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ABSTRACT:

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Land degradation in sub-Saharan Africa reduces the land's potential productivity through soil erosion, nutrient depletion, soil moisture stress, deforestation and overgrazing. Efforts to reverse land degradation require an understanding of why it takes place and what factors govern farmers' willingness to invest in land conservation. These factors differ importantly between private and public lands.

This study synthesizes results from analyses of the technological and institutional factors determining the adoption of natural resource conservation at both the household and the community levels in the northern Ethiopian region of Tigray. Using 1995-96 data from 250 Tigray farm household interviews, it first examines private land management, focusing on 1) What factors determine farmer perceptions of the severity and yield impact of soil erosion? 2) Is soil conservation profitable, and if so, then under what conditions? 3) What determines farmers' willingness to invest in soil conservation? Using 1998-99 data from a survey of 100 Tigray villages, it proceeds to examine the management of communal lands (grazing lands and woodlots), focusing on 4) What makes communities engage in collective NRM activities? 5) What determines the effectiveness of collective NRM?

At the household level, results highlight the importance of (1) the physical characteristics of plots and villages in shaping farmer perceptions, (2) the land tenure horizon and access to capital in determining willingness to invest in soil conservation. At the community level, they highlight the importance of population density, agricultural potential, as well as access to markets and external organizations in determining community collective action and its effectiveness in establishing and managing protected grazing areas and woodlots.

Sustainable Management of Private and Communal Lands in Northern Ethiopia

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Land degradation is one of the fundamental problems confronting sub-Saharan Africa in its efforts to increase agricultural production, reduce poverty and alleviate food insecurity. With the land frontier shrinking, future increases in agricultural production will have to come from yield increases rather than area expansion. Yet the production potential of the land resource is declining due to soil erosion, nutrient depletion, soil moisture stress, deforestation and overgrazing. The continent confronts the challenge of how to increase current agricultural production while maintaining the future productive capacity of the natural resource base.

Land degradation is especially severe in the East African highlands. In Ethiopia it stands out as one of the major contributors to the slow growth rate of agricultural production. Land degradation has been particularly damaging in the highlands, those areas over 1500 meters above sea level, which account for more than 90% of the cultivated land, 75% of the livestock, and more than 80% of Ethiopia's farming population.

Public intervention to halt land degradation in Ethiopia started in the early 1970's (Campbell, 1991). However, a top-down approach, inadequate scientific and technical base of the recommended practices, and lack of involvement of local people rendered the efforts ineffective. Those experiences emphasize the importance of understanding how and why individual farms adopt soil conservation measures if those measures are to be diffused successfully.

Apart from private, household-level conservation measures, some natural resource conservation is most usefully done at the community level. Hence, for communal hillsides, grazing lands and woodlots, the community-level motives and impediments to resource conservation are important.

In this paper, we synthesize results of recent research conducted in the northern Ethiopian region of Tigray, which has experienced severe land degradation. We examine the technological and institutional factors determining the adoption of natural resource conservation at both the household and the community levels. Using 1995-96 data from 250 Tigray farm household interviews, we first examine private land management, focusing on the following questions:

1. What factors determine farmer perceptions of the severity and yield impact of soil erosion?
2. Is soil conservation profitable? Under what conditions?
3. What determines farmers' willingness to invest in soil conservation?

Using 1998-99 data from a survey of 100 Tigray villages, we next examine the management of communal lands (grazing lands and woodlots), focusing on two additional questions:

4. What makes communities engage in collective NRM activities?
5. What determines the effectiveness of collective NRM?

The setting

The study area, Tigray, is the northernmost region of Ethiopia located in the semi-arid Sudano-Sahelian zone (Warren and Khogali, 1992). It covers an approximate area of 80, 000 square km, with a population of more than 3.3 million and an estimated annual population growth rate of 3%.

The region lies on a mountainous plateau with a tropical semi-arid climate characterized by erratic and unreliable rainfall. The average annual rainfall in the region is 600 mm. Most of the precipitation falls intensively within the three months of June to August, contributing to soil erosion and is characterized by high spatial and temporal variability. Soils are shallow and infertile, and frequent outbreak of crop pests and diseases is a major problem of agricultural production.

Agriculture is the mainstay of the economy of Tigray. More than 85% of the regional population depends on mixed crop-livestock subsistence agriculture, with oxen power supplying the only draft power for plowing. Most of the region either produces just enough for subsistence during good rainfall years or faces chronic food deficit.

As in many semi-arid settings, livestock are a key element of farming systems. According to the 1998 livestock census, Tigray has about 3.04 million cattle, 0.94 million sheep, 1.47 million goats, 0.41 million equines, and 0.013 camels (Bureau of Agriculture and Natural Resource Development (BoANRD), 1999). Communal grazing lands of about 3.2 million hectare have been important sources of livestock forage in Tigray. Recently, however, the free and unrestricted access has resulted in severe degradation of the grazing lands.

Deforestation is very severe in Tigray. Cutting trees for fuel, timber, and agricultural implements, and clearing forests to expand agricultural lands have exhausted the forest cover of the area. Currently, only about 1.6% of the region is covered with forests or woodlots (BoANRD,1995).

Since 1991, the Tigray region has embarked on a regional development strategy for natural resource conservation based upon popular participation. The strategy focuses on soil and water conservation, the development of irrigation, and environmental rehabilitation through area enclosures, reforestation and development of community woodlots, through public, communal and private efforts.

Adoption of Soil Conservation Practices on Private Lands

The existing literature on technology adoption identifies adoption determinants associated with expected profitability, farm characteristics, household characteristics, and technology characteristics (Feder et al., 1985; Feder and Umali, 1993), as well as awareness and perception of the soil erosion problem and the practices that can treat it (Ervin and Ervin 1982).

Our research examined the determinants of erosion perceptions and the adoption of soil conservation practices on 250 farms in rural Tigray region in Ethiopia during 1995-96. Purposive selection of villages based on topography, followed by random sampling of households ensured representation of the diverse agro-ecological conditions. In the following subsections, we present results from analyses of determinants of perceived soil erosion, profitability of investments in stone terraces, and determinants of soil conservation adoption apart from perceptions.

The perception of soil erosion and its yield impact

Soil erosion is an insidious and slow process. Yet, farmers need to perceive the severity of soil erosion and the associated yield loss before they can consider investing in its prevention. In Tigray, where soil erosion is generally severe, understanding of the level and determinants of farmer perceptions of soil erosion and its impact is important for policy purposes. Prior research in the United States (Ervin and Ervin, 1982; Bultena and Hoiberg, 1983) and Ethiopia (Shiferaw and Holden, 1998) has highlighted the importance of perceptions for enhancing the adoption of soil conservation technologies.

Farmer perceptions of the severity of soil erosion on each plot were solicited in four subjectively assessed categories (1=severe, 2=moderate, 3=slight, 4=none). Farmers were also asked to estimate the likely yield impact of erosion that would occur on their fields in a normal year without any soil conservation measures using five possible levels (1=no yield reduction, 2=20% reduction, 3=25% reduction, 4=33% reduction, and 5=50% reduction). Following Ervin and Ervin (1982), we specified explanatory variables in three categories: physical factors, socio-institutional factors, and demographic characteristics. Physical factors include those natural physical elements that make soil erosion more likely, such as rainfall, soil texture, and topography (Yoder and Lown,1995). The socio-institutional variables include land tenure and the existence of related conservation projects (for demonstration or substitution effect). The demographic characteristics include human capital as well as other conditioning factors, such as age and gender.

At least moderate erosion was perceived on 58 percent of the 565 plots surveyed (Gebremedhin 1998, pp. 168-169). Statistical analyses of the determinants of these perceptions used as dependent variables both the four levels of erosion (ordered probit) and a binary variable distinguishing between some erosion perceived and none perceived (probit). A separate ordered probit model examined determinants of the yield loss estimates due to erosion. Plot-level physical characteristics that aggravate erosion are important determinants of farmer perceptions of soil loss and its yield impact (Table 1). Younger farmers tended to recognize erosion better perhaps due to better education or longer planning horizon. Experience with prior public campaigns that construct bunds or terraces on private lands detracted from perceived erosion. Plots operated longer and those close to the homestead were perceived to have worse erosion, suggesting that more frequent observation and more cultivation activity add to awareness. Farmers with more extension service contacts tended to perceive less erosion and yield loss.

[Table 1]

Profitability of soil conservation: The case of stone terraces

Given that soil erosion and its yield impact are recognized as problems among most Tigrayan farmers interviewed, the next question is whether investment in conservation practices is likely to be profitable. Prior research in Ethiopia and elsewhere has found that profitability is central to the farm-level adoption and maintenance of soil conservation practices. Failure to adopt or maintain conservation practices occurs because a) socially desirable projects are not privately profitable (Lutz et al., 1994) or b) privately profitable projects fail to offer immediate benefits or generate a positive cash flow (G/Michael, 1992).

In order to evaluate the return on soil conservation investments in Tigray, we conducted a capital budgeting analysis of an investment in stone terrace construction. The results were driven by the change in a one-year cross-section of wheat and fava bean grain and hay yields as observed in on-farm research plots. The plots were divided equally between wheat and fava bean on 70 terraced plots as compared with 70 unterraced plots planted to the same two crops. In order to capture accurately the effect of terracing, each terraced plot included one $8m^2$ quadrate just above the terrace (in the soil accumulation zone) and one just below the terrace (in the soil loss zone). Likewise each unterraced plot had one quadrate (designated the control treatment). Crop yields were measured in all quadrates and converted to quintals per hectare (qt/ha). Raw yields were also adjusted for planted area lost to terracing, assuming 5 and 15 percent levels of loss to planted area. Based on the 5 percent planting area loss scenario, inter-treatment yield differences were regressed on two farm management variables (tillage frequency and weeding frequency) in order to correct for management differences.

The corrected yield gains between treatments were incorporated into budgets based on constant 1995-96 farm-gate crop prices at harvest, input costs (including family labor at rural daily wage of 6 Birr = US$1), and terrace investment and maintenance costs. Finally, these partial budget data were incorporated into capital budgets to calculate the net present value (NPV) of investments in stone terraces (Gebremedhin et al., 1999). Given that the terraces were observed *in situ* and already stabilized, the capital budgets assumed (conservatively) that terraced fields would not show a yield advantage until the fourth year after terracing, at which time they would obtain the full yield advantage from terracing. Due to differences between government agricultural loan interest rates of 15% versus prevailing informal interest rates around 50% (Shiferaw and Holden, 2000), both rates were applied in separate NPV scenarios.

The results of the on-farm experiments reveal dramatic differences between yields in the soil accumulation zone and both the soil loss zone and the control plots, as showing in Table 2. The yield advantage of the soil accumulation zone is consistent across both wheat and fava bean crops and also across both grain and straw yields. Moreover, coefficient of variation shows that yield from soil accumulation zone is more stable than that from the unterraced and control zones.

[Table 2]

The capital budgeting analysis showed that returns to investments in stone terraces are highly sensitive to the discount rate applied. As illustrated in Figure 1, the payback period at a 15 percent discount rate was five years, versus 14 years at a 50 percent discount rate. Over the thirty-year time horizon projected, the NPV was 3907 Birr (US$ 650) at a 15 percent discount rate versus 12 Birr (US $2) at a 50 percent discount rate, indicating that investment in stone terraces results in an internal rate of return (IRR) of 50 percent.

[Figure 1]

Determinants of investment in soil conservation: The value of secure land tenure

Our investment profitability analysis was predicated upon the assumption of secure land tenure. Yet the 5 – 14 year range of payback periods highlights the minimum period of land tenure over which land must be held to make terracing investments financially worthwhile. Having established the potential profitability of investments in terraces via a capital budgeting analysis, it was fitting to analyze determinants of soil conservation adoption in Tigray in the broader context of farm resources and their physical and institutional setting.

The conceptual model underlying the soil conservation investment analysis focuses on six classes of investment determinants that have proven influential in rural settings of the developing world (Feder et al., 1985; Christensen, 1989). Those determinants include 1) market access (as a proxy for prices), 2) physical factors (as a proxy for the technology set), 3) capacity to invest, 4) land tenure security, 5) other socio-institutional factors (including community pressure and government services), and 6) household demographic characteristics (including human capital).

Both our conceptual and empirical models distinguish between those factors that trigger the decision to invest and those factors that determine the degree (intensity) of investment, based a double-hurdle model linking the probability of adoption (as a probit regression) and, where terraces were adopted, the degree of adoption (density in meters of terrace per hectare) as a truncated regression1 [Cragg, 1971]). This analysis was applied to stone terrace density, but not to soil bunds, which were present on only one percent of the fields studied. The analyses were applied separately to decisions on adoption of both stone terraces and soil bunds on 638 fields in Tigray in 1995-96.

The results of the analysis (Table 3) highlighted the importance of the institutional setting within which Ethiopian farmers make conservation decisions (Gebremedhin, 1998; Gebremedhin and Swinton, 2000). Land tenure security was a major determinant of the conservation technology adoption. Farmers with secure land tenure who 1) expected to bequeath their fields to their children and 2) lived in villages with no recent land redistribution were both more likely to build stone terraces and less likely to build soil bunds. Those who expected to operate the field in five years time (but presumably not bequeath it to their children) were less likely to build terraces. By

1 A comparison between the tobit and double-hurdle models showed that the double-hurdle model fits the data better (Gebremedhin, 1998, p. 187).

contrast, farmers with an immediate time horizon – those who currently operate a field -- were more likely to adopt soil bunds.

[Table 3]

Other government interventions influenced adoption as well. Public soil conservation programs had a substitution effect on fields where they had operated, making subsequent private conservation investments less likely. However, the existence of food-for-work programs in the village increased adoption of stone terraces, while decreasing adoption of soil bunds, perhaps because of either a demonstration effect or a liquidity effect. Interestingly, the number of extension contacts did not affect adoption of either stone terraces or soil bunds, related, perhaps to its significant negative effect on the perception of soil erosion. A variety of other physical factors also played fairly predictable roles in determining the adoption of conservation investments.

The intensity of adoption did, in fact, depend on different variables than adoption alone. Market access factors proved especially relevant, as the density of terraces increased with distance to an all-weather road and to a regional market. This link suggests that off-farm labor opportunities may be fewer in more remote areas, reducing the opportunity cost of terrace construction. The majority of farmers in the study area are likely to be net buyers of food grains, thus rendering the price advantage of proximity to road less important. As expected, terracing density was less on larger fields (suggesting economies of scale in terrace construction), and greater in the rainier upper highland areas (where erosion pressure is greater) (Gebremedhin, 1998; Gebremedhin and Swinton, 2000).

Inducements to sustainable management of communal lands

Apart from the direct effect of reducing yields on a given field, water-driven soil erosion on one field triggers further damage down-slope. It can induce gully formation and harm terraces and bunds on lower slope fields, as well as contribute to the sedimentation of waterways. When impacts beyond one household's fields affect the welfare of others, these economic externalities may mean that private initiatives are inadequate to rectify resource degradation problems since external costs are not considered in private decision making. Due to the rugged and mountainous topography, soil erosion and excessive run-off on uplands of the Tigray region result in significant public externalities.

Private incentives for conservation are also inadequate in common property resources where open access can make the rewards for good resource stewardship open to anyone, regardless of effort. Common property resources that have been important sources of fuel wood, timber, and grazing lands in Tigray, have been severely degraded due to unrestricted access or ineffective use regulations.

In the following subsection, we draw on community-level data to analyze the nature, impact and determinants of collective action for community management of woodlots and grazing lands.

Managing common property resources: Woodlots and grazing lands

Community management of common property resources is increasingly recognized as a viable alternative to privatization, state ownership, or environmentally regulated private or communal ownership (Rasmussen and Meinzen-Dick, 1995; Baland

and Plateau, 1996). However, devolving rights to local communities to manage natural resources is a necessary but not sufficient condition for successful community resource management. Sustainable resource management also requires that community rules and regulations be effectively observed (Turner et al., 1994; Swallow and Bromley,1995). Hence, the identification of factors that favor or retard the development and effectiveness of community institutions for resource management becomes important. In order to investigate the nature, impact and determinants of effectiveness of community woodlot and grazing land management in the region, we held group interviews with a stratified random sample of community leaders from 50 *tabias*[2] and 100 villages in Tigray during 1998-99 cropping season.

How to measure collective action and its effectiveness raises the challenge of identifying measurable indicators suited to each natural resource. For woodlot management, our indicators of collective action included the amount of collective labor input per hectare invested in managing the woodlot, whether the community paid for a guard to protect the woodlots, whether there were any violations of use restrictions of the woodlot, the number of trees planted per ha on the woodlot since it was established, and the survival rate of trees. The indicators of collective action for grazing land management included whether the community practices use restrictions on its grazing land[3], whether the community had established penalties for violations of use restrictions, whether there had been any violations of use restrictions in 1998, and whether those violations were penalized.

The analysis showed that in the highlands of Tigray 88% of *tabias* have

2 *Tabia* is the lowest administrative unit in the region and usually consists of 4-5 villages.
3 Every community has some kind of communal grazing land.

woodlots and 89 % of villages have restricted grazing areas (Gebremedhin et al., 2000a; Gebremedhin et al., 2000b). While most woodlots (96%) were promoted by external organizations, most restricted grazing lands (78%) were established by local communities, indicating the existence of local initiatives to develop use restrictions of grazing areas by rural communities in Tigray. While the establishment of community woodlots is a recent phenomenon in Tigray, especially since 1991, the establishment of restricted grazing areas has a long tradition in the region.

Most woodlots and all restricted grazing areas are managed at the village level. Hired guards are the dominant means of protection for both woodlots and grazing lands, and communities use cash penalties for violations of use restrictions for both resources. Compared with *tabias*, villages reported more intensive management of woodlots, with fewer problems and more benefits from woodlots. Despite the limited current benefits that communities receive from woodlots due to use restrictions, it was estimated that at one harvest woodlots can contribute more than US $600,000 to *tabia* (community) wealth in timber value. Communities tend to be more likely to enforce penalties when violations of use restrictions are more frequent. The communities perceived that community management of woodlots and grazing lands had resulted in significant regeneration of the resources. They also reported few problems as a result of the use restrictions of woodlots and grazing lands.

These descriptive differences between motives for collective management of woodlots and grazing lands prompted an econometric analysis of their roots. Following the literature on collective action and induced institutional innovation in managing common property resources, we used population density, access to market, agricultural potential, the presence of external organizations, whether the woodlot was managed at the *tabia* or village level, area of the woodlot or grazing land, and age of the grazing land as determinants of collective action or its effectiveness (Boserup, 1965; Olson, 1965; Hayami and Ruttan, 1985; North, 1990; Rasmussen and Meinzen-Dick, 1995; Baland and Platteau, 1996; Pender, 1999; Pender and Scherr, 1999; Otuska and Place, 1999).

The econometric analyses point to several key determinants of collective action for woodlot and grazing land management (Tables 4 and 5; Gebremedhin et al., 2000a; Gebremedhin et al., 2000b). Intermediate population density (rather than high or low population density) generally favors community management of woodlots. This finding supports an inverted U-shaped relationship between population density and collective action for resource management. Violations of use restrictions of grazing lands were also low at intermediate population density. Market access undermines collective action of woodlot management, but favors collective action of grazing land management. The effect was powerful, undermining not only collective labor input, but also tree planting density, and the survival rate of trees in woodlots. On the other hand, proximity to market appears to have increased the resource value of the grazing lands or returns from their use. Farmers who live closer to towns are more likely to sell dairy products, especially milk, thus perhaps increasing the return from sustainable use of grazing lands.

[Table 4]

The presence of external organizations detracted from collective action of woodlot management but failed to have significant impact on grazing land management, suggesting that external organizations displace local effort of community woodlot management. Although external organizations play important role in promoting the establishment of woodlots, their role in managing the resource seems to be substituting or contradicting local efforts and/or preferences. Since most grazing lands were established by local communities themselves, the role of external organizations appears to be insignificant.

[Table 5]

Woodlot size had no significant impact on woodlot management, indicating that there are no economies of scale in woodlot management. However, more extensive grazing lands reduced the need to set and enforce penalties for misuse. Perhaps the detection of violations of use restrictions was difficult in larger areas. Community experience in grazing land management (as measured by the age of the restricted grazing areas) did not matter for effective management, suggesting that there is little "learning effect" in community grazing land management.

Low potential areas reduced collective labor input and planting density but increased survival rate of tress planted in woodlots. Low potential areas were also less likely to have restricted grazing lands but more likely to observe use restrictions once the grazing areas are established. These results suggest that community resource management tends to be more difficult to establish in low potential areas but is more likely to be effective once the hurdle of establishment is overcome.

Conclusions and Implications

This synthesis of NRM adoption research in northern Ethiopia offers several lessons that may be extrapolated to other mountainous areas of sub-Saharan Africa. It appears that most farmers who live in a degraded, hilly and rugged environment are well aware that soil erosion is a problem. Most connect it with the physical conditions that aggravate erosion. Farmers are more likely to recognize erosion on plots that they cultivate longer or are closer to the homestead suggesting that stable tenure systems may contribute to awareness of NRM problems. Literacy of farmers, as evidenced by younger farmers being more likely to perceive the erosion problem, appears to be one entry for public intervention to increase awareness of NRM problems. Although extension services are important communicators, they may need to change in order to succeed at raising farmer awareness of NRM problems.

Farmer perceptions of the severity of soil erosion and the need to treat it is a necessary but not sufficient condition for farmer investment in soil conservation technologies. Conservation practices must also offer short term benefits and be profitable. The profitability of conservation practices depends not only on biophysical factors but also on such institutional factors as the availability of credit and secure land tenure. These elements determine the length of the planning horizon and hence the expected return on investment. In steeply sloped East African highland area like Tigray, the most effective soil conservation investments are terraces.

Stone terraces increased yield substantially under farmer management. In the mountainous terrains such as those found in Tigray and in many other parts of Ethiopia stone terraces can be important in the intensification process of agricultural production by 1) conserving water and 2) preventing fertilizer from being washed away. The yield stability advantage from stone terraces in an environment characterized by erratic and unreliable rainfall reduces the risk of crop failure. These combined effects are likely to contribute to food security in areas that are chronically food insecure.

Yet, the high initial investment in terrace construction is practical only if a prolonged payoff is expected. For poor farmers operating in an imperfect credit market like Tigray's, costly credit is likely to constrain conservation investment. Our investment analysis found that investment in stone terraces can yield a 50% internal rate of return. Impressive as that may sound, it is no more than equal to the prevailing rural discount rates (Shiferaw and Holden, 2000). So investment in stone terraces is merely a break-even proposition to private farmers. Although the yield stability benefits offered could increase private household's expected utility the benefits from terrace construction that are pivotal to induce adoption are the social benefits that pertain beyond the farm's own fields. The value of these benefits has not been quantified, but would arise from reduced gullying, micro-dam sedimentation and consumer losses due to higher food prices resulting from production losses. Assessing the value of these benefits would be a first step to determine the justifiability of added financial inducements needed to elicit more soil conservation effort, for example subsidized credit. But institutional innovations such as enhancing land tenure security can yield comparable inducements without drawing on the public treasury.

Prior research on conservation adoption has considered that the determinants of adoption and the intensity of use are the same (Sureshwaran et al., 1996; Pender and Kerr, 1998). Our results show that the determinants of both decisions can indeed be different. Land tenure security was a key determinant of adoption of stone terraces, but not of how much terracing was done. The same was true of household labor availability. Opportunity cost of labor and greater erosion threat due to higher rainfall were important determinant of intensity of stone terraces, but not the likelihood of adoption. These results imply that cost of investment and returns to investment influence effective use of labor intensive conservation practices.

Apart from private cultivated lands, communal lands such as woodlots and grazing lands are subject to degradation if utilized under unrestricted access or ineffective use regulations. Under such management institutions, resource economic theory suggests that each individual user of the resource tends to use the resource up to the level where his or her average revenue is equal to the marginal cost of utilizing the resource. These incentives tend to result in overexploitation of the resource and the dissipation of the scarcity rent. The effectiveness of public interventions to improve NRM also depends to a large extent on local level institutions and organizations of resource management (Rasmussen and Meinzen-Dick, 1995).

Our research on collective action for resource management showed that community resource management tends to be more effective at intermediate population densities and if conducted by the most local of collective institutions. When population density is low, the need for collective action to manage resources may be low and the cost of organizing effective collective action may be high. Resource scarcity increases with population growth raising the benefits of improved resource management. However, when population density becomes very high, the incentive to benefit from "free riding" on the effort of others may outweigh the benefit from abiding by community rules.

External organizations have played important roles in establishing community management institutions of woodlots and grazing lands. However, external organizations can best promote community resource management by complementing local, demand-driven efforts, rather than displacing them. When the NRM practice is labor intensive, community resource management can be more effective in remote areas, far from markets, where the opportunity cost of labor is low. In densely populated, well-connected areas, labor intensive community NRM may not be effective, at least not for woodlots. When community NRM is less labor intensive and the return from use of the resource is more directly integrated with the market, such as grazing lands in Tigray, market access can have a positive impact on collective action. Community NRM appears more difficult to establish in low potential areas, but is more likely to be effective if established.

Overall, the Tigray experience suggests that the NRM adoption process hinges not only on the natural environment, but also the human institutional environment and the kind of decision maker. The NRM practices relevant in Tigray are those of populous mountainous regions where the leading natural resource challenges relate to soil erosion on sloped lands, and where impoverished populations have over-exploited shared forests and pastures. But the institutional lessons can be extrapolated more widely. They suggest that public policies to foster NRM adoption should be attuned both to private and community incentives for action. For NRM investments that pay off over time, public intervention may be necessary if private decision makers are to find NRM investments more attractive than alternatives. Where significant public benefits can be had that are unlikely to be captured by the private decision maker, public subsidies are justifiable and can be effective if well-administered.

Community-managed resources will require different policy incentives than individually managed ones. While guidelines for influencing individual action have been developed fairly well, further work is needed on the design and support of local institutions for NRM in sub-Saharan Africa. Communities that are neither too dispersed to organize shared natural resource access rules nor too large to prevent free-riding have most effectively managed community woodlots. But for this part of Africa's eastern highlands, what policies will best facilitate collective NRM for other scales of community and what specific local institutional designs work best remain to be determined.

Table 1: Statistically Significant* Determinants of Farmer Perceptions of Soil Erosion and its Yield Impact (signs in parentheses)

Variable	**Erosion Severity**		**Yield Impact**
	Ordered Probit	**Probit**	**Ordered Probit**
1. Village Physical Factors	Location in rainier upper highland[τ](-) Hilly topography (+) Dung used as major fuel source (+)	Location in rainier upper highland(-) Hilly topography (+) Dung used as major fuel source (+)	Dung used as major fuel source (+)
2. Plot Physical Factors	Loam soil [ξ] (-) Distance from homestead (-) Plot slope degree (+) Convex slope [Ψ](+) Concave slope (+) Area (+) Plot age (+)	Loam soil (-) Distance from homestead (-) Plot slope degree (+) Convex slope (+) Concave slope (+) Area (+)	Distance from homestead (-) Plot slope degree (+) Convex slope (+)
3. Socio-institutional factors	Extension contact (-)	Extension contact (-)	Extension contact (-) Beneficiary of public campaign conservation (-)
4. Demographic Characteristics	Age of HH head (-)	Age of HH head (-)	Age of HH head (-)
Chi-square	128.3	89.8	72.4
Prob. >Chi-square	0.000	0.000	0.000
Pseudo R-Square	0.084	0.135	0.047
Predicted Probability at mean	N/A	0.583	N/A
N	565	565	487

* Significant at least at 10% level.

[τ] Upper highland is defined as location at or above 2500 meters above sea level.
[ξ] Soil dummies were compared against clay soil.
[Ψ] Slope dummies were compared against rectilinear slope.

Source: Gebremedhin, 1998, pp. 168-169, 172-173.

Table 2: Mean Wheat and Fava Bean Grain and Straw Yield in Soil Accumulation Zone, Soil Loss Zone and Control Zone, 100 kg/ha (standard deviations in parentheses)*

Output	Treatment	Unadjusted	Adjusted for 5% area loss to terraces
Wheat			
Grain	Accum Zone	16.1 (6.09)[a]	15.3 (5.79)[a]
	Loss Zone	8.5 (3.35)[b]	8.1 (3.18)[b]
	Control	6.6 (4.08)[b]	6.6 (4.08)[b]
Straw	Accum Zone	27.9 (9.84)[a]	26.5 (9.35)[a]
	Loss Zone	14.5 (5.42)[b]	13.8 (5.15)[b]
	Control	12.0 (6.05)[b]	12.0 (6.05)[b]
Fava bean			
Grain	Accum Zone	8.0 (3.13)[a]	7.6 (2.97)[a]
	Loss Zone	5.5 (2.37)[b]	5.2 (2.25)[b]
	Control	5.4 (4.19)[b]	5.4 (4.19)[b]
Straw	Accum Zone	11.8 (4.07)[a]	11.2 (3.87)[a]
	Loss Zone	7.5 (3.22)[b]	7.1 (3.05)[b]
	Control	6.4 (5.09)[b]	6.4 (5.09)[b]

*Figures followed by different letters were significantly different within each crop and product at 5 percent level using Bonferroni multiple range test (Watson et al., 1990). (Table reprinted from (Gebremedhin et al., 1999) pp. 570-571.)

Table 3: Statistically Significant* Determinants of Adoption and Intensity of Use of Conservation Practices (signs in parentheses)

Variable	**Stone Terrace**		**Soil Bund**
	Adoption (Probit regression)	**Intensity of Use (Truncated regression)**	**Adoption (Probit regression)**
1. Financial Incentives to Invest	**No significant variables**	Distance to market(+) Distance to road(+)	Distance to market place(-)
2. Physical factors	Location in rainier upper highland$^{\tau}$(-) Hilly topography (+) Distance from homestead (-) Loam soil $^{\xi}$ (-) Plot on lower slope$^{\zeta}$(+) Slope (+) Slope squared (-) Concave slope $^{\psi}$(+) Plot area (+)	Location in rainier upper highland(+) Silt soil (+) Slope (+) Slope squared (-) Plot area (-) Plot age (+)	Loam soil (+) Number of plots cultivated (+) Plot on upper slope (-) Plot on middle slope (-) Slope (+) Slope squared (-) Mixed slope (-) Plot age (+)
3. Capacity to inveest	Number of working age household members (+)	**No significant variables**	**No Significant variables**
4. Land tenure security perception	Up to five years more (-) Bequeath land to children (+)	**No significant variables**	Bequeath land to children (-) Owner operator (+)
5. Socio-institutional factors	Beneficiary of public campaign conservation (-) Food for work project available (+) Years since last land redistribution in village (+)	**No significant variables**	Beneficiary of public campaign conservation (-) Food-for-work project available (-)
6. Demographic characteristics	**No Significant Variables**	Literate HH head(-)	Age of HH head(-) Literate HH head(-)
Chi-square	141.89	N/A	101.2
Prob.> chi-square	0.000	N/A	0.000
Pseudo R-Squared	0.28	N/A	0.27
Predicted prob. at mean	0.219	N/A	0.013
N	638	139	638

* Significant at least at 10% level.

$^{\tau}$ Upper highland is defined as location at or above 2500 meters above sea level

$^{\xi}$ Soil dummies are compared against clay soil,

$^{\psi}$ Slope dummies are compared against rectilinear slope

$^{\zeta}$ Location of plot dummies were compared against location at the flat land part of a catchment

Source: Geberemedhin, 1998, pp 194-95, 198-99.

Table 4: Statistically Significant* Determinants of Collective Action and its Effectiveness on Community Woodlot Management (signs in parentheses)

Indicators of Collective action and its effectiveness				
Collective labor input (person-days/hectare) **(Tobit regression)**	**Whether community pays for guard** **(Probit regression)**	**Whether any violations of restrictions occurred** **(Probit regression)**	**Number of trees planted /hectare** **(OLS regression)**	**Survival rate of planted trees** **(Tobit regression)**
Central zone[§] (-) Eastern zone (-) Western zone, Population density (+) Population density squared (-) Distance to district town (+)	Central zone (-) Eastern zone (+) Woodlot promoted by external organization[†](-)	Eastern zone (-)	Central zone (-) Population density (-) Population density squared (+) Distance to district town (+)	Central zone(+) Eastern zone (+) Distance to district town (+) Woodlot promoted by external organization (-)

* Significant at least at the 10% level.

[§]The study region is divided into four zones. The southern and western zones are considered relatively high potential areas. Zonal dummies are compared against the southern zone.
[†] External organizations are those organizations which are not locally constituted, such as the Bureau of Agriculture, NGO's etc..

Source: Gebremedhin et al., 2000a, p. 25.

Table 5: Statistically Significant* Determinants of Collective Action and Its Effectiveness on Grazing Land Management (Signs in parentheses)

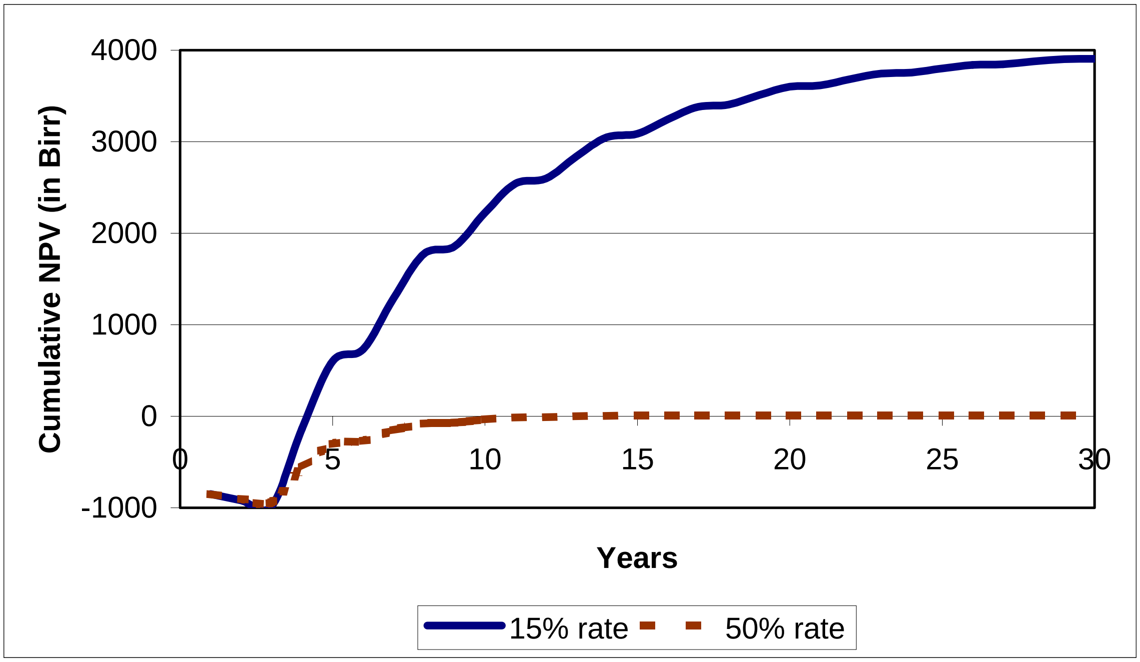
Indicators of Collective Action and its Effectiveness			
Whether village has restricted grazing area **(Probit regression)**	**Whether penalties for violations of use restriction were established** **(Probit regression)**	**Whether violations of use restrictions occurred** **(Probit regression)**	**Whether violations in 1998 were penalized** **(Probit regression)**
Central zone[§](-) Eastern zone (-) Western zone (-) Population density (-) Population density squared (+)	 Population density (-) Area of restricted grazing land (-) Distance to district town (+)	Central zone(-) Eastern zone(-) Population density (-) Population density squared (+) Distance to district town (+)	 Population density (-) Population density squared (+) Area of restricted grazing area (-)

* Significant at least at 10% level.

[§]The study region is divided into four zones. The Southern and Western zones are considered relatively high potential areas. Zonal dummies are compared against the southern zone.

Source: Gebremedhin et al. 2000b, p. 17.

Figure 1: Cumulative Net Present Value of Stone Terrace Investment over 30-year Period, Tigray, Ethiopia (in Ethiopian Birr as of 1995-96 [US$1=6 Birr]): Discounted at 15% and 50% rates.



Source: Table 6 in (Gebremedhin, Swinton and Tilahun 1999), p. 573.

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