Determinants of the Adoption of Sustainable Land Management Practices and Their Impacts in the Ethiopian Highlands
Acknowledgments

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Acronyms and Abbreviations

BoaA  Bureau of Agriculture
Br    Birr
C     Centigrade
CV    Coefficient of variation
d     Day
FFW   Food for work
ha    Hectare
HPC   High-potential cereals
HPP   High-potential perennial
km    Kilometer
LPC   Low-potential cereals
masl  Meters above sea level
mm    Millimeter
\INPV Marginal net present value
NPV   Net present value
REST  Relief Society of Tigray
SNNPR Southern Nations, Nationalities, and People’s Region
SWC   Soil and water conservation
t     Metric ton
TLU   Tropical livestock unit
VCR   Value–cost ratio
WFP   World Food Programme
Abstract

An extensive review of literature on the determinants of adoption and impacts of land management technologies in the Ethiopian highlands was undertaken to guide policy makers and development agencies in crafting programs and policies that can better and more effectively address land degradation in Ethiopia. Several generalizations emerge from the review:

- The profitability of land management technologies is a very important factor influencing technology adoption. In many cases it is a threshold consideration (necessary but not sufficient).
- Risk is also a very important consideration. Profitability is more critical for technologies that increase risk, such as inorganic fertilizer, than for technologies that reduce risk, such as soil and water conservation (SWC) investments in drought-stressed environments.
- Land tenure insecurity and limited transfer rights undermine land management investments.
- The impacts of credit on input use are positive where input use is profitable and not too risky; in other cases credit is not a binding constraint, because farmers ration their use of credit to avoid risk.
- The impacts of household endowments on technology adoption are mixed.
- Generally, better market and road access are associated with less SWC investment, probably because the opportunity costs of labor are higher.
- The adoption of SWC investments is undermined by high discount rates, which are generally higher for poorer households in the Ethiopian highlands.

Further research on the adoption and impacts of land management practices is needed to build on this understanding of what works, and where. Based on this review, as well as the findings from two companion papers and stakeholder workshops, it appears that research in different biophysical and socioeconomic domains to assess the off-site as well as on-site costs and benefits of alternative land management approaches would be particularly useful in supporting efforts to scale up successful sustainable land management practices in Ethiopia.
1.0 Objectives of This Review

This review synthesizes the knowledge gained from past studies of the adoption and economic impact of land management technology in the Ethiopian highlands. An improved understanding of the factors affecting adoption and of the economic impacts of adoption should guide policy makers and development agencies in crafting programs and policies that can better and more effectively address land degradation in Ethiopia.

Following the framework described by Blaikie and Brookfield (1987), this paper begins by reviewing knowledge related to the costs of land degradation. It describes the biophysical and socioeconomic features of the Ethiopian highlands and provides a detailed examination of the many factors that can influence the adoption of land management technologies in this context. The literature review, its companion papers, and information from two stakeholder workshops held in Addis Ababa in 2005 and 2006 yield a number of general conclusions on factors affecting efforts to address land degradation. These conclusions appear at the end of the paper, accompanied by a brief discussion of their implications for future research.

2.0 The Economic Costs of Land Degradation in Ethiopia and Past Responses

Land degradation is a major cause of Ethiopia’s low and declining agricultural productivity, continuing food insecurity, and rural poverty. Estimates of the magnitude and on-site costs of land degradation in Ethiopia vary substantially across the six major studies undertaken over the last two decades. Even so, all of the studies concur that soil erosion is a major problem with substantial costs to agriculture in the Ethiopian highlands, amounting annually to a minimum of 2–3 percent of agricultural gross domestic product.

Since the early 1980s, donors and the government have supported large efforts to promote soil conservation and environmental rehabilitation in Ethiopia. More recent soil conservation measures rely largely on food for work (FFW) programs as an incentive and emphasize such labor-intensive activities as terracing, building bunds, and planting trees. The growing consensus appears to be that many past soil conservation programs were disappointing for a number of reasons: they used a flawed “environmental narrative” to promote large-scale, top-down interventions; gave inadequate consideration to farmers’ perspectives, constraints, and local conditions; provided limited options to farmers; and in some contexts promoted options of very limited profitability (Bojø and Cassells 1995; Hoben 1995; Shiferaw and Holden 1999; Keeley and Scoones 2000; Dejene 2003; Rahmato 2003; Bekele 2004).

The downward spiral of land degradation and poverty cannot be reversed in a sustained fashion unless farmers adopt profitable and sustainable land management practices or pursue livelihood strategies that are less demanding of the land resource than current agricultural strategies. “One-size-fits-all” approaches will not solve land management problems in the heterogeneous environment of the Ethiopian highlands. A more nuanced strategy involves identifying which land management options work, and where; providing farmers with an array of potentially

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2 See the detailed review in “The Cost of Land Degradation in Ethiopia: A Review of Past Studies.”
effective options and combinations of options; identifying constraints to adopting appropriate options; and addressing those constraints through policies and investment programs.

3.0 Biophysical and Socioeconomic Features of the Ethiopian Highlands

The highlands3 extending across more than one-third of Ethiopia’s area (World Bank 2004) are divided by the Great Rift Valley, running from the southwest to northeast, and surrounded by lowlands on all sides. Nearly 85 percent of Ethiopia’s population, 95 percent of its cultivated land, and 80 percent its 35 million cattle are found in the highlands. The considerable diversity of Ethiopia’s highland areas means that many factors influencing the adoption of land management inputs and investments are highly sensitive to the local biophysical and socioeconomic context.

3.1 Biophysical characteristics

Table 1 summarizes the main biophysical characteristics of the Ethiopian highlands at the region level. All regions are distinguished by differences in elevation, climate, and degree of exposure to animal and livestock disease hazards. In the northern and eastern regions, annual average temperatures range from 20–22° Centigrade (C) in lower elevations (weyna-dega zones) to 10–12° C in higher elevations (dega zones). Rainfall patterns exhibit high temporal and spatial variability. Rainfall is generally lower in the eastern and northern highland areas than in the western and southwestern highlands; for example, annual rainfall ranges from about 500 millimeters in eastern Tigray to nearly 2,000 millimeters in western Oromiya. The coefficient of variation (CV) of annual rainfall is between 20 and 30 percent in most places, with a tendency to be lower in the higher-rainfall western and southwestern areas than in the lower-rainfall north and east. Not surprisingly, the length of the growing period also varies from the northeast to southwest, from less than three months in parts of Tigray to more than six month in high-rainfall areas of western Oromiya and Southern Nations, Nationalities, and People’s Region (SNNPR) (Tefera et al. 2002).

<table>
<thead>
<tr>
<th>Region</th>
<th>Area (km²)</th>
<th>Elevation (masl)</th>
<th>Agroecological zone</th>
<th>Mean rainfall (mm)</th>
<th>Rainfall CV(%)</th>
<th>Length of growing period (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tigray</td>
<td>56,435</td>
<td>1,548</td>
<td>WD</td>
<td>778.5</td>
<td>26.0</td>
<td>109</td>
</tr>
<tr>
<td>Amhara</td>
<td>150,374</td>
<td>1,888</td>
<td>WD</td>
<td>1,162.5</td>
<td>23.4</td>
<td>160</td>
</tr>
<tr>
<td>Oromiya</td>
<td>310,483</td>
<td>1,532</td>
<td>WD</td>
<td>1,288.0</td>
<td>24.7</td>
<td>152</td>
</tr>
<tr>
<td>SNNPR</td>
<td>115,818</td>
<td>1,422</td>
<td>UK</td>
<td>1,357.0</td>
<td>24.7</td>
<td>187</td>
</tr>
</tbody>
</table>

Source: Extracted and adapted from World Bank 2004, Country Economic Memorandum database. a WD= Weyna-dega and dega (1,500–3,200 masl); UK=Upper Kolla (500–1,500 masl).

Highland soils are diverse, and their distribution is influenced greatly by physiographic and geological conditions. The shallow, stony soils of the mountainous areas differ greatly from the deep soils of the gently rolling hills, with their dark-red to brown color. Black, clayey soils are common in depressions and plains and alluvial soils are found in the foothills (Desta et al. 2001; Tefera et al. 2002). Soils are generally much deeper and more fertile in the western and southwestern high-potential cereals (HPC) and high-potential perennial (HPP) zones; they are more highly eroded and of lower fertility in the northern and eastern low-potential cereals (LPC) zones (Hurni 1988; Braun et al. 1997). Soil erosion is more severe in LPC than in HPC or HPP zones because of the rugged terrain, intensive use of plowing, and limited vegetative cover (see Hurni 1988; Hagos, Pender, and Gebreselassie 1999; Desta et al. 2001). Soil nutrient depletion is

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3Highlands are defined as areas that are 1,500 meters above sea level.
more critical in HPC than in LPC zone (see Sutcliffe 1993; Hagos, Pender, and Gebreselassie 1999; Desta et al. 2001; World Bank 2004). Even though the HPC zone has less erosion and farmers use more fertilizer, higher yields and sales of crop products in this zone lead to greater outflows of soil nutrients.

### 3.2 Socioeconomic characteristics

Table 2 summarizes the main socioeconomic characteristics of the Ethiopian highlands. Total population was about 22 million in 2003, with generally higher densities in the higher-rainfall zones, especially in southern SNNPR (World Bank 2004). The average population density ranges from 30 people per square kilometer in western Tigray to more than 500 people per square kilometer in some areas of SNNPR. The holding of an average rural household can range from 0.3 hectares in the densely populated areas of SNNPR to slightly more than 1.0 hectare in the less densely populated parts of Oromiya and Amhara. Average livestock holdings generally also vary inversely with population density and rainfall, from as little as 0.2 tropical livestock units (TLU) per household in some areas of SNNPR to 1.3 TLU per household in western Tigray.\(^4\)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Region</th>
<th>Tigray</th>
<th>Amhara</th>
<th>Oromiya</th>
<th>SNNPR</th>
<th>National</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (000s)</td>
<td></td>
<td>4,006</td>
<td>17,669</td>
<td>24,395</td>
<td>13,686</td>
<td>69,127</td>
</tr>
<tr>
<td>Population density (persons/000 km(^2))</td>
<td></td>
<td>71.0</td>
<td>117.5</td>
<td>78.6</td>
<td>118.2</td>
<td>61.5</td>
</tr>
<tr>
<td>Road density (km/000 km(^2))</td>
<td></td>
<td>44.0</td>
<td>46.0</td>
<td>30.1</td>
<td>50.6</td>
<td>30.9</td>
</tr>
<tr>
<td>Average rural household landholding (ha)</td>
<td></td>
<td>0.8</td>
<td>1.0</td>
<td>1.0</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Average livestock holding (TLU/household)</td>
<td></td>
<td>0.9</td>
<td>0.7</td>
<td>0.8</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Percentage population employed off of the farm</td>
<td></td>
<td>26</td>
<td>15</td>
<td>17</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Gross primary school enrolment (%)</td>
<td></td>
<td>70</td>
<td>57</td>
<td>65</td>
<td>69</td>
<td>62</td>
</tr>
<tr>
<td>Per capita biofuel consumption (t/capita)</td>
<td></td>
<td>0.71</td>
<td>1.18</td>
<td>0.80</td>
<td>0.98</td>
<td>0.87</td>
</tr>
</tbody>
</table>


Agriculture in the highlands is dominated by rainfed, mixed crop–livestock farming. In lower- and medium-rainfall areas, cereals and cattle dominate the farming system (Hagos, Pender, and Gebreselassie 1999; Desta et al. 2001). In high-rainfall areas, perennial crops such as coffee, enset ("false banana"), and chat are important in the farming system, as well as various annuals and livestock (Tefera et al. 2002). The wide variety of field crops planted in the highlands includes several cereals (teff, sorghum, maize, barley, wheat, millet, and oats) and legumes (horsebeans, faba beans, haricot beans, field peas, chickpeas, lentils, and others). Root crops such as taro, yams, and sweet potatoes are also common in higher-rainfall areas (Tefera et al. 2002). The vast majority of farms are small-scale, subsistence operations that usually occupy less than one hectare. Productivity is generally low, linked to fluctuations in rainfall.

Farmers make little use of inorganic fertilizer, especially in lower-rainfall areas. On average, only 27 percent of cropland in Amhara and 35 percent of cropland in Tigray received chemical fertilizer in 2003, compared to cropland in Oromiya (45 percent of cropland) and SNNPR (47 percent of cropland), where rainfall is higher (table 2). Woody biomass, cow dung, and crop residues account for nearly 99 percent of the energy for household cooking and heating in Tigray and Amhara (Hagos, Pender, and Gebreselassie 1999; Desta et al. 2001). Per capita biofuel consumption is generally higher in higher-rainfall zones (table 2), probably because biomass is more scarce in LPC zones.

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\(^4\) One TLU is equivalent to a 250-kilogram animal in terms of feed requirements.
4.0 Factors Affecting Technology Adoption in the Ethiopian Highlands

This section describes the most common underlying factors affecting the adoption of land management technology in the Ethiopian highlands.

4.1 Land tenure

The effects of land tenure on the adoption of land management practices are related mainly to the transferability of property rights, which in turn affects the reversibility of land investments and the ability to use land as collateral. The current land policy in Ethiopia is based on the notion that land is both a factor of production, contributing to growth, and an essential element in providing for the welfare of the population. Under the 1994 constitution, land is state property and farmers have use rights over the plots they farm. Land cannot be sold, exchanged, or mortgaged, although short-term leasing or sharecropping is allowed. Land is heritable, but with conditions in some regions. Private property on land is prohibited in all regions. Land is transferred through periodic redistributions, with each person reaching the age of 18 being entitled to land in their kebele.

Secure and easily transferable land tenure rights are a key element in promoting long-term investment and facilitating the reallocation of production factors in ways that maximize efficiency in their use. Tenure security is also centrally important to the development of an off-farm economy. Unfortunately, the current land tenure system in Ethiopia has led to widespread tenure insecurity among farmers. In 2001, for example, a national survey on perceived land rights and tenure preferences (Deininger et al. 2003b) found that only 27 percent of farmers were confident that land would not be redistributed in the future, and 9 percent expected redistribution in the next five years. Another survey found that about 7 percent of households in 1999 had lost land during redistribution in the preceding five years (UAA/Oxford data) and that 11 percent of households expected to lose land in the next five years owing to land reform.

Based on nationally representative survey data, Deininger et al. (2003b) found that the impact of tenure insecurity on adoption of land management technologies varied across types of investments, encouraging the planting of trees (any type) but strongly discouraging investment in terraces. They also found that transfer rights and more secure tenure for the future significantly increased investment incentives for planting trees and building terraces. Gebremedhin and Swinton (2003) suggested that farmers’ perceived land tenure security in Tigray was significantly and positively associated with long-term durable soil conservation investments such as stone terraces. Gebremedhin, Pender, and Ehui (2003) argued from village-level data that perceived tenure security increased land investments.

Studies focusing on longer-term investments have not established negative effects of tenure insecurity on adoption of land management technologies. Holden and Yohannes (2002) investigated the planting of perennial crops in southern Ethiopia and found tenure insecurity had little effect on farmers’ decisions. Instead they identified resource poverty as the main factor leading to underinvestment in tree crops.

Ayalew, Dercon, and Gautam (2005) noted that farmers’ lack of tenure security has given them insufficient incentives for sustainable land husbandry on their individual fields. Their research showed that higher tenure security would increase investment and agricultural growth. They recommended that the government significantly strengthen land tenure by: (1) allowing rights on a continuous basis for a long enough period to provide incentives for long-term investment, (2)
removing the uncertainty of tenure by assuring the holder that rights will not be arbitrarily taken away, and (3) providing the holder freedom to use, dispose, or transfer the asset without interference from others, with support from the courts.

4.2 Agricultural extension and credit programs

In the Ethiopian highlands, agricultural extension has strongly promoted increased use of external inputs such as fertilizer and improved seed and has provided credit to obtain these inputs. Credit is provided in kind and must be repaid immediately after harvest; failure to pay often brings harsh punishment, including expropriation of oxen and other property and imprisonment (Amare et al. 2000). Because of frequent crop failures, farmers in low-rainfall areas often avoid agricultural credit. For these farm households, the supply of credit \textit{per se} is not a binding constraint. Instead, risk is the crucial factor in deciding whether to take credit. For example, Amare et al. (2000) documented the high incidence of credit risk in low-potential and drought-prone zones of Amhara, mainly in South Wollo and Oromiya. Similarly, Boetekees (2002) noted that rural households in a highly drought-prone area of eastern Tigray were reluctant to take credit because the chances of crop failure and subsequent indebtedness were high.

Access to formal credit arrangements is associated with greater use of fertilizer and other purchased inputs such as improved seed, but it has more limited impacts on other land management practices. Using data from a nationally representative household survey, Croppenstedt, Demeke, and Meschi (2003) found that greater access to credit substantially increased households' likelihood of using fertilizer. Pender and Gebremedhin (2004) found positive associations between the use of formal credit arrangements and fertilizer use in Tigray, but they found insignificant associations between credit and most other land management investments and practices.

Using results from community surveys in Tigray and Amhara, Pender et al. (2001) found that the impact of credit on land management depended on the source and terms of credit and type of technology promoted. Credit obtained from the Bureau of Agriculture (BoA) was negatively associated with the use of fallow, manure, and compost but positively associated with tree planting. Credit from the Relief Society of Tigray (REST) was associated with greater use of compost, soil bunds, tree planting, and live fences, whereas credit from the Amhara Credit and Saving Institution was associated less with using fallow and planting trees and more with investment in soil bunds and live fences. These relationships probably reflect the types of technical assistance associated with the credit, at least in the case of BoA and REST, which provided technical assistance.

Bioeconomic models have been used to analyze the potential impacts of credit on land management under alternative scenarios and evaluate factors conditioning these impacts. Using a bioeconomic modeling approach, Holden and Shiferaw (2004) predicted that the availability of credit for fertilizer would significantly increase the adoption of chemical fertilizer in eastern Amhara. The same model predicted that fertilizer credit would lead to tradeoffs in terms of land management: by reducing investment in soil and water conservation, the use of chemical fertilizer would contribute to increased erosion. In earlier work, Shiferaw and Holden (1998) showed that the effect of fertilizer credit on the adoption of long-term conservation structures would depend on the productivity effects of the technologies and on farmers' individual discount rates. When the conservation technology reduced or did not affect yield, the availability of more fertilizer credit caused fertilizer to be substituted for soil conservation (consequently discouraging soil conservation), unless the discount rate was less than 5 percent. When conservation technology increased yield, however, the increased availability of fertilizer credit encouraged the adoption of
soil conservation practices. In the presence of credit constraints, an increase in the fertilizer price would lead farmers to grow crops that did not need much fertilizer, such as legumes, and spend more time on off-farm activities and less time on soil conservation.

The impacts of agricultural extension also appear to be context-dependent. In their national sample, Deininger et al. (2003a) found that access to agricultural extension (within the woreda) was positively associated with farmers’ investments in planting trees and especially in constructing terraces. In Tigray, Pender, Gebremedhin, and Haile (2003) and Pender and Gebremedhin (2004) found that contact with agricultural extension agents had statistically insignificant impacts on farmers’ land investments, annual land management practices, and use of inputs. It is not clear why the impacts of extension were generally insignificant in Tigray but significant in the national sample. Perhaps the impacts of extension are greater in higher-potential areas such as southern and southwestern Ethiopia.

4.3 Household endowments of physical and human capital

If markets for productive factors such as land and labor are imperfect, then the standard perfect market decision criteria (that is, profit maximization) for technology adoption will be violated, and the decision to adopt technologies will also depend on each household’s endowment of productive factors. For example, if hired labor is costly to monitor, households with a greater endowment of labor might find it cheaper to use their own labor to adopt labor-intensive land management technologies such as stone terraces and manuring, provided that no competitive off-farm employment opportunities increase the opportunity cost of labor. Similarly, farmers who have better access to land or other physical or financial assets may be more able to finance purchases of inputs such as fertilizer and seed through their savings or better access to credit. Households with more land can better afford to adopt structures that take up productive space. Households with more livestock may be more able to use manure on their fields. Households with more education or other forms of human capital may have greater access to nonfarm income and thus purchase inputs more easily. They may also be more aware of the benefits of modern technologies and more efficient in their farming practices. On the other hand, more-educated households may be less likely to invest in labor-intensive land investments and management practices, because they may be able to earn higher returns to their labor and capital in other activities.

In the northern Ethiopian highlands, labor availability—when measured as the number of adult male or female household members—is positively linked to the adoption of short- and long-term land management technologies. This is particularly true in areas where nonfarm or off-farm opportunities are limited, such as areas with poor market access. In Tigray, Hagos (2003) identified a positive association between adult labor availability and chemical fertilizer use, whereas Gebremedhin and Swinton (2003) and Alemu (1999) reported a positive association between labor availability and investment in stone terraces. Using similar measurements of labor availability and using nationally representative sample survey data, Croppenstedt, Demeke, and Meschi (2003) found a positive and significant relationship between labor availability and fertilizer adoption, while Deininger et al. (2003b) found a strong positive relationship between labor availability and investment in terraces and trees.

The evidence is mixed, however, when family size is used to measure labor availability. Some researchers found no relationship between family size (as a proxy for labor supply) and fertilizer adoption (Holden and Yohannes 2002; Pender and Gebremedhin 2004; Yesuf 2004), and others encountered no significant link between family size and long- and medium-term land management technologies (Demeke 2003; Pender, Gebremedhin, and Haile 2003; Teklewold
Theoretically, the relationship between farm size and technology adoption (or agricultural intensification) can be positive or negative. On the one hand, larger farm size increases farmers’ liquidity or access to credit and reduces risk aversion, so households with bigger farms are more likely to adopt technology than those with smaller farms. On the other hand, if labor and land markets do not function properly, households with smaller farms are more likely to intensify production, and an inverse relationship between farm size and technology adoption may be observed.

Evidence on how farm size affects the adoption of short-term land management technologies (such as chemical fertilizer) is mixed. A positive relationship was found between farm size and fertilizer adoption in South Wollo and East Gojjam in Amhara (Yesuf 2004) and in southern Ethiopia (Holden and Yohannes 2002). A negative relationship was found in Tigray (Hagos 2003; Pender and Gebremedhin 2004) and at the national level (Croppenstedt, Demeke, and Meschi 2003). Based on a survey of 98 woredas in the Ethiopian highlands, Mulat, Ali, and Jayne (1998) did not find a significant relationship between farm size and fertilizer adoption.

The impact of farm size on the adoption of medium- and long-term land management technologies depends on the technologies being promoted. Physical structures such as stone terraces, soil bunds, fanya juu terraces, trees, and vegetative practices take agricultural space which otherwise could have been used to grow crops, so their adoption is likely to depend on farm size. On the other hand, many land management practices such as making compost, manuring, incorporating crop residues, and contour plowing do not require more space, so farm size might not be an important decision factor.

A positive relationship between land size and investment in physical SWC structures, such as stone and soil bunds, is documented in studies in Tigray (Alemu 1999; Hagos 2003) and Amhara (Shiferaw and Holden 1998; Demeke 2003; Yesuf 2004; Teklewold 2004; Kassie and Holden 2005). On the other hand, Pender, Gebremedhin, and Haile (2003) found the association between farm size and investment in stone terraces to be insignificant in the highlands of Tigray. They found a significant positive relationship between farm size and use of reduced tillage and a negative relationship between farm size and use of contour plowing or intercropping, but no significant relationship between farm size and use of manure, compost, or burning. Deininger et al. (2003a) found a negative relationship between farm size and tree planting. Bioeconomic model predictions are consistent with some of these empirical findings. Using data from a community in the North Shewa zone of Amhara, Shiferaw and Holden (2003) showed how the incentive for physical SWC drastically decreased when the new technology increased land scarcity and reduced crop yields in the short run. On the other hand, when the land–labor ratio was large, households were unlikely to carry out labor-intensive investments in soil and water conservation.

The ownership of livestock, which are a very important component of wealth in the Ethiopian highlands, is also positively related to adoption of some land management technologies. In addition to contributing to households’ general wealth and liquidity, livestock serve as a source of draft power, manure, and transportation, thus directly affecting farmers’ land management options. The effect of livestock ownership on fertilizer adoption is positive in Tigray (Hagos 2003; Pender and Gebremedhin 2004) and in a national sample (Croppenstedt, Demeke, and Meschi 2003). The impact on other land management practices depends on the type of practice.
Pender and Gebremedhin (2004) found positive relationships between livestock ownership and use of manure/compost and contour plowing and a negative relationship with reduced tillage. Holden and Yohannes (2002) found a positive association between livestock ownership and planting of perennial crops.

Households with better education are expected to be more aware of new technologies and thus more likely to adopt them. However, more-educated households may be less prone to adopt labor-intensive technologies if they have higher labor opportunity costs as a result of better opportunities off of the farm. A positive relationship between education and fertilizer adoption is observed in many studies in the Ethiopian highlands (for example, Mulat, Ali, and Jayne 1998; Holden and Yohannes 2002; Croppenstedt, Demeke, and Meschi 2003). However, Pender and Gebremedhin (2004) found a negative association between primary education level of the household head and fertilizer adoption in Tigray, although they found that education is associated with a greater likelihood of using improved seed. The impacts of education on other land management practices are mixed, but with education generally favoring land investments and improved land management practices. Deininger et al. (2003a) found a significant positive association between the maximum education of household members and investment in terraces and tree planting. Pender, Gebremedhin, and Haile (2003) found that primary education of the household head was associated with more investment in stone terraces. Ersado, Amacher, and Alwang (2003), in a study of sequential adoption of technologies in Tigray, found that education contributed to the simultaneous adoption of productivity-enhancing and soil-conserving technologies so as to benefit from their complementarities in drought-stressed areas.

Gender is another human capital variable that influences the adoption of land management technologies. Pender and Gebremedhin (2004) found that male-headed households in Tigray were more likely to use contour plowing and manure on their plots than female-headed households. This finding likely reflects a cultural taboo against women plowing in Ethiopia (Bauer 1977; Abay et al. 2001). Holden and Yohannes (2002) found that in southern Ethiopia male-headed households used more purchased farm inputs than female-headed households. By contrast, Mulat, Ali, and Jayne (1998) found that male-headed households in the northern Ethiopian highlands were less likely to use fertilizer than female-headed households.

4.4 Access to markets, roads, and off-farm opportunities

The theoretical impacts of market and road access on land management technology adoption are ambiguous. Better access can increase labor and/or capital intensity by increasing output to input price ratios (Binswanger and McIntire 1987). Thus better access may promote adoption of fertilizer as well as SWC technologies. This relationship may be particularly true in high-potential areas, where returns from farming are higher. However, better access may also increase nonfarm opportunities, thus reducing the intensity of crop production and soil and water conservation. This may be particularly true in low-potential areas.

The impacts of market access on the adoption of land management technology in the Ethiopian highlands are generally mixed. Hagos (2003) in Tigray and Yesuf (2004) in eastern Amhara showed that households that were more distant from the market were more likely to adopt labor-intensive SWC structures than households closer to markets and all-weather roads. Pender, Gebremedhin, and Haile (2003) similarly found that households farther from a seasonal road in Tigray were more likely to invest in stone terraces but that those farther from bus services were less likely to make such investments. Pender and Gebremedhin (2004) found that fertilizer was more likely to be used closer to an all-weather road or a seasonal road and, surprisingly, farther from a woreda town. They also found that burning and contour plowing were more common.
close to an all-weather road, that use of reduced tillage and manure or compost were more common close to a seasonal road, but that contour plowing was more common farther from a woreda town, and the use of manure/compost was more common farther from an input supply shop (suggesting substitution of inorganic fertilizer for manure). Using community-level data from Tigray and Amhara, Pender et al. (2001) found that declining use of fallow between 1991 and 1998/99 and increasing use of compost were more common closer to towns, suggesting that market access was promoting intensification. On the other hand, increased use of fertilizer and investments in soil bunds were less common in communities where road access had improved.

As with the effects of market access and education, the impacts of off-farm opportunities on land management are theoretically ambiguous. Off-farm income may enable households to finance input purchases or land investments, but such opportunities may also undermine on-farm activities, especially labor-intensive activities. In Tigray and Amhara, Pender et al. (2001) found that increased adoption of fertilizer was less common in communities where off-farm income was an important component of people's livelihoods, while investment in soil bunds was greater in such communities. Similarly, in Tigray Pender, Gebremedhin, and Haile (2003) found that households regarding cereals as a secondary income source (many of these households earned their primary incomes off of the farm) were more likely to invest in stone terraces. Pender and Gebremedhin (2004) found that such households (as well as those for whom trading was a secondary source of income) were more likely to use reduced tillage, possibly because of labor and/or oxen constraints. Households involved in farm employment off their own farms were less likely to use contour plowing, also possibly because of such constraints, and somewhat less likely to use fertilizer, possibly due to liquidity constraints. Several smaller studies conducted in Tigray and low-potential zones of Amhara consistently showed a negative relationship between off-farm opportunities and the adoption of SWC technology (Alemu 1999; Ersado, Amacher, and Alwang 2003; Shiferaw and Holden 1998). However, one study from a high-potential area of Amhara showed a positive relationship (Teklewold 2003), emphasizing that the relationships between off-farm activities and land management depend on the particular context.

### 4.5 Presence of public projects and institutional support

The impacts of public projects such as FFW programs on private land management incentives are very much contested in the literature. Proponents of these programs argue that they promote (or "crowd-in") private land management efforts, not only through the direct benefits derived from financial gains, which relieve financial constraints, but also from the additional technical skills acquired through "learning by-doing." Critics argue that FFW programs will have a "crowding-out" effect by increasing the competition for household labor.

The empirical evidence in Ethiopia so far is mixed. Gebremedhin and Swinton (2003) found evidence supporting the crowding-out effect of FFW projects on private incentives to adopt SWC in Tigray. On the other hand, FFW programs as a secondary source of household income had an insignificant effect on households' investment in stone terraces in Tigray (Pender, Gebremedhin, and Haile 2003). Kinfe (2002) and Hagos (2003) showed the crowding-in effects of public project support (such as FFW) on private investment in SWC in Tigray. Pender and Gebremedhin (2004) found that FFW income was associated with less use of labor and oxen for draft power, less use of burning or manure/compost, but greater use of improved seed, suggesting that increased use of seed (perhaps because FFW programs made it available) substituted for labor-intensive inputs in this case. Using bioeconomic modeling, Holden, Shiferaw, and Pender (2004) made some qualifications to the two contradictory outcomes in Tigray. In their simulation, they showed that public projects could promote private investment in SWC if they were applied within agriculture
in the form of SWC investments. But if they were applied outside agriculture (such as for road construction), they crowded out private investment in soil and water conservation.

4.6 Population pressure

Holding other factors constant, population pressure (higher population density) is expected to cause higher labor intensity in agriculture by increasing the availability and thus reducing the costs of labor relative to land (Boserup 1965). Few studies assess the impacts of population pressure on land management technology adoption in the Ethiopian highlands. Using community-level data from Tigray and Amhara, Pender et al. (2001) found that greater population growth was associated with declines in fallowing and use of manure. Declining use of manure possibly results from fuel constraints that occur when population growth and deforestation cause households to burn more dung for fuel. Using community-, household-, and plot-level data in Tigray, Pender and Gebremedhin (2004) found that higher population density was associated with several measures of intensification, including intensive use of labor and oxen per hectare, greater use of fertilizer, manure/compost, and intercropping.

4.7 Profitability, risk, and discount rates

Expected profitability is often the minimum threshold requirement for adoption of farm technologies (except those that significantly reduce risk). Mulat, Ali, and Jayne (1998) argued that agricultural reform programs over the last decade in Ethiopia showed little success because the value–cost ratio (VCR) of fertilizer fell below the threshold value of two for many crops. Using data from eastern Amhara, Yesuf (2004) found a negative relationship between risk aversion and fertilizer adoption. Hagos (2003), on the other hand, showed a positive correlation between risk aversion and fertilizer adoption in Tigray. These mixed results regarding the role of risk warrant further investigation elsewhere in Ethiopia.

On SWC investments, Teklewold (2004) showed a positive and strong link between risk aversion and SWC in northern Shewa. He also found a negative relationship between subjective discount rates and SWC investments. Yesuf (2004) and Shiferaw and Holden (1998) also found a negative relationship between subjective discount rates and SWC adoption decisions in eastern Gojjam, southern Wollo, and north Shewa (all in Amhara region). These results are consistent with bioeconomic modeling, which showed that high discount rates created disincentives to soil conservation adoption (see Shiferaw and Holden 2000; Shiferaw and Holden 2001; Bekele 2004). Holden and Shiferaw (2002) also showed that farmers' willingness to pay for soil conservation declined with increasing discount rates.

5.0 Decision Rules for Land Management Technology Adoption and Use Intensity

Depending on the nature of the land management technology, optimal decision rules for adoption and intensity of technology use can be described for static and dynamic frameworks. Some land management technologies (inorganic fertilizer, for example) can be viewed as annual inputs into agricultural production. Adoption decisions for such inputs can be modeled in a static framework. However, many land management technologies, including SWC structures, have an investment element in which the flow of investment in any given period contributes to the stock of investment existing at any given time. Dynamic models are the natural candidates to explain decisions to adopt such technologies. Additionally, decision rules for technology adoption are different in perfect and imperfect markets.
In a static framework and perfect market case, farmers' optimal decisions in a given period are derived from the maximization of expected utility (or expected profit). In this case, only factors affecting the prices of inputs (including labor), outputs, input requirements, and the productivity impacts of the input will affect expected profitability and hence adoption decisions. It is optimal for farmers to use the technology up to the point where the marginal return equals marginal cost of the input (in other words, the use of the input is optimum where the marginal VCR equals one). If the VCR is greater than one, farmers have an incentive to increase the use of the technology until VCR equals one, beyond which it is no longer attractive to do so, since the costs of additional inputs would exceed their return. Real-world markets are less than perfect (especially in developing countries) for many reasons, including information asymmetry, prohibitive transaction costs, or government intervention and lack of capital (de Janvry et al. 1991). In this case, other factors affecting the market and institutional environment and farm-level constraints can influence adoption/investment decisions, such as property rights and land tenure relationships, as well as household endowments of labor, land, physical capital, financial capital, and social capital. In imperfect market situations, generally farmers require a higher marginal return-cost ratio (a VCR greater than one) in order to adopt the new farm technology.

6.0 Productivity and Economic Impacts of Land Management Technologies

Studies assessing the productivity and economic impacts of land management practices used in the Ethiopian highlands are quite limited. However, most of them consistently show that short-run returns from physical SWC structures are positive in drought-stressed areas and negative in higher-rainfall areas, whereas returns from fertilizer use are greater in high-rainfall areas than in drought-stressed areas of Tigray (Herweg 1993; Gebremedhin, Swinton, and Tilahun 1998; Holden et al. 2001; Shiferaw and Holden 2001; Bekele 2003; Benin 2004; Holden and Shiferaw 2004; Pender and Gebremedhin 2004; Kassie and Holden 2005).

Based on an experimental study in central Tigray, Gebremedhin, Swinton, and Tilahun (1998) estimated that the internal rate of return to investments in stone terraces averaged about 50 percent. Pender and Gebremedhin (2004) estimated a lower but still relatively favorable rate of return (34 percent) for stone terraces based on an econometric analysis of data from the highlands of Tigray. Other land management practices also showed significant impacts in Tigray, including the use of contour plowing (25 percent higher productivity, controlling for use of labor, inputs, and other factors), reduced tillage (57 percent higher productivity), and manure/compost (15 percent higher productivity) (Pender and Gebremedhin 2004). The positive and significant impact of reduced tillage is consistent with the findings of Aune, Asrat, and Tulema (2003) based on

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5 The marginal VCR measures the incremental increase in production value resulting from an additional unit of an input, divided by the incremental cost of that unit. A VCR greater than one implies that the economic value of increasing use of the input is greater than the cost—in other words, using the input is profitable. A more precise mathematical definition of this concept is given below.

6 Unlike ordinary annual production inputs, such as inorganic fertilizer, most land management technologies involve some element of investment (examples include composting or creating soil and water conservation structures and vegetative barriers, such as terraces, bunds, or grass strips). Under a perfectly competitive market structure, the optimal private investment rule for such technologies is to invest as long as the marginal net present value (NPV) is positive (Nickell 1978)—that is, up to the point where the marginal net present value (MNPV) of benefits equals the MNPV of costs of the investment, with future costs and benefits discounted at the market rate of interest. This is completely analogous to the VCR=1 rule for the static model. In the case of discrete investments, the optimal rule is to invest in all projects for which the NPV is positive (Nickell 1978).
experiments in various locations of the highlands and may be attributed to the conservation of scarce soil moisture, organic matter, and nutrients resulting from reduced tillage.

Pender and Gebremedhin (2004) found that the impact of inorganic fertilizer was statistically insignificant, and the value of its estimated average productivity impact—240 Birr (Br) per hectare—was insufficient to cover the average fertilizer cost (Br 280 per hectare), indicating the lack of average profitability of fertilizer use in Tigray. The variation of productivity impacts of fertilizer was also fairly large (CV greater than 0.5), indicating the risk of the impacts.

Similar patterns of returns to fertilizer and physical conservation structures are also found in medium-rainfall and drought-prone areas of eastern Amhara (Benin 2004). Benin found that the impact of inorganic fertilizer was positive but statistically insignificant in drought-prone areas of Amhara, while stone terraces increased productivity by 20 percent on average. Using a bioeconomic model for a site in north Shewa, eastern Amhara, Holden and Shiferaw (2004) predicted a significant impact of access to fertilizer and credit on crop production and income, with unconstrained access to credit for fertilizer predicted to increase income by up to 20 percent per year. However, they found that the impacts of fertilizer credit on income were much lower when the risk of drought was higher, supporting Benin’s (2004) findings that returns to fertilizer were lower in areas more prone to drought.

In contrast to findings in Tigray and drought-prone areas of eastern Amhara, Benin (2004) found that short-run returns to physical structures and other low external input land management practices were statistically insignificant in more reliable rainfall areas of Amhara region. On the other hand, returns to fertilizer were much higher in high-rainfall/high-potential areas of western Amhara. Benin estimated crop productivity to be 70 percent higher on plots using chemical fertilizers in high-rainfall areas of Amhara. Holden, Shiferaw, and Pender (2001) also found statistically insignificant impact of SWC structures on short-run agricultural productivity in a site in north Shewa, eastern Amhara, which is characterized by medium rainfall. Based on both parametric and nonparametric approaches and data from a site in high-rainfall areas of west Gojjam (west Amhara), Kassie and Holden (2005) found the mean yield for plots with *fanya juu* terraces to be lower than the mean yield for plots without them, probably reflecting the cropping area they displaced.

Using experimental data from Anjeni (western Amhara) and Andit Tid (eastern Amhara), Shiferaw and Holden (2001) found that the profitability of most types of investment in conservation structures (level bunds, graded bunds, *fanya juu*, and grass strips) was generally low, with internal rates of return under 10 percent. An exception was the use of grass strips in Anjeni. Although the strips reduced crop area by 10 percent, the practice yielded a positive NPV in teff production even at a 50 percent discount rate. Returns were even higher if the loss of area could be offset by use of the grass or other vegetation planted on the grass strips. This result supports the hypothesis of greater potential for vegetative SWC approaches in higher-rainfall areas. Despite the seemingly high payoffs for grass strips, low investments in grass strips in Anjeni may point to other constraints, which may include the seasonally uncontrolled grazing system, poor extension services, and insecurity of land tenure (Shiferaw and Holden 2001). Based on their findings, Shiferaw and Holden (2001) argue that the benefits to investments in physical conservation methods are low either on deep soils where current crop yields are high and immediate costs of soil erosion are low (as in barley production in Andit Tid) or on shallow soils where crop yields are already very low (as in barley production in Anjeni). They argue that conservation benefits are higher on highly degrading soils which have not yet reached the point of depletion (as in teff production in Anjeni). This argument suggests that soil conservation efforts should be targeted to areas with rapidly degrading but still productive soils. On shallow soils,
Barbier (1990) suggested that the success of soil conservation depends on the opportunity it offers to switch to high-value and less-erosive crops. In Ethiopia, the opportunity to switch to high-value but less-erosive crops such as eucalyptus trees, coffee, and chat may be inhibited by lack of tenure security, limits on transferability of use rights (Ayalew, Dercon, and Gautam 2005), and lack of market access (Holden et al. 2003).

Results of a recent evaluation of SWC projects supported by the World Food Programme (WFP) in Tigray, Amhara, Oromiya, SNNPR, and Dire Dawa are consistent with many of the findings discussed above (WFP 2005). The analysis estimated that farm-level financial profitability of physical SWC structures was generally higher in dry areas than in moist areas, as a result of the near-term impact of soil moisture retention on crop yields in drier areas. The estimated financial rates of return ranged from 10 percent in some of the moist areas to over 30 percent in drier areas. Economic profitability of the projects was generally lower than financial profitability: economic rates of return for projects were in the range of 11–18 percent, including forestry as well as SWC activities. The estimated economic returns to forestry activities were generally low, though variations in returns to forestry activities were found to offset variations in returns to SWC investments, since forestry practices were more profitable in more humid areas, while SWC structures were more profitable in drier areas.

These estimates did not account for off-site benefits (or costs) of SWC and forestry measures, such as increased recharge of aquifers, reduced formation of gullies, reduced sediment loads in downstream irrigation dams, reduced flooding, increased biodiversity, and carbon sequestration. Community members interviewed for the WFP study reported that the conservation and forestry measures had substantial positive impacts on many of these off-site considerations (WFP 2005). For example, several communities reported substantially higher groundwater levels in downstream wells after the measures were implemented, compared to continued depletion in untreated watersheds. Communities also perceived reduced flooding and erosion hazards downstream. There were also indications of significant benefits to biodiversity (which increased, especially in area enclosures) and carbon sequestration resulting from the forestry measures.

### 7.0 Conclusions

This review of literature on the determinants of adoption and impacts of short-, medium-, and long-term land management technologies in the Ethiopian highlands suggests several general conclusions.

- The profitability of land management technologies is a very important, though certainly not the only, factor influencing technology adoption. In many cases, profitability is a threshold consideration (necessary but not sufficient) for adoption; other considerations become less relevant without sufficient profitability.
- Risk is also a very important consideration. Profitability is more critical for technologies that increase risk, such as inorganic fertilizer, than for technologies that reduce risk, such as SWC investments in drought-stressed environments.
- Land tenure insecurity and limited transfer rights undermine land management investments.
- The impacts of credit availability on input use are positive where input use is profitable and not too risky; in other cases, credit is not a binding constraint, as farmers ration their use of credit to avoid risk. The impacts of access to credit on other land management practices are less clear.
- The impacts of household endowments on technology adoption are mixed. Factors generally favoring intensive land management include labor endowment, livestock ownership, and
male head of household. Farm size, education, and involvement in off-farm and nonfarm activities have more mixed impacts on land management.

- Generally, better access to markets and roads is associated with less investment in SWC (probably because of higher labor opportunity costs) but greater use of fertilizer, probably because of higher profitability and better access to inputs.
- Adoption of SWC investments is undermined by high discount rates, which are generally higher for poorer households in the Ethiopian highlands.

Further research is needed to clarify our understanding of what works where, in terms of adoption and impacts of land management practices. Research in different biophysical and socioeconomic domains to assess the off-site as well as on-site costs and benefits of alternative land management approaches would be particularly useful in supporting efforts to scale up successful sustainable land management practices in Ethiopia.
References


