Strategies to Improve Land Management, Crop Production and Household Income in the Highlands of Tigray, Northern Ethiopia

John Pender [1] and Berhanu Gebremedhin[2]

[1] International Food Policy Research Institute, Washington, D.C.
j.pender@cgiar.org

[2] International Livestock Research Institute, Addis Ababa, Ethiopia
b.gebremedhin@cgiar.org

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Abstract

This paper investigates the land management practices used in the highlands of Tigray, northern Ethiopia, the factors influencing them, and their implications for crop production and income. Several factors commonly hypothesized to have a major impact on land management and agricultural production—including population pressure, small landholdings, access to roads and irrigation, and extension and credit programs—are found to have limited direct impact on crop production and income, though most affect the intensity of production. The increase in farming intensity due to these factors has limited impact on value of crop production and income due to low marginal product of labor in crop production, limited productivity impact of inputs such as fertilizer in the moisture-stressed environment of Tigray, and limited adoption of such inputs.

We find that profitable opportunities exist to increase agricultural production and achieve more sustainable land management in the highlands of Tigray. These opportunities include improvement of crop production using low-external input investments and practices such as stone terraces, reduced tillage, and reduced burning. The comparative advantage of people in the Tigray highlands is apparently not in input-intensive cereal crop production but more in such low-input approaches and in alternative livelihood activities such as improved livestock management and non-farm activities. As a result, greater emphasis on developing these alternatives in agricultural extension and other development programs is needed. Food crop production should not be ignored in the development strategy, but more prudent use of external inputs such as fertilizer and improved seeds, and greater emphasis on low input sustainable land management practices, would be helpful.

1. Introduction

Low agricultural productivity, poverty and land degradation are severe and closely related problems in the highlands of Tigray in northern Ethiopia. Cereal yields average less than one ton per ha. in this region and over half of the area of the Tigray highlands has been characterized as severely degraded (Hurni, 1988). The average farm size is only 1 ha., and most households subsist on incomes of less than one dollar per day. In recognition of these problems, the regional government of Tigray has undertaken a massive program of investment and resource conservation since 1991. The regional development strategy of Conservation-based Agricultural Development-Led Industrialization has focused on promoting conservation of natural resources and improvement of agricultural productivity and welfare through a broad program of investment in infrastructure, agricultural extension, education, and other services. Empirical evidence of the impacts of these policies, and identification of specific areas where problems need to be addressed, is needed. Addressing this need is the primary objective of this study.

This study is based upon a household and plot-level survey conducted in 100 villages in 50 *tabias* (the lowest administrative unit in Tigray, usually comprising of 4-5 villages) in the highlands of Tigray during 1999/2000. This broad sample enables investigation of the impacts of community level factors such as population density, investments in irrigation and roads, as well as household and plot-level factors such as household wealth, education, land tenure, and other factors on land management and the implications for agricultural productivity and income.

2. Empirical Model, Methods, and Hypotheses

Empirical Model

The key outcomes of interest in this study are agricultural production and per capita income. We consider the proximate causes of each of these, including household choices regarding income strategies, land management and other decisions, and the underlying determinants of these choices.

Crop Production

We assume that the value of crop production by household h on plot p (y_{hp}) is determined by the inputs (labor, oxen power, fertilizer, seeds) used (IN_{hp}); the land management practices (manure or compost, burning, contour plowing, reduced tillage, intercropping) used (LM_{hp}); the "natural capital" of the plot (NC_{hp}) (biophysical characteristics and presence of land investments); the tenure characteristics of the plot (T_{hp}) (how plot acquired; i.e., whether allocated in prior land distribution, inherited, leased (sharecropped in almost all cases), received as gift, or borrowed); the household's endowments of physical capital (PC_h) (land, livestock, radio (reflecting access to information as well as wealth)), human capital (HC_h) (education, age, and gender of household head, size of household), financial capital (use of credit and accumulation of savings), and "social capital" (SC_h) (indicated by participation in programs and organizations); the household's income strategy (IS_h) (primary and secondary income sources); village level factors that determine local comparative advantages (X_v) (agro-ecological conditions, access to markets and infrastructure, and population density); and random factors (u_{yhp}):

1) $$y_{hp} = y(IN_{hp}, LM_{hp}, NC_{hp}, T_{hp}, PC_h, HC_h, FC_h, SC_h, IS_h, X_v, u_{yhp})$$

Since many different crops are produced in different locations in Tigray, we do not include crop prices as determinants of the value of crop production, because this would result in many missing observations for farm level prices. Instead, we assume that farm level prices are determined by village level factors determining local supply, demand and transportation costs of commodities (X_v), and household level factors affecting households' transactions costs and marketing abilities (HC_h, FC_h, SC_h, IS_h). Land tenure (T_{hp}) can affect productivity, for example, by affecting incentives to apply labor effort and other inputs to sharecropped land compared to owner-operated land (Shaban 1987).[1] Household endowments of physical capital (PC_h) can also affect crop production if there are imperfect factor markets. In addition, agro-ecological conditions, households' human and social capital and their farming experience may also influence agricultural productivity, even if these factors have no impact on prices.

Input Use and Land Management

Input use and land management are choices in the current year, determined by the natural capital and tenure of the plot; the household's endowments of physical, human, social, and financial capital at the

[1] If labor effort and other inputs are measured perfectly, these effects will be reflected in the effects of these inputs on production. However, if they are measured imperfectly, tenure may have additional impacts on productivity.

beginning of the year; the household's income strategy; by agro-ecological conditions, access to markets and infrastructure, and population density (X_v); and by unobservable factors (u_{INhp} and u_{LMhp}):

2) $IN_{hp} = IN(NC_{hp}, T_{hp}, PC_h, HC_h, SC_h, FC_h, IS_h, X_v, u_{INhp})$

3) $LM_{hp} = LM(NC_{hp}, T_{hp}, PC_h, HC_h, SC_h, FC_h, IS_h, X_v, u_{LMhp})$

Most of the determinant factors in equations 2) – 3) are either exogenous to the household (e.g., X_v) or state variables that are predetermined at the beginning of the current year (e.g., NC_{hp}, PC_h, HC_h and FC_h). Income strategies may change from year to year, but are usually slow to change, because of irreversible investments in human and social capital (e.g., development of new skills and investments in developing market connections are needed to shift from subsistence to cash crop production).[2] Thus, we assume that households' current income strategies are determined by fixed or slowly changing factors, and therefore predetermined in equations 1)-3).

Participation in programs and organizations (SC_h) and use of credit (FC_h) may be determined in the current year, and hence potentially endogenous to current decisions about input use and land management. In the econometric analysis we use predicted participation in programs and organizations and predicted use of credit as instrumental variables to address this potential endogeneity concern. We predict participation in programs and organizations and use of credit using village level factors affecting local comparative advantages and placement of programs (X_v), household endowments of land (NC_h) and human capital (HC_h). For example, membership in an agricultural cadre requires literacy and some experience in modern agricultural practices, access to credit may depend on the household's endowment of land, and placement of programs may depend on local comparative advantages.

4) $SC_h = SC(HC_h, NC_h, X_v)$

5) $FC_h = FC(HC_h, NC_h, X_v)$

The determinants of value of crop production will be estimated using the structural model

[2] Less than 3% of households in our sample changed their primary source of income between 1991 and 1998, and only one-fifth changed their secondary income source.

(accounting for potential endogeneity bias, as discussed further below) represented by equation 1), as well as in reduced form. The reduced form is obtained by substituting equations 2) – 5) into equation 1):

6) $y_{hp} = y'(NC_{hp}, T_{hp}, PC_h, HC_h, IS_h, X_v, u'_{yhp})$

Per Capita Income

We assume household per capita income is determined by the same endowments that determine land management and input use decisions, with plot level factors aggregated to household level[3]:

7) $I_h = I(NC_h, T_h, PC_h, HC_h, SC_h, FC_h, IS_h, X_v, u_{Ih})$

Equation 7) is a reduced form equation, since we do not include endogenous decisions that affect income such as input use and land management practices, as in equation 1). It is not fully reduced form however, since it includes FC_h and SC_h, which are potentially endogenous variables as noted above. Substituting equations 4) and 5) into 6), we also can derive the fully reduced form version of equation 7):

8) $I_h = I'(NC_h, T_h, PC_h, HC_h, IS_h, X_v, u'_{Ih})$

Methods

Data sources

This study is based on a survey of 500 households in 100 villages in 50 communities (*tabias*) in the highlands of Tigray conducted in 1999 and 2000. *Tabias* below 1500 m.a.s.l. elevation were excluded from the sample frame. A random sample of *tabias* was used, stratified by distance to the *woreda* (district) town and whether an irrigation project was present in the *tabia*. Two villages were randomly selected within each sample *tabia*, and five households were randomly selected from each village. In addition to household-level information, information was collected on all plots owned or operated by the respondent households. The survey data were supplemented by data from *tabia* and village surveys on prices and other factors, secondary data from the 1994 Population Census on the population of each *tabia*, and maps of the boundaries of each *tabia* (used to calculate population density).

Econometric approach

[3] For example, in the income regression, we use share of farmland of different tenure, slope and soil type classes.

The dependent variables analyzed in this study include the amount of inputs used on each plot in 1998 (labor, draft animal power, and seeds), adoption of the most common crop and land management practices in 1998 (use of fertilizer, improved seeds, manure or compost, burning to clear the plot, contour plowing, reduced tillage, intercropping or mixed cropping), value of crop production on the plot, per capita income of the household, and whether the household head participated in the extension program, used formal or informal credit, or participated as a member in certain community organizations (*tabia* council, village council, marketing cooperative, or agricultural cadre[4]). The econometric model used depends on the nature of the dependent variable. For use of labor, oxen-power and seeds, the value of crop production, and per capita income, least squares regressions were used. For explaining whether various land management practices were used, whether the household participated in agricultural extension, organizations or used credit, probit models were used.

The explanatory variables include indicators of agricultural potential (average rainfall and altitude); population density; access to roads and markets (walking time to nearest all-weather road and to the *woreda* town); wealth (land and livestock owned); human capital (gender, age and education of household head, and household size (a proxy for family labor endowment)); income strategy (primary and secondary income source); ownership of a radio (a determinant of access to information); availability of cash savings; household social capital (membership in various organizations); use of formal or informal credit; contact of the household with the agricultural extension program; and various plot-level factors, including the land use (whether homestead, rainfed or irrigated cultivated[5]), land tenure (how plot acquired), presence of investments on the plot (stone terrace, soil bund, fence) and several indicators of different aspects of quality of the plot (size of plot, distance of the plot to the farmer's residence, plot slope, position on slope, soil depth, color, texture, and presence of gullies).

In the crop production regression and input use regressions, we used a logarithmic Cobb-Douglas specification. We included interaction terms between fertilizer use and presence of a stone terrace, a soil

[4] Agricultural cadres are considered innovative farmers who are contact farmers for technical assistance programs.
[5] Pasture, woodlots and fallow plots were excluded from the analysis.

bund, or irrigation, to test whether there is complementarity between fertilizer use and these investments, as hypothesized. Since inputs and land management practices are endogenous choice variables in the crop production regression, and participation in programs and organizations and use of credit may be endogenous, we use instrumental variables (IV) estimation, using instruments for input use, land management practices, participation in programs and organizations and use of credit. We also estimate the full model using ordinary least squares (OLS), and test for endogeneity bias using a Hausman (1978) test. Predicted values of the endogenous explanatory variables were used as instrumental variables. Exclusion restrictions for other instrumental variables excluded from the regressions were based on joint statistical tests (only variables that were jointly statistically insignificant at the 20% level or greater in both OLS and IV models were excluded). We also estimate the reduced forms (RF) specified in equation 6) and report the robustness of our results across specifications.[6] The reduced form gives an indication of the total effect of underlying explanatory variables on crop production, allowing for change in input use, land management practices, participation in programs and organizations and use of credit. We also investigate indirect effects using simulations based on the econometric results from the structural models. We simulate the predicted responses implied by the estimated econometric relationships under alternative assumptions about the values of the explanatory variables for the entire sample, and carry these predicted responses forward to determine their impact on subsequent relationships in the system.[7]

We also use IV estimation in the input use and income per capita regressions to account for endogeneity of participation in programs and organizations and use of credit, and report the robustness of our results. In the land management (probit) regressions, IV estimation could not be used. Instead, we used predicted values of the endogenous variables as explanatory variables. Due to space limitations, we do not report the results of the regressions used to predict participation in programs and organizations and use of credit.[8] We also estimate the determinants of per capita income in reduced form (equation 8)).

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[6] Except where noted, the results discussed below are statistically significant at the 5% level in at least two of the specifications.

[7] The method used to predict direct and indirect impacts is explained fully in Nkonya, et al. (2004).

[8] These regression results are available upon request.

We tested the regression specifications for problems of multicollinearity, but found this not to be a serious problem in any of the specifications.[9] Various regression diagnostics were used to identify outliers and influential observations, to find and correct data errors. All models used the Huber-White estimator of the covariance matrix, which is robust to heteroskedasticity, accounted for clustering of the data by household (i.e., standard errors are robust to non-independence of multiple observations from the same household), and accounted for the stratification and probability of sampling each village and household in the sample frame (StataCorp 2003). The results are thus robust to potential problems of heteroskedasticity and non-independence, and are statistically representative of the highlands of Tigray.

Hypotheses

A large number of hypotheses could be tested concerning the relationships in equations 1) – 7). We focus on the effects of several key factors on the value of crop production and income.

Population pressure: Population pressure causes higher labor intensity in agriculture, including production on marginal lands, less use of fallow, adoption of labor-intensive commodities and land management practices (Boserup 1965). This is expected to increase the value of crop production per hectare, but may reduce labor productivity and income per capita due to diminishing returns to labor (Salehi-Isfahani 1988; Pender 2001).

Market and road access: Market and road access can increase labor and/or capital intensity in agriculture by increasing output to input price ratios (Binswanger and McIntire 1987) or promoting adoption of higher value commodities, thus increasing the value of crop production and income. However, better access may reduce the intensity of crop production by increasing off-farm opportunities. In either case, better access to roads and markets is expected to promote higher income per capita.

Income Strategies: Different income strategies are expected to be associated with different agricultural practices as a result of differences in access to cash, credit, market information and opportunities. For example, households who earn significant off-farm income may be better able to finance purchased inputs

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[9] The maximum variance inflation factor was less than 5 in all cases (except when using predicted values of explanatory variables, in which case multicollinearity was a problem).

or investments than other households, and thus obtain higher value of crop production (Reardon, et al. 1994). On the other hand, off-farm activities may increase farmers' labor opportunity costs and thus reduce the labor intensity of agriculture.

Irrigation: Irrigation is expected to increase the intensity of crop production by enabling multiple crops per year and increasing the return to and reducing the risk of use of inputs. This is expected to increase input use and yields. Irrigation may also enable production of high value crops. These effects are expected to increase value of crop production and incomes.

Agricultural extension and credit: The impacts of extension and credit programs depend on what technologies they promote and the terms and availability of credit. In Tigray, as elsewhere in the Ethiopian highlands, the agricultural extension program has promoted increased used of external inputs such as fertilizer and improved seeds, and has provided short term credit to help finance use of these inputs. We expect that these programs have contributed to increased use of fertilizer and seeds, and that this has contributed to increased crop production. However, given the uncertain rainfall and thin soils in Tigray, the yield response and income impact of these inputs may be limited. If such inputs are applied in combination with irrigation or soil and water conservation measures, the yield response may be greater.

Household endowments: If markets for productive factors do not function efficiently, there may be differences among households in their use of inputs, land management and productivity due to differences in household endowments (de Janvry, et al. 1991). If labor markets are imperfect, households with a greater family labor endowment may be able to farm more intensively and conduct critical operations at the right time, and attain higher yields. Households with more oxen may be more able to use oxen at critical times and attain higher yields and income. Households with better access to land or liquid assets may be more able to finance input purchase or hired labor, and attain higher yields and income. Households with more education or other forms of human capital may have greater access to nonfarm income and/or credit, and thus be more able to purchase inputs. 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 agricultural practices due to higher labor opportunity costs, so may attain lower yields. Households with greater "social capital" (e.g., those with more social relationships, possibly through involvement in local organizations), may have better access to information or timely availability of inputs, and thus able to be more productive. Social capital may also increase farmers' returns from marketing their products or improve timely access to inputs (e.g., membership in marketing cooperatives).

3. Results of Econometric Analysis[10]

Input Use and Land Management Practices

Population pressure is associated with higher use of labor and animal draft power per hectare, and with a higher probability of use of fertilizer and intercropping (Table 1). We also find that households that own more land are less likely to apply fertilizer to a particular plot and more likely to use reduced tillage. These findings support the Boserup (1965) hypothesis that population pressure causes farmers to intensify use of labor and other inputs and to adopt more intensive land management practices.

Access to roads, markets and farmers' fields also affects the intensity of land management. Households closer to an all-weather road use more labor per ha. and are more likely to use fertilizer, burning and contour plowing. Households closer to a *woreda* town use more draft animal power per ha., but are less likely to contour plow. Farmers are more likely to use fertilizer, improved seeds, and manure/compost on plots closer to their residence, probably because of the difficulty of transporting inputs to distant plots. This is consistent with the findings of Gebremedhin and Swinton (2003)—who reported that farmers in central Tigray were more likely to use stone terraces on plots nearer to the homestead—in the sense that more intensive land management is used on plots closer to the residence.

Income strategies affect land management. Households for whom cereals are a secondary income source use less oxen power per hectare and are more likely to use reduced tillage. Producers of perishable

[10] Descriptive results are not presented due to space limitations, but are available from the authors.

annuals and perennial crops are more likely to use improved seed than cereals-only producers. Perishable annual producers also are more likely to use reduced tillage. Cattle producers use less labor and draft power than cereals-only farmers and are less likely to use burning, suggesting that cattle producers are less focused on intensive crop production than cereals-only producers. Similarly, small ruminants producers are less likely to apply manure or compost, or use intercropping. Households dependent on Food for Work or farm employment use less labor and draft power than cereals-only producers, but are more likely to use improved seeds. Households involved in trading are more likely to use reduced tillage, probably due to labor and capital constraints. Households dependent on food aid or other assistance use less draft power and are less likely to apply manure/compost, use burning, or use intercropping. Such households apparently lack the ability to farm as intensively as others.

As expected, irrigation increases use of labor, oxen power, improved seeds, and fertilizer (impact on fertilizer weakly significant at 10% level), due to producing multiple crops per year. Irrigation also promotes reduced tillage. Fertilizer use and contour plowing are more likely on plots with a stone terrace, suggesting complementarity of such soil and water conservation investments with use of inputs and contour plowing. Labor use and use of manure and compost are greater on plots that have a fence, suggesting that fences help to promote labor intensive practices. Burning is more common on plots with soil bunds; perhaps such bunds contribute to problems with weeds (Herweg 1993).

Not surprisingly, use of formal sector credit is strongly associated with greater use of fertilizer and improved seeds. This is because this credit is used primarily to purchase such crop inputs. Informal credit is not significantly associated with use of any crop inputs or land management practices, perhaps because informal credit is used for other purposes than agricultural production. Surprisingly, contact with the extension program is not significantly associated with use of inputs or land management practices. It appears that it is not the extension program per se that is leading to significant increases in use of fertilizer in Tigray, but rather availability of credit and other factors.

Ownership of livestock and other assets affects land management. Households who own more oxen use more labor and oxen draft power per ha., suggesting that oxen and labor are complements and that imperfect markets for hiring oxen constrain households who own fewer oxen. Greater oxen ownership also increases use of manure/compost and contour plowing, but reduces use of reduced tillage. Greater ownership of other types of cattle is associated with greater use of seeds and fertilizer, probably because income generated from cattle products helps farmers afford to buy these inputs. Consistent with this explanation, households with cash savings are more likely to use fertilizer and less likely to use manure and compost, suggesting that cash constraints limit use of fertilizer. By contrast, greater ownership of small ruminants is associated with less use of labor, draft power, seeds, and burning. This suggests that small ruminants producers focus less of their effort on crop production.

Human capital affects land management. Female-headed households use significantly less labor and draft power, probably due to labor constraints and a cultural taboo against women plowing in Tigray. Consistent with this, female-headed households also are less likely to apply manure or compost, and less likely to use contour plowing. Older household heads use more labor, probably because of greater availability of family labor old enough to be involved in crop production. Farmers who have completed three years of education use more labor than uneducated heads.

Social capital also affects land management. Households with members of a village council use more labor per ha. and are more likely to use improved seeds, manure/compost and intercropping. Such households appear to be more oriented towards intensive crop production than other households.

Crop Production

The amount of seed and oxen power used have relatively large and statistically significant positive impacts on production (elasticities of 0.27 and 0.20 in the OLS model) (Table 2). By contrast, the impact of human labor is quantitatively small (elasticity = 0.04) and statistically insignificant. This suggests that surplus labor exists in crop production in Tigray, with additional labor yielding little positive impact. This is not surprising, given the very small farm sizes and marginal agricultural conditions in Tigray, and it implies that population growth can have very negative consequences for human welfare, since the additional labor may not be productively used in agriculture (Lewis, 1954). Of course, as we have seen, population pressure and small farm sizes contribute to adoption of more intensive practices such as use of oxen and fertilizer, which can increase yields. Thus, the negative consequences of population pressure can be mitigated to some extent by such Boserupian responses. We investigate the extent of this mitigation below.

Several land investments and land management practices have a large and statistically significant impact on the value of crop production. The predicted value of production is 23% higher on plots with stone terraces, controlling for labor use, land management practices, and other factors.[11] Use of burning to prepare the field is associated with 29% lower yields and reduced tillage with 45% higher yields. Use of fertilizer is associated with 14% higher yields, and manure or compost with 13% higher yields (both effects statistically significant only at 10% level). Presence of a soil bund reduces the predicted return to fertilizer. This may be because of weed or pest problems caused by the combination of these technologies.

Almost all of these impacts are robust to the regression specification. The impacts of stone terraces, fertilizer, seed, oxen labor, and reduced tillage are still statistically and quantitatively significant in the IV model.[12] Stone terraces also have a significant positive impact on crop production in the reduced form specification.

Population pressure and farm sizes have a small and statistically insignificant impact on crop production per hectare in all regressions, even though we found that higher population density and smaller farm size promote greater use of some inputs. Larger households attain lower crop yields (significant at 10% level). These findings do not support the Boserupian optimistic perspective about the responses of households to population pressure leading to increased yields, and suggests that food production per capita will not keep pace with increasing population as farm sizes decline, since there is very little possibility to expand area under crop production in the densely populated highlands of Tigray. Unless households are able to depend on alternative livelihoods, food insecurity is thus likely to worsen as population continues to grow.

Households with better access to a *woreda* town had higher value of crop production, probably

[11] Considering the logarithmic specification for the dependent variable, the predicted impact of stone terraces using the OLS specification is exp(0.206) = 1.229, or a 23% increase.
[12] The Hausman test failed to reject the OLS model (p=1.000), so the OLS model is the preferred model.

because of greater production of high value products closer to towns. For example, teff (the highest value cereal produced in Tigray) production is negatively correlated with distance to the nearest *woreda* town (correlation = -0.12, 0.6% significance level).

Most income strategies have an insignificant impact on crop production. One exception is households dependent on food aid or other assistance, whose yields are surprisingly significantly higher than other households. We also find that households dependent on food aid and other assistance have higher incomes per capita than cereals only households (results for income discussed in the next subsection). These findings may be related to a lack of targeting of food aid in Tigray, as has been observed by other authors (Clay, et al. 1999).

We do not find a statistically significant effect of irrigation on the value of crop production, controlling for other factors. However, irrigation may increase crop production indirectly by increasing the use of inputs, including labor, oxen, fertilizer, and improved seeds. Below, we estimate the impacts of these indirect effects of irrigation and other factors.

Use of credit (formal or informal) is not associated with significant increases in crop production, even though we found that formal credit promotes use of fertilizer. This is consistent with the fact that our evidence shows only limited impacts of fertilizer on crop production. Contact with the agricultural extension program also has insignificant impact on crop production.

Ownership of cattle other than oxen is associated with higher crop productivity. This may be related to greater deposition of manure on plots operated by households owning more livestock (especially homestead plots).

Female-headed households achieve 42% lower crop yields than male-headed households, controlling for use labor, oxen power, and other inputs. Thus, not only are female-headed households disadvantaged in terms of their ability to apply inputs, but their productivity in using inputs is lower.

Households with members of a marketing cooperative attain substantially higher output value per hectare, probably because they focus on higher value crops, and have more timely availability of inputs. For example, members of marketing cooperatives produce nearly three times as much teff (the highest value cereal in Tigray), on average, as non-members.

Income

Many of the same factors that affect the value of crop production also affect per capita income (Table 2). Households with better access to a *woreda* town earn higher income (significant only in the IV regression), consistent with the result that value of crop production is higher closer to towns. Households with more cattle (other than oxen) earn higher income, while female-headed households earn significantly lower income per capita. Members of a marketing cooperative earn significantly higher income than other households (significant only in the OLS regression). Larger households earn less income per capita. Population density, farm size, other assets, and access to credit and extension have statistically insignificant impacts on per capita income.

Household pursuing many types of income strategies earn higher incomes than cereals-only producers. This includes households for whom cereals are a secondary income source and households whose secondary income source is cattle, food for work or farm employment, salary employment, trading, other nonfarm activities, and food aid or other assistance. In general, households with secondary income sources earn higher income per capita than those solely dependent on cereals production. The fact that households dependent on food aid or other assistance earn higher incomes (excluding such aid as income) is consistent with the finding discussed above that these households have higher crop yields, and with the argument that food aid is not well targeted.

Direct and Indirect Effects on Production and Income

The predicted direct and indirect effects of changes in selected policy relevant factors on crop production and per capita income, based on the econometric results, are shown in Table 3. The factors considered include increase in population density, improved access to an all-weather road or to a *woreda* town, increased education, increased access to extension or formal credit, increased participation in marketing cooperatives, investment in irrigation or stone terraces, or increased oxen or cattle ownership.

Participation in marketing cooperatives has the largest predicted impacts on both crop production and income, increasing both by more than 40%. Investment in stone terraces also has relatively large and positive predicted impacts on both crop production and income (around 14%), though the impacts on income are statistically insignificant. Improved access to a *woreda* town (by up to one hour walking time) is predicted to increase both the value of crop production and income by about 5-6%. Increased ownership of cattle (by one cow) also is predicted to increase crop production and income moderately. All of these scenarios represent possible "win-win" outcomes, increasing both productivity and incomes.

Many of the changes considered have relatively small (less than 5% change) and statistically insignificant predicted quantitative impacts on crop production and income. This includes the impacts of population growth (10 persons/km^2 increase), improved access to an all-weather road (up to one hour closer), universal access to formal credit, and increased oxen ownership (by one ox). Some of the changes have quantitatively large but statistically insignificant impacts, including investment in primary education (large positive impacts on both crop production and income), extension (negative impact on crop production but positive impact on income), and irrigation (small impact on crop production but large impact on income). Given the statistical insignificance of the coefficients upon which these predicted impacts are based, not too much should be made of the magnitudes of these impacts, however.

These results suggest that the most promising investments for increasing agricultural productivity and incomes in the highlands of rural Tigray are in marketing institutions, access to markets, in soil and water conservation measures such as stone terraces, and in cattle (other than oxen). Investments in roads, extension, and credit are of less clear benefit. The impacts of education may be large and positive, though we cannot be confident of the impacts of education based on our results.

4. Key Findings and Implications

Population Pressure

Population pressure, as reflected by higher population density, is associated with more intensive use of labor, oxen power, fertilizer, and intercropping. Smaller farms are also more likely to use fertilizer on a given plot and less likely to use reduced tillage. These findings are consistent with the predictions of population-induced intensification, as hypothesized by Boserup (1965) and her followers. However, increased farming intensity in more densely populated areas was not found to lead to significantly higher crop yields. In addition, population pressure at the household level, in terms of larger household size, is associated with lower yields and lower income per capita. These findings suggest that population growth, larger households and smaller farm sizes will lead to reduced food production and income per capita, since options for expanding crop production onto new land are very limited in the highlands of Tigray. The negative implications of population pressure are consistent with findings of other recent studies in the Ethiopian highlands (Pender, et al. 2001; Grepperud 1996).

Access to Roads and Markets

Better access to an all-weather road contributes to more intensive use of labor, fertilizer, burning, and contour plowing. However, we find little impact of better road access on the value of crop production or income. This probably is due to the fact that even in areas with relatively better road access, most households are still quite far from roads and rely primarily on walking and donkeys to transport commodities and inputs. The impacts of improved road access are quite limited in such a setting.

Households with better access to a *woreda* town use more oxen draft power but less contour plowing, and obtain higher value of crop production and higher per capita income than households in more remote locations (impact on per capita income significant only in IV regression). In contrast to road access, access to even small urban markets makes a difference for rural livelihoods.

Income Strategies

As expected, different income strategies are associated with differences in input use and land management practices. Households having several types of non-crop income use labor and oxen draft power less intensively than cereals-only producers, while producers of perennials and perishable annuals were more likely to use improved seeds. Despite such differences in cropping practices, we find no significant difference among most income strategies in value of crop production, except (surprisingly) households dependent on food aid and other assistance, which have higher crop production. These aid-dependent households also earn higher income per capita than cereals-only households (suggesting lack of targeting of food aid and other assistance), as do households pursuing many other income strategies. In general, households with more diversified income sources have higher incomes per capita.

Irrigation

As expected, irrigation increases the intensity of input use in crop production, including labor, oxen power, fertilizer, and improved seeds. Surprisingly, however, we do not find that irrigation contributes to higher value of crop production or income, even after accounting for the indirect effects of increased intensity of production. There are many problems affecting the performance of small-scale irrigation in Tigray, including problems of inadequate access to irrigation water when needed, salinity buildup due to seepage and poor drainage, lack of experience in using irrigation, etc., that are limiting the potential of small-scale irrigation in Tigray (Tesfay, et al. 2000). But our inability to identify an effect of irrigation may also be due to multicollinearity and an inadequate sample of irrigated plots.[13] We have a relatively small sample of irrigated plots in our sample (91 plots), and irrigation is correlated with other plot quality factors, especially plot size. Further research on the impacts of small-scale irrigation in Tigray, and the policy, institutional and technical factors affecting its effectiveness, is needed.

Agricultural Extension and Credit

The agricultural extension and credit program has sought to boost productivity largely by promoting use of fertilizer and improved seeds. The evidence presented shows some impact of fertilizer use on crop production (though the impact is statistically weak and not robust), increasing predicted value of production by 250 EB/ha on average, controlling for other factors. This yield increase is insufficient to cover the average costs of fertilizer (about 280 EB/ha in 1998), indicating that fertilizer use was unprofitable on average and explaining why farmers' are reluctant to adopt it, despite substantial efforts to promote its use. In a semi-arid environment as in the highlands of Tigray, use of fertilizer can be risky as well as unprofitable if adequate soil moisture cannot be assured. Given the heavy emphasis of the agricultural extension and credit program on promoting fertilizer use at the time of the study, it is thus not surprising that these programs were found to have little impact on crop production and income.

Although the return to fertilizer is low, there are indigenous technologies with potential to

[13] Recall that the value of crop production per hectare was much higher on irrigated plots. Such differences are not found in the econometric analysis when plot size and quality indicators are included.

substantially increase crop yields. Stone terraces increase crop productivity by an estimated 23%. Since stone terraces help to conserve soil moisture, they also increase the benefit of using fertilizer, which is probably why we find more fertilizer adoption on plots that have stone terraces. The estimated average rate of return to stone terraces is 46%, based on the predicted increase in annual value of crop production and our data on costs of constructing these terraces. This is comparable to the estimated rate of return to stone terraces in south central Tigray by Gebremedhin, et al. (1998), who estimated a 50% rate of return to stone terraces, and shows that investment in stone terraces is fairly profitable in Tigray. Several other indigenous land management practices, including application of manure and compost, reduced tillage and no burning also could have substantial impacts on crop productivity. Promotion of such technologies by the extension program could yield greater benefits than the emphasis on fertilizer and improved seeds.

Endowments of Physical, Human and Social Capital

Households that own more oxen use more oxen draft power, are more likely to use contour plowing and apply manure and less likely to use reduced tillage, suggesting imperfections in oxen rental markets. Despite these differences, we find no significant differences in crop production or income per capita resulting from differences in oxen ownership, suggesting that informal arrangements to share or lease oxen work relatively well in Tigray. Ownership of other cattle is associated with greater use of seed and fertilizer, perhaps because this helps to relax financial constraints. Households with more cattle (other than oxen) obtain higher yields and incomes, suggesting that milking animals are more profitable than oxen in the highlands of Ethiopia. Ownership of small ruminants appears to reduce intensity of crop production; small ruminants are associated with less use of labor, oxen power, burning and intercropping.

Primary education is associated with more intensive use of labor, though the reason for this is not clear. We find generally insignificant impacts of education on other aspects of land management, crop yields and income. By contrast, gender is very important in affecting land management and outcomes. Female-headed households use much less labor and oxen power, are less likely to apply manure, and obtain much lower crop yields and incomes than male-headed households. A cultural taboo against women using oxen for plowing is one factor disadvantaging female-headed households. Moreover, women are not usually included in agricultural extension programs. Priority should be given to promoting changes in such attitudes, as well as assisting female-headed households to pursue alternative livelihoods.

Some forms of social capital, as measured by involvement in local organizations, have a significant impact on crop production. Village council members farm with greater labor intensity and are more likely to use improved seeds, manure and intercropping than other households. Members of a marketing cooperative use less burning and attain more than 50% higher value of crop production per hectare, probably because they produce higher value crops and/or have better access to markets.

5. Conclusions

We have investigated the impacts of many factors commonly hypothesized to affect land management, and agricultural productivity in the highlands of Tigray. Some of these factors—including population pressure, small landholdings, access to roads, irrigation, extension and credit programs—have weaker impacts on agricultural production and incomes than often hypothesized. Most of these factors do affect the intensity of agricultural production and adoption of various land management practices. However, these impacts on intensity do not add up to much impact on total crop production, in part due to the low marginal product of labor in crop production and limited productivity impact of inputs such as fertilizer that have been promoted by some of these factors.

Some land management practices were found to substantially increase crop production, including construction of stone terraces, reduced burning, and reduced tillage. These practices apparently contribute to productivity by helping to conserve soil moisture and organic matter. Greater ownership of cattle (other than oxen) is also strongly associated with increased crop productivity, probably as a result of increased manure availability, and higher income. Promotion of such conservation practices and exploitation of complementary livestock production show more promise to boost crop production and incomes than large application of modern inputs such as inorganic fertilizer and improved seeds. However, there do appear to be opportunities to exploit complementarities between use of such inputs (especially fertilizer) and investment in stone terraces.

Livelihood diversification is key to reducing poverty in the highlands of Tigray, due to population pressure and the low productivity of land. Households that focus only on cereal production earn significantly lower incomes than households having more diversified income sources, including livestock, off-farm employment and non-farm activities.

Special attention to the problems of female-headed households is needed. Efforts to change attitudes about women plowing, enhance their farming skills, and promote alternative livelihoods, are needed to address the low levels of agricultural productivity and income of this vulnerable group.

Overall, the findings of this study show that profitable opportunities exist to increase agricultural production, incomes and achieve more sustainable land management in the highlands of Tigray. These opportunities include improvement of crop production using low-external input investments and practices such as terraces, reduced tillage and reduced burning; and improved livestock management. The comparative advantage of people in the Tigray highlands is not in input-intensive cereal crop production but more in low input technologies and alternative livelihood activities, such as livestock raising and non-farm activities. As a result, greater emphasis on developing these alternatives in agricultural extension and other development programs is needed. Food crop production should not be ignored in the development strategy, but more prudent use of external inputs such as fertilizer and improved seeds, and greater emphasis on low input sustainable land management practices, would be helpful.

Table 1. Determinants of input use and land management practices in crop production in 1998

Variable[e]	*Labor ln(person-days/ha)*[a]	*Oxen ln(animal-days/ha)*[a]	*Seeds ln(kg./ha.)*[a]	*Fertilizer*[b]	*Improved seed*[b]	*Manuring/ Composting*[b]	*Burning to Prepare Field*[b]	*Contour Plowing*[b]	*Reduced Tillage*[b]	*Intercropping/ Mixed cropping*[b]
ln(Population density) (/km^2)	0.122^{**+}	0.154^{***+++}	0.079	0.076^{**++}	0.0002	0.0491*	-0.0025	-0.0048	-0.0160	0.0605^{***+++}
Female head of hh	-0.415^{***---}	-0.207^{***--}	0.241**	-0.050	-0.0018	-0.0871^{***---}	0.0245	-0.1112***	0.0018	-0.0199
ln(Age of hh. head) (years)	0.224^{**++}	-0.045	0.216	0.071	0.0024^{*+++}	-0.0464	0.0347^{*+++}	0.0466^{*++}	-0.0325	0.0182^{+++}
ln(Household size) (no.)	0.123*	0.061	0.152*	-0.019	-0.0006	-0.0138	-0.0043^{++}	0.0049	-0.0472*	0.0199^{++}
Education of hh. Head										
- 3+ years	0.319^{***++}	-0.001	0.201	-0.009	0.0014^{+++}	0.0171	0.0220^{+++}	0.0278^{++}	-0.0126	-0.0148^{++}
- Literacy campaign	0.047	0.119	-0.005	-0.012	0.0020	0.0489	0.0442^{+++}	-0.0075	-0.0118	-0.0063
Walking time to (hours)										
- All weather road	-0.081^{***---}	-0.016	-0.001	-0.048^{***---}	0.0009	-0.0097	-0.0156^{***---}	-0.0143^{**-}	0.0069	0.0049
- Woreda town	0.016	-0.044^{***---}	-0.009	0.006	-0.0012*	0.0061	0.0054^{+++}	0.0114^{**++}	-0.0036	-0.0110**
- Plot from residence	-0.125	-0.026	0.077	-0.095^{**--}	-0.0082^{***---}	-0.3178^{***---}	0.0106	-0.0317^{*-}	0.0381	-0.0280^{-}
Ownership of assets										
- Land (tsimad)	0.015	-0.005	-0.025	-0.059^{**-}	-0.0009	-0.0136	0.0072	-0.0276**	0.0551^{***++}	-0.0082
- Oxen (number)	0.087^{**+}	0.071^{**++}	0.039	0.013	0.0008^{+}	0.0388^{***++}	0.0097	0.0378^{***+++}	-0.0359^{***--}	0.0153^{*+}
- Other cattle (number)	0.012	0.007	0.022^{*+++}	0.011^{**++}	0.0000	0.0043	0.0046^{**+}	0.0000	0.0021	0.0024
- Small ruminants (number)	-0.008^{**--}	-0.006^{***--}	-0.014^{***---}	-0.002	-0.0001	0.0017	-0.0028^{***---}	0.0009	0.0018	-0.0019^{**-}
- Pack animals (number)	-0.004	-0.009	0.026	-0.015^{--}	-0.0014^{***---}	-0.0143	-0.0056	0.0064	0.0026	-0.0195^{***--}
- Radio (yes/no)	0.028	-0.127^{**--}	0.096	0.052^{+}	-0.0014	0.0051	-0.0150	-0.0030	0.0402	-0.0362^{*--}
- Cash savings (yes/no)	0.080^{+}	-0.008	0.125	0.058^{*+++}	0.0003	-0.0659^{**--}	0.0058	-0.0231	-0.0063	-0.0050
Secondary income source										
- Cereals	-0.112	-0.404^{**--}	0.003	-0.009	-0.0005	-0.1002	-0.0192	-0.0439	0.1922^{**++}	-0.0356*
- Perishable annuals	0.534**	-0.108	0.004	-0.012	0.1522^{***+++}	0.0180	0.0123	-0.1398*	0.1838^{**++}	0.0631
- Perennial crops	0.247^{*+}	0.039	0.001	-0.009	0.0592^{***+++}	-0.0790	-0.0377^{*--}	-0.0248	-0.0255	c
- Cattle	-0.188^{**--}	-0.211^{***--}	0.145	-0.012	0.0044^{*+}	-0.0092	-0.0681^{***---}	-0.0367	0.0295	-0.0419**
- Small ruminants/beekeeping	-0.272^{*-}	-0.215	0.163	-0.009	c	-0.0935^{**--}	0.0271	0.0578	0.0501	-0.0493^{***---}
- Food for work/farm work	-0.438^{***---}	-0.368^{***---}	0.248*	-0.012	0.0163^{**+}	-0.0520	-0.0337^{*-}	-0.0711*	0.0715^{++}	0.0015
- Salary employment	0.129	-0.067	0.192	-0.009	0.0041	-0.0981^{*-}	-0.0291	-0.0043	-0.0445	-0.0112
- Trading	0.019	-0.119	-0.189	-0.012*	0.0079	-0.0193	-0.0277	0.0245	0.1383^{**+++}	0.0025
- Food/other assistance	-0.310*	-0.351^{***---}	0.321*	-0.009	0.0087^{+}	-0.0852^{**--}	-0.0448^{**---}	-0.0561	0.0407	-0.0430^{**--}
- Other nonfarm	0.006	-0.099	0.083	-0.012	0.0088	-0.0667	-0.0142	-0.0391	-0.0011	0.0238
Contact with extension	-0.095	-0.120^{*-}	-0.061	-0.046	0.0013^{---}	-0.0207	-0.0190^{---}	0.0171^{-}	-0.0039^{--}	0.0185^{-}

Variable[e]	*Labor ln(person-days/ha)*[a]	*Oxen ln(animal-days/ha)*[a]	*Seeds ln(kg./ha.)*[a]	*Fertilizer*[b]	*Improved seed*[b]	*Manuring/ Composting*[b]	*Burning to Prepare Field*[b]	*Contour Plowing*[b]	*Reduced Tillage*[b]	*Intercropping/ Mixed cropping*[b]
Membership in orgs.										
- Tabia council	-0.041	-0.036	-0.263	-0.057	c	-0.0713^{-}	0.0349	d	0.0312	c
- Village council	0.644^{***+++}	0.178	0.243	0.119	0.2415^{***++}	0.2785^{***+++}	c	d	-0.0476	0.2535^{**+}
- Marketing coop.	-0.111	0.007	0.250^{*+}	0.013	0.0001	0.0174	-0.0326^{*--}	-0.0110	0.0389	0.0189
- Agricultural cadre	-0.301**	0.079	-0.778***	0.191	-0.0017*	-0.0755^{-}	0.0548	-0.0036	-0.0265	0.0007^{--}
Use of credit										
- Formal credit	0.023	-0.006	0.179**	0.191***	0.0024^{**+}	0.0060	0.0183^{-}	0.0305*	0.0001	-0.0249
- Informal credit	0.048	-0.064	-0.066	0.038	-0.0011^{+++}	-0.0304	0.0238^{++}	0.0143^{+}	0.0292^{+}	-0.0224^{+}
Land use (cf. rainfed plot)										
- Homestead plot	0.426^{***+++}	0.160^{***+++}	0.236^{***+++}	0.006	-0.0028^{***---}	0.4402^{***+++}	0.0092	0.0365^{*+}	0.0371	0.0228
- Irrigated plot	0.875^{***+++}	0.308^{**++}	-0.025	0.160^{*+}	0.0156^{**++}	0.1125	0.0380	-0.0171	0.125^{***+++}	-0.0382
Initial investment on plot										
- Stone terrace	0.023	-0.028	0.068	0.091^{***+++}	-0.0004	0.0274	0.0137	0.0361^{**++}	0.0193	0.0068
- Soil bund	0.064	0.090^{++}	0.024	0.052	-0.0015^{-}	-0.0188	0.0773^{***+++}	0.0387	0.0196	0.0154
- Fence (live or constructed)	0.367^{***+++}	0.002	0.053	0.016	0.0020	0.2783^{***+++}	0.0096	0.0375	-0.0259	0.0015
Intercept	7.215^{***+++}	6.652^{***+++}	3.394	NR	NR	NR	NR	NR	NR	NR
Number of observations	1402	1353	1435	1607	1528	1607	1559	1524	1588	1528
Mean of dependent variable	3.932	3.184	4.229	0.2698	0.0236	0.2429	0.1078	0.8803	0.1181	0.1176
Mean predicted dep. variable	3.932	3.184	4.229	0.2685	0.0233	0.2437	0.1078	0.8674	0.1182	0.1171
R^2 or Pseudo R^2	0.5314	0.3357	0.4913	0.2125	0.3512	0.4241	0.2717	0.2951	0.1748	0.2747

[a] Least squares regression. Coefficients and standard errors adjusted for sampling weights, clustering and stratification. Hausman test failed to reject OLS model in all cases (p=1.000).
[b] Probit regression. Reported coefficients represent effect of a unit change in explanatory variable on probability of use at the mean of the explanatory variables.
[c] No positive values of dependent variable for positive values of the explanatory variable. Observations with positive values of the explanatory variable dropped from the regression.
[d] Only positive values of dependent variable for positive values of the explanatory variable. Observations with positive values of the explanatory variable dropped from the regression.
[e] Coefficients of biophysical variables (annual rainfall, altitude, plot slope, position on slope, soil depth, soil color, soil texture, and presence of gullies), plot area and how plot acquired not reported to save space. Full results available upon request.
$^{*, **, ***}$ mean coefficient statistically significant at 10%, 5% and 1% levels, respectively.
$^{+, ++, +++}$ and $^{-, --, ---}$ mean coefficient positive (negative) and statistically significant at 10%, 5% and 1% levels, respectively in IV regressions and probit models using predicted values of participation in extension, credit and organizations.
NR – The intercept is not reported by the Stata procedure showing marginal effects in probit models.

Table 2. Determinants of value of crop production per ha. and per capita income in 1998[a]

Variable[b]	ln(value of crop production/ha)			Per capita income		
	OLS[c]	IV[c]	RF	OLS[c]	IV[c]	RF
ln(Population density) (/km^2)	-0.013	-0.154	0.016	-0.36	-0.36	-0.36
Female head of hh	-0.551***	-0.478**	-0.481***	-108.76*	-110.82**	-106.23*
ln(Age of hh. head) (years)	-0.148	[d]	-0.090	-0.02	[d]	0.58
ln(Household size) (no.)	-0.145*	-0.212*	-0.090	-74.27***	-71.14***	-73.78***
Education of hh. Head						
- 3+ years	0.139	[d]	0.235*	101.15	[d]	93.70
- Literacy campaign	0.003	[d]	0.066	185.11*	173.50	175.5*
Walking time to (hours)						
- All weather road	0.017	[d]	0.014	-7.96	[d]	-9.41
- Woreda town	-0.056**	-0.028	-0.069***	-20.53	-25.83**	-19.76
- Plot from residence	0.066	[d]	0.052	59.00	[d]	66.42
Ownership of assets						
- Land (ha.)	-0.009	[d]	-0.019	24.58	[d]	21.86
- Oxen (number)	-0.043	[d]	-0.035	6.55	[d]	3.18
- Other cattle (number)	0.052***	0.014	0.063***	12.48*	18.63**	15.15**
- Small ruminants (number)	0.006	[d]	0.005	-0.39	[d]	-0.50
- Pack animals (number)	-0.046*	[d]	-0.032	27.30	[d]	24.49
- Radio (yes/no)	-0.147*	[d]	-0.078	49.55	[d]	47.38
- Cash savings (yes/no)	0.098	[d]	0.027	30.45	[d]	19.12
Secondary income source (cf. none)						
- Cereals	0.263	[d]	0.121	213.10**	272.38***	256.72***
- Perishable annuals	-0.250	-0.413	-0.337	-93.50	-99.15	-90.61
- Perennial crops	0.269*	[e]	0.199	84.36	103.78	85.10
- Cattle	-0.226*	-0.245*	-0.223*	127.20**	148.49**	135.16**
- Small ruminants/beekeeping	0.049	[d]	0.080	372.22	425.59*	411.00
- Food for work/farm employment	0.007	[d]	0.133	200.80***	191.54***	202.78***
- Salary employment	-0.197	[d]	-0.190	251.63***	241.93***	267.01***
- Trading	0.106	[d]	0.193	149.20*	243.32*	206.37**
- Food/other assistance	0.403**	0.319	0.604***	313.93**	344.18***	327.76**
- Other nonfarm	-0.016	[d]	-0.009	152.63**	178.41***	159.38**
Contact with extension	-0.142*	0.104	[f]	32.00	[d]	[f]
Membership in orgs.						
- Tabia council	0.435**	[e]	[f]	-223.03	[d]	[f]
- Village council	0.227	[d]	[f]	-64.58	[d]	[f]
- Marketing coop.	0.342***	0.073	[f]	195.92**	-137.19	[f]
- Agricultural cadre	-0.130	[d]	[f]	14.31	[d]	[f]

Variable[b]	ln(value of crop production/ha)			Per capita income		
	OLS[c]	IV[c]	RF	OLS[c]	IV[c]	RF
Use of credit						
- Formal credit	0.067	[d]	[f]	-13.32	[d]	[f]
- Informal credit	-0.067	[d]	[f]	-38.48	[d]	[f]
Land use (cf. rainfed plot)[g]						
- Homestead plot	0.147**	-0.359	0.425***	-28.15	-57.74	-33.39
- Irrigated plot	-0.173	-0.714	0.134	151.72	229.14	194.61
Initial investment on plot[g]						
- Stone terrace	0.206***	0.397***	0.163**	93.10	89.32	93.72
- Soil bund	0.153	-0.458	-0.100	73.16	76.09	89.23
- Fence (live or constructed)	0.083	0.086	0.068	-107.32	-39.94	-94.29
Use of inputs						
- Fertilizer (1=yes)	0.130*	0.799*	[f]			
- Fertilizer x stone terrace	-0.076	-0.804**	[f]			
- Fertilizer x soil bund	-0.455***	0.369	[f]			
- Fertilizer x irrigation	0.131	0.663	[f]			
- ln(Seed/ha) (kg./ha)	0.268***	0.617***	[f]			
- Improved seed (1=yes)	0.162	0.352	[f]			
- ln(Labor/ha) (days/ha)	0.040	-0.124	[f]			
ln(Oxen labor/ha) (days/ha)	0.199***	0.819*	[f]			
Use of land management practices						
- Burning to prepare field	-0.336***	-0.728	[f]			
- Contour plowing	0.099	0.276	[f]			
- Reduced tillage	0.375***	1.571***	[f]			
- Intercropping/mixed cropping	-0.043	-0.048	[f]			
- Manure or compost	0.125*	0.628	[f]			
Intercept	18.159***	11.231**	23.124***	662.32*	851.47***	658.51**
Number of observations	1160	1020	1340	436	425	436
R^2	0.4948	0.0735	0.3758	0.2604	0.2129	0.2445

[a] Least squares regressions. Coefficients and standard errors adjusted for sampling weights, clustering and stratification.
[b] Coefficients of biophysical variables (annual rainfall, altitude, plot slope, position on slope, soil depth, soil color, soil texture, and presence of gullies), plot area and how plot acquired not reported to save space. Full results available upon request.
[c] Hausman test failed to reject OLS model compared to IV model for value of production (p=1.000). The Hausman test comparing the OLS and IV models for per capita income was inconclusive, due to negative value of the test statistic.
[d] Variables jointly statistically insignificant in full version of both OLS and IV models dropped from reported version of IV model.
[e] Variable coefficient not estimable due to multicollinearity. Variable dropped in IV estimation.
[f] Endogenous variable excluded from reduced form.
[g] Explanatory variables are dummy variables in plot level crop production regression, shares of total area in household level income regression.
*, **, *** mean coefficient statistically significant at 10%, 5% and 1% levels, respectively.

Table 3. Simulated impacts of changes in selected variables on value of crop production and per capita income[a]

(percent change in mean predicted values)

Variable	Scenario	Mean of Selected Variable		Value of Crop Production (plot level)		Per capita income	
		Before Change	After Change	Direct Effects	Total Effects	Direct Effects	Total Effects
Population density (persons/km^2)	10 persons/km^2 increase	137	147	-0.1%	+0.4%	-1.0%	-1.1%
Access to all-weather road (hours walking)	Maximum 1 hour closer	2.3	1.3	-1.4%	-1.2%	+1.7%	+2.8%
Access to market town (hours walking)	Maximum 1 hour closer	3.5	2.5	+5.5%**	+6.8%^{R}	+5.3%$^{++}$	+5.6%
Primary education (proportion of hh heads)	Minimum 3 years for hh heads with less	0.06	0.92	+12.0%	+17.6%	+23.4%	+23.4%
Access to extension (proportion of hh)	Universal access	0.11	1.00	-11.1%*	-14.0%	+7.6%	+7.6%
Access to formal credit proportion of hh)	Universal access	0.58	1.00	+2.0%	+3.9%	-1.5%	-1.5%
Participation in marketing cooperative (proportion of hh)	Universal participation	0.06	1.00	+33.7%***	+45.5%	+48.7%**	+48.7%
Irrigation (proportion of plots)	All rainfed plots irrigated	0.07	0.80	-10.7%	-1.2%	+25.8%	+19.0%
Stone terraces (proportion of plots)	All plots terraced	0.37	1.00	+13.6%$^{***+++}$	+13.8%^{R}	+14.5%	+14.5%
Oxen ownership (number owned)	1 additional ox owned	1.1	2.1	-4.2%	-2.4%	+1.8%	+1.8%
Other cattle ownership (number owned)	1 additional animal owned	2.7	3.7	+5.4%$^{***+}$	+6.2%^{R}	+3.3%$^{*++}$	+3.3%^{R}

[a] Simulation results for direct effects based upon predictions from OLS model regressions reported in Tables 4 and 5. Results of OLS and probit regressions predicting input use and land management practices were used to predict indirect impacts on crop production. Results of multinomial logit regression for determinants of income strategies and probit regressions for determinants of use of credit, participation in extension and organizations used to predict indirect impacts on income.

$^{*, **, ***}$ mean direct effect is based on a coefficient that is statistically significant in the OLS regression at 10%, 5%, or 1% level, respectively.

$^{+, ++, +++}$ and $^{-, --, ---}$ mean direct effect is of the sign shown and statistically significant in the IV regression at 10%, 5% or 1% level respectively.

^{R} means that the coefficient is of the same sign and statistically significant at 5% level in the reduced form regression.

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