 2000) and 25 by T.A. Bull (1988)

xvii Dercon and Hill (2009); BMGF Irrigation Diagnostic

xviii Cereal production and yields: FAO; Population: UN World Population Prospects

xix Dercon and Hill (2009)

xx UN World Population Prospects

xxi Asnakew et al. (1991); Tekalign et al. (2001)

xxii Eyasu (2009, unpublished); Dercon and Hill (2009)

xxiii FAO

xxiv Heisey and Mwangi (1996)

xxv Vanlauwe et al. (2001)
xxvi FAO Land Degradation Assessment, citing Young (1998)

xxvii FAO (1998); Eyasu (2002); Amare et al. (2005)

xxviii Led by Professor Murphy

xxix Some parts of Amhara region are apparently using woreda-specific recommendations, but this is not typical

xxx FAO (1984)

xxxi SCRP; Okigbo (1986)

xxxii FAO Land Degradation Assessment, citing Young (1998)

xxxiii Zenebe (2007)

xxxiv Tilahun and Assefa (2009)

xxxv Chilot et al. (2002); Getachew and Taye (2005)

xxxvi Fox et al. (1979)

xxxvii Mesfin (1998)

xxxviii Desta Beyene (1983); AHI (1997)

xxxix Asgelil et al. (2007)

x SCRP; Okigbo (1986)

xi FAO Land Degradation Assessment, citing Young (1998)

xii Eyasu (2009, unpublished)

xiii MoARD (2007)

xiv EIAR

xv FAO (1984)

xvi Jutzi (1988)

xvii Fassil Kebede and Charles Yamoah (2009); Eyelachew et al. (2006)

xviii Bationo et al. (2006)

xlix Increased focus on compost preparation and use has been through large efforts from woreda OARDs and donors such as WFP and GTZ

i National Fertilizer Industry Agency; FAO

ii BMGF Pulses diagnostic

iii Edwards et al
liii Esser et al. (2002)
liv Bationo et al. (2004)
 lv Bationo et al. (2003)
 lvi Bojo and Cassels (2005)
lvii Zenebe (2007)
lviii IAEA (2001)
l ix SCRP
lx Spielman et al. (2009)
l xii Teklu and Gezehagn (2003); Pound and Ejigu (2005)
l xiii CSA (2007)
lxiv Eyasu (2009, unpublished); Spielman (2009)
l xv Sanginga and Woomer (2009)
l xvi Gruhn et al. (2000)
l xvii Amare et al. (2006); Singh and Pavan (2005); Pound and Ejigu (2005)
l xviii Simeon (2008)
l xix Mekonnen et al. (2008)
lxx Tenaw Workayehu et al. (2001)
l xxi Reddy and Kidane (1993)
l xii Getachew et al. (2006)
l xiii Vanlauwe et al. (2009)
l xiv Vanlauwe et al. (2009)
l xv As per Cooper et al. (1996)
l xvi Ethiopian Reporter, June 5 2010: “WFP, German bank sign accord to raise money for various initiatives”