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Full Length Research Paper

Does Irrigation enhance and food deficits discourage fertilizer adoption in a risky environment? Evidence from Tigray, Ethiopia

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The northern Ethiopian highland in general and the Tigray region in particular is a drought prone area where agricultural production risk is prevalent. Moisture stress is a limiting factor for improved agricultural input mainly fertilizer use. Lack of capital and consumption smoothing mechanisms limits households' investment in production enhancing agricultural inputs, possibly leading into poverty trap. Using a Cragg (Double Hurdle) model, we analyzed how rainfall risks, access to irrigation and food deficits affect the probability that farm households' use fertilizer and given that the probability is positive and significant, the amount (intensity) of fertilizer use. Accordingly, we found that households were more likely to use fertilizer and that they used significantly higher amounts of fertilizer on their irrigated plots than on rain-fed plots. Furthermore, households with access to irrigation were more likely to use fertilizer, but the intensity (amount) of fertilizer they used was not significantly different from those households without access to irrigation. In investigating the effect of rainfall risk on fertilizer use, we found that fertilizer use was significantly higher in areas with higher average rainfall and in areas with lower rainfall variability. In general, irrigation was found significantly important for fertilizer adoption mainly in areas with low rainfall and high rainfall variability. Finally, we investigate the effect of food deficit on fertilizer adoption and found that both food self-sufficient and food deficit households were less likely to use fertilizer as coping mechanism. However, among those who decided to adopt, the food deficit households used higher amount of fertilizer than the food self-sufficient.

Keywords: Tigray, irrigation, average rainfall, rainfall variability, food deficit, fertilizer use.

INTRODUCTION

There have been many studies on the effect of irrigation on fertilizer adoption (Abdoulaye and Sanders, 2005; FAO, 2002; Fox and Rockstrom, 2000; IFA, 2002; Morris et al., 2007; Shah and Singh, 2001; Smith, 2004; Wichelns, 2003; Yao and Shively, 2007). Some of these studies suggest strong complementarities between irrigation and fertilizer. For example, Abdoulaye and Sanders (2005) argued that fertilizer and water are issues that need to be handled simultaneously because, when water is a limiting factor, fertilizer may have no positive effect or may indeed have an adverse effect. Shah and Singh (2001) considered irrigation as a major catalyst for agricultural growth through the adoption of Green Revolution technologies in India. FAO (2002) and Morris et al. (2007) have also argued that households with access to irrigation benefit more because of the complementarities of irrigation and fertilizer. However, irrigation and the Green Revolution have not been successful in Africa as in Asia (Feder et al., 1985).

Differing from findings from other parts of the world, previous studies in Tigray, Pender et al. (2002) reported

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that irrigation has insignificant effect on fertilizer adoption. Furthermore, using Deaton's (1997) approach to correct selection bias, Hagos (2003) finds a negative relationship between irrigation and fertilizer adoption. More recent work by Pender and Gebremedhin (2007) reports that fertilizer use on irrigated plots is less likely than on plots with stone terraces implying that the impact of irrigation on fertilizer use was less than the impact of stone terraces.

However, the previous studies from Tigray suffer from small sample size of irrigated plots, which constitute only 1% of the sample plots of Hagos (2003) and 5.6% of that of Pender et al. (2002) and Pender and Gebremedhin (2007). Although these studies were not mainly focused to study the effect of irrigation on fertilizer use, comparing such a small sample of irrigated plots with a large and heterogeneous sample of rain-fed plots makes it difficult to uncover any causal effect of irrigation. This makes estimation unreliable and more dependent on model specification and spurious correlations, while estimation results are susceptible to bias (Ho et al., 2007). Pender and Gebremedhin (2007) acknowledge this problem and suggest the need for further research.Forexample,heir paper does not properly control the effect of bio-physical factors, such as soil type, slope, and land quality. Given that farmers consider environmental and plot characteristics as a basis for their decision to invest in inputs, the omission of such variables may lead to omitted variable bias in the estimated parameters (Sherlund et al., 2002).

The effect of production risk and food deficit on technology adoption in general and fertilizer use in particular is mixed in the literature. The standard theory and view has been that producers' risk aversion leads to low adoption of new technologies (Dercon and Christiaensen, 2007; Feder et al., 1985; Sandmo, 1971). On the other hand, Finkelshtain and Chalfant (1991) and Fafchamps (1992) showed that poor households do not systematically produce less if they think that adoption of the new technology may help them to become more food self-sufficient. Our study area and data represent an excellent opportunity to test this.

Different studies have empirically investigated the determinants of fertilizer adoption in Ethiopia. Among others, Kassie et al. (2008) used output variance as a proxy of production risk and found that higher output variance and probability of crop failure were negatively related to the probability and intensity of fertilizer adoption. Consistent with this, they found that farmers' output (return) was positively related to the probability and amount of fertilizer use. Fufa and Hassan (2006), on the other hand, have investigated factors that affect the probability and intensity of fertilizer use on maize production in the Dadar district in eastern Ethiopia. They found that the age of the farm household's head and fertilizer price were negatively related to the probability and intensity of fertilizer use.On the other hand, farmers' fertilizer use. Demeke et al. (1998) has controlled for the effect of a wide range of factors affecting farm households' fertilizer use in four major crop producing regions (Amhara, Ormiya, SNNPR and Tigray) of Ethiopia. Among other factors, access to fertilizer distribution centers, access to credit and extension services were found to be important in influencing whether farm households in the Wereda* have used fertilizer. In the same study, teff (a staple crop in Ethiopia) was positively related to fertilizer use. This could be because the cultivated teff area covered the largest proportion of the total cultivated area. However, since growing teff is an endogenous decision of the farm household, the result could be susceptible to a problem of endogeniety. Surprisingly, Demeke et al. (1998) found no significant relationship between average rainfall and fertilizer use.

Despite their importance in informing policy makers, these studies have not adequately examined the role of irrigation in reducing production risk due to adverse climatic conditions and its effect on fertilizer adoption. They have not assessed the effect of average annual rainfall and rainfall variability on fertilizer adoption.

The objectives of this paper are, therefore, to: (1) analyze the effect of production risk due to rainfall scarcity and rainfall variability on fertilizer adoption, (2) investigate the role of irrigation in hedging against production risk and then to stimulate fertilizer adoption, and (3) investigate the effect of food deficit (consumption shocks) on fertilizer adoption.

Accordingly, this paper attempts to fill some of the gaps by analyzing the role of irrigation in mitigating the negative effect of low average rainfall and rainfall variability on fertilizer adoption. We also tried to investigate the effect of food deficit on fertilizer adoption. Since we lack a good measure of households' risk preference and risk aversion behavior, we could not control for its effect on fertilizer adoption. But the response to food deficit may also give a hint about households' risk preferences. The paper has also attempted to control for the effect of agro-ecological factors on fertilizer use, which is missing in the previous studies from Tigray. The analysis was made based on plot level data of both irrigated and rain-fed plots using a Cragg (Double Hurdle) model.

Literature Review: Risk and Technology Adoption

Sandmo (1971) has shown that a risk adverse profit maximizing firm reduces investment in purchased inputs and production, compared to what would be if it were risk neutral and maximizes the expected profit. This implies that firms without perfect insurance under-invest in purchased inputs and hence under-produce. This explanation has attracted attention among economists

*Wereda is an administrative unit under the regional state equivalent to a district. It consist different kebeles (tabias).

working on technology adoption. Producers' resistance to risk has been used to explain the failures of farm households to adopt new technologies (Feder et al., 1985). But, this view has been challenged in the sense that poor households do not systematically under-produce (Fafchamps, 1992; Finkelshtain and Chalfant, 1991). Fafchamps (1992) has showed that if people are poor and concerned about their survival, the solution may not be to under-invest and under-produce. However, they may even adopt risk increasing technologies if they think that it helps them to become food self-sufficient. Finkelshtain and Chalfant (1991) extended the analysis of Sandmo (1971) by assessing the behavior of a producer-consumer household rather than a pure producer, assessing the effect of being a net seller or net buyer producing an inferior or a normal good that is also consumed by the household, and varying the level of risk aversion. They derive an alternative measure of the risk premium, taking into account the covariance between income and price of output and show that the Sandmo result only holds strictly when $\eta > r > 0$, where η is the income elasticity of the household's demand for home-consumption of the farm crop and *r* is the relative risk aversion. They show that a net buyer of food who is risk neutral or slightly risk-averse has the same qualitative response as in the Sandmo model, while a more risk-averse producer increases output with increased risk. Furthermore, an increase in relative risk aversion is associated with increased output for a given level of risk. This suggests that net-selling producers use less input and produce less under risk than under certainty, while net-buying households with severe risk aversion increase their input use and production (Finkelshtain and Chalfant, 1991).

There is an agreement that fertilizer adoption, or modern input use in general, is crucial in achieving agricultural productivity growth and ensuring food security, especially in Sub-Saharan Africa, where agriculture is characterized by low use of modern technology and low productivity (Franklin, 2006; Kassie et al., 2008). In the adoption literature, production uncertainty (risk) and risk avoidance behavior of poor people are often associated with low adoption of modern inputs (Franklin, 2006; Hazell, 1988; Kassie et al., 2008; Rosenzweig and Binswanger, 1993). The most common factor for the low adoption of modern inputs is risk and farmers' resistance to technological innovations, which raises both the mean and variability of income (Hagos, 2003; Koundouri et al., 2006). Uncertainty associated with the adoption of modern inputs has two dimensions: the riskiness of farm yield after adoption and price uncertainty related to agricultural production itself (Koundouri et al., 2006).

Hazell (1988) has suggested that, despite the fact that production risk is prevalent everywhere, it is particularly burdensome to smallholder farmers in developing countries. They try to avoid it through different mechanisms, such as diversifying their crops, using traditional farming techniques (avoiding less familiar modern inputs) and using other risk sharing mechanisms such as sharecropping contracts. The types and levels of risk vary with the type of farming system, climate, degree of market integration, policy and institutional characteristics (Hazell, 1988). When farmers are constrained by either ex-ante resource constraints or limited by ex-post coping (insurance) mechanisms, they become hesitant to invest in modern technology such as fertilizer (Just and Pope, 1979; Rosenzweig and Binswanger, 1993). This may lead to a risk induced poverty trap, as those who are better endowed with ex-ante resources can self-finance their investment or can easily insure their consumption against ex-post income shocks and thereby take advantage of modern technology. On the other hand, those who are poor and resource constrained are engaged in low risk and low yield activities and may therefore be trapped in poverty (Kassie et al., 2008; Rosenzweig and Binswanger, 1993). Since low agricultural productivity causes persistent poverty, interventions that can help poor households to hedge against shocks and then adopt modern inputs might be an effective poverty reduction strategy (Dercon and Christiaensen, 2007).

Market imperfections such as those in labor and credit markets, can substantially influence farmers' technology adoption. This is important in developing countries in general and in Sub-Saharan Africa in particular, where rural infrastructures such as roads and communication networks are underdeveloped (Shiferaw et al., 2006). Imperfect markets are characterized by high transactions costs due to asymmetric information and imperfect competition that leads to non-separability of production and consumption decisions of households (de Janvry et al., 1991; Singh et al., 1986). When markets are imperfect, households' resource endowments become important determinants of investment and production decisions (Holden et al., 2001), implying that resource poor households are less likely to adopt purchased inputs. For example, an imperfect labor market leads households to equate their demand for labor with their family labor. Households with larger labor endowments are likely to adopt more labor intensive technologies than labor poor households. For example, Abdoulaye and Sanders (2005) found that fertilizer application also needs high labor input for weeding in Niger, indicating that labor rich farm households are more likely to adopt fertilizer.

An imperfect credit market also affects households' investment and production decisions. For example, fertilizer adoption requires an initial investment. With limited access to credit, poor households may not have the capacity to purchase it. Hence, wealthier households with accumulated savings in the form of cash or capital (such as livestock) are more likely to invest in fertilizer and reap the benefits. For example, Wills (1972) has reported that shortage of financing is a major limiting factor of fertilizer use. However, credit alone may not limit technology adoption, particularly if the technology requires small amount of resources (Feder et al., 1985).

Consumption risk is another important determinant of fertilizer adoption. Production risk is one major source of income fluctuations for rural households, especially in developing countries (Giné and Yang, 2008). This is due to the fact that output variability affects total agricultural output, which influences food security at household level. Households lacking insurance against shocks in food stock are likely to stick to their traditional production techniques. Since ensuring food security is important for subsistence-producing households, farmers may prefer inputs that are stable in output at different moisture levels (Kaliba et al., 2000). This implies that, despite enhancing productivity,fertilizer also increases income variability. Hence, households experiencing food deficit may decide not to adopt it, because they are ill-equipped to cope with shocks (Dercon and Christiaensen, 2007; Giné and Yang, 2008). Farm households may make their decision to adopt or not to adopt fertilizer based on its *ex-ante* and *ex-post* consumption plans. In general, food deficiency may affect households' fertilizer use in two dimensions. Firstly, food insecure households may have stocks or savings that partially facilitate consumption smoothing. Secondly, poor farm households that aim to minimize consumption fluctuations due to covariate shocks (such as drought) may opt for less risky inputs in order to avoid permanent damages (Dercon and Christiaensen, 2007; Giné and Yang, 2008). However, higher returns in good years may help to bridge the deficit in bad years, meaning that risky inputs may be preferred and result in higher food security overall.

In general, output variability causes substantial consumption risk under subsistence production, especially when production depends on rainfall. This is relevant in areas where insurance against production risk is absent and credit markets are imperfect. Dercon and Christiaensen (2007) reported that farmers in a semi-arid district of western Tanzania with limited options to smooth ex-post consumption were found to grow lower return, but safer crops. Gafsi and Roe (1979) have reported that poor farmers in Tunisia preferred domestically developed varieties to the imported varieties which are less known to them.

Based on this review of the theoretical and empirical literature, an analytical framework is developed in the next section relating production risk and irrigation to farm households' consumption needs and fertilizer adoption.

Analytical Framework

The framework focuses on a production environment where rainfall is scarce and erratic, markets are imperfect, peasant households are poor and strive for subsistence, and are net food buyers. With access to irrigation, a farm household produces on its irrigated and rain-fed plots. Assuming that the household i has p plots with $p = n + m$, where n represents irrigated and m represents rain-fed plots, income from agricultural production is specified as:

$$\begin{aligned} Y_i = &\sum_{n=1}^{n} p_q \theta^{(I)} Q_{ip}^{(I)} \left(x_{ip}^{f(I)}, x_{ip}^{nf(I)}; z_h, A_c, \psi_i \right) + \sum_{m=1}^{m} p_q \theta^{(R)} Q_{ip}^{(R)} \left(x_{ip}^{f(R)}, x_{ip}^{nf(R)}; z_h, A_c, \psi_i \right) \\ &- p_f \left(\sum_{n=1}^{n} x_{ip}^{f(I)} + \sum_{m=1}^{m} x_{ip}^{f(R)} \right) - p_{nf} \left(\sum_{n=1}^{n} x_{ip}^{nf(I)} + \sum_{m=1}^{m} x_{ip}^{nf(R)} \right) \end{aligned} \quad (1)$$

Where Y is a stochastic net income (Birr[†]) of household i produced on irrigated and rain-fed plots, Q is a vector of crop production outputs and p_q is a vector of output price. The variable x represents purchased inputs (such as hired labor, oxen, seed, chemicals and pesticides, etc.) used by household i on plot p where the superscripts f and nf represent fertilizer and other inputs, respectively, where p_f is price of fertilizer and p_{nf} is price of other inputs. The superscripts (I) and (R) indicate irrigated and rain-fed agriculture, respectively. Variable z_h represents household-specific characteristics (such as age, gender and education), the household's labor and capital endowments (such as, livestock and oxen) and the household's food stocks. These are included due to market imperfections leading to household-specific shadow prices for these endowment variables. Variable A_c captures plot characteristics, and ψ_i is unobserved household heterogeneity that captures unreported household characteristics, such as farming experience and skills, risk aversion, and other factors that affect households' input use and production decisions in an environment with imperfect markets. Production risk is represented by the random variable θ, which has mean 1 and variance

[†] Birr is an Ethiopian currency

$\theta_{\text{var}} = \sigma_{\theta}^{2}$. The distribution of this random variable is exogenous to the farmer's decision. The effect of the random variable (production risk) depends on the type of plot (that is, whether a plot is irrigated or rain-fed), implying that $\theta_{\text{var}}^{(I)} < \theta_{\text{var}}^{(R)}$.

When rainfall is variable and unpredictable, it affects agricultural production and causes production risk in two ways. First, shocks in weather conditions (θ) cause direct crop failure. On the other hand, if rainfall is unpredictable, the risk of investment in fertilizer becomes high, because when water is not available at the right time and in sufficient amount, fertilizer use may even have an adverse effect (Abdoulaye and Sanders, 2005), therefore, increasing production risk. Production risk due to adverse weather conditions may also affect prices (Holden and Shiferawl, 2004). Self-sufficient households or even surplus producers in normal years may become net buyers in drought years, when food prices tend to be higher because a larger area may face the same problem. In order to meet their food needs, households may have to sell some of their livestock, which creates a downward pressure on livestock prices. The indirect negative effects through changes in crop and livestock prices may be as big as the direct production loss effect (Holden and Shiferaw, 2004). With access to irrigation, the negative effect of stochastic environment and associated production risk should be lower. This implies that production risk on irrigated plots is less than that of rain-fed plots $\left(\theta^{(I)} < \theta^{(R)}\right)$.

We assume that both output and input prices are non-random (that is, farmers are assumed to be price takers in both markets). Risk adverse farm households maximize the expected utility of gross output specified as follows:

$$\max_{x_{ip}^{f(I)},x_{ip}^{f(R)},x_{ip}^{nf(I)},x_{ip}^{nf(R)}} EU\left[\begin{array}{l}\sum_{n=1}^{n} p_q\theta^{(I)}Q_{ip}^{(I)}\left(x_{ip}^{f(I)},x_{ip}^{nf(I)};z_h,A_c,\psi_i\right)+\sum_{m=1}^{m} p_q\theta^{(R)}Q_{ip}^{(R)}\left(x_{ip}^{f(R)},x_{ip}^{nf(R)};z_h,A_c,\psi_i\right)\\ -\left[p_f\left(\sum_{n=1}^{n} x_{ip}^{f(I)}+\sum_{m=1}^{m} x_{ip}^{f(R)}\right)-p_{nf}\left(\sum_{n=1}^{n} x_{ip}^{nf(I)}+\sum_{m=1}^{m} x_{ip}^{nf(R)}\right)\right]\end{array}\right] \quad 2)$$

Where E is the expectation operator and U is a well-behaved concave and non-decreasing utility function of total income. Other variables are as explained above.

The utility maximization problem of the farm household is subject to cash constraint specified as:

$$\left[p_f\left(\sum_{n=1}^{n} x_{ip}^{f(I)}+\sum_{m=1}^{m} x_{ip}^{f(R)}\right)+p_{nf}\left(\sum_{n=1}^{n} x_{ip}^{nf(I)}+\sum_{m=1}^{m} x_{ip}^{nf(R)}\right)\right]+p_qQ^D\left(z_h,\psi_i\right)\le \bar{C}\left(z_h,\psi_i\right) \quad (3)$$

where $p_qQ^D\left(z_h,\psi_i\right)$ is household's food consumption deficit and $\bar{C}(.)$ captures the farm household's cash constraint, both of which are conditioned by a household's characteristics, consumption preferences, access to credit and other unobserved household heterogeneities. Therefore, with a binding cash constraint, the maximization problem is specified as follows:

$$\max_{x_{ip}^{f(I)},x_{ip}^{f(R)}} L = EU\left[\begin{array}{l}\sum_{n=1}^{n} p_q\theta^{(I)}Q_{ip}^{(I)}\left(x_{ip}^{f(I)},x_{ip}^{nf(I)};z_h,A_c,\psi_i\right)+\sum_{m=1}^{m} p_q\theta^{(R)}Q_{ip}^{(R)}\left(x_{ip}^{f(R)},x_{ip}^{nf(R)};z_h,A_c,\psi_i\right)\\ -\left[p_f\left(\sum_{n=1}^{n}x_{ip}^{f(I)}+\sum_{m=1}^{m}x_{ip}^{f(R)}\right)-p_{nf}\left(\sum_{n=1}^{n}x_{ip}^{nf(I)}+\sum_{m=1}^{m}x_{ip}^{nf(R)}\right)\right]\end{array}\right] \quad (4)$$
$$+\lambda\left[\bar{C}\left(z_h,\psi_i\right)-p_f\left(\sum_{n=1}^{n}x_{ip}^{f(I)}+\sum_{m=1}^{m}x_{ip}^{f(R)}\right)-p_{nf}\left(\sum_{n=1}^{n}x_{ip}^{nf(I)}+\sum_{m=1}^{m}x_{ip}^{nf(R)}\right)-p_qQ^D\left(z_h,\psi_i\right)\right]$$

Given that:

$Y = p_q\theta^{(I)}Q^{(I)} + p_q\theta^{(R)}Q^{(R)}$, the first order conditions (FOCs) for x_f^I and x_f^R are:

$$\frac{\partial L}{\partial x^{f(I)}} = \frac{\partial EU}{\partial Y}\left[p_q\theta^{(I)}\frac{\partial Q^{(I)}}{\partial x^{f(I)}} - p_f\right] - \lambda p_f = 0 \quad (5)$$

$$\frac{\partial L}{\partial x^{f(R)}} = \frac{\partial EU}{\partial Y}\left[p_f\theta^{(R)}\frac{\partial Q^{(R)}}{\partial x^{f(R)}} - p_f\right] - \lambda p_f = 0 \quad (6)$$

Equations (5) and (6) show the marginal benefit minus marginal cost of fertilizer used on irrigated and rain-fed plots, respectively. λp_f is the opportunity cost of reducing current consumption due to investment in fertilizer. Variable λ is a markup shadow price of fertilizer. From Equations (5) and (6), we see that the marginal cost of production and the opportunity cost of reduction in current consumption are the same in both irrigated and rain-fed agriculture. Given that other inputs remain the same, we assume that expected income from irrigated agriculture is greater than rain-fed agriculture, that is, $E\left(p_q\theta^{(I)}Q^{(I)} - C^{(I)}\right) > E\left(p_q\theta^{(R)}Q^{(R)} - C^{(R)}\right)$. This is due to the fact that the effect of random shocks is less in irrigated agriculture than in rain-fed agriculture $\left(\theta_{\text{var}}^{(I)} < \theta_{\text{var}}^{(R)}\right)$. Accordingly, we expect that

$$\frac{\partial EU}{\partial Y}p_q\theta^{(I)}\frac{\partial Q^{(I)}}{\partial x^{f(I)}} = \frac{\partial EU}{\partial Y}p_q\theta^{(R)}\frac{\partial Q^{(R)}}{\partial x^{f(R)}}, Q^{(I)} > Q^{(R)}, x^{f(I)} > x^{f(R)} \quad (7)$$

Equation (7) implies that the average return of fertilizer used in irrigated agriculture is greater than the average return of fertilizer used in rain-fed agriculture.

$$EU\left(Y\middle|x^f > 0\right) > EU\left(Y\middle|x^f = 0\right) \quad (8)$$

Based on the theory that we review and the theoretical framework, we have developed the following hypotheses for empirical testing:

H1: Farm households are more likely to use fertilizer on irrigated plots than on rain-fed plots. The implication is that the dummy variable plot type (1=irrigated) has a positive and significant effect on the likelihood of household's fertilizer use.

H2: Access to irrigation enhances fertilizer use. The intuition behind this hypothesis is that controlling for the effect of other plot characteristics, farm households use more fertilizer on irrigated plots than rain-fed plots. Therefore, if the stated hypothesis hold, the coefficient of plot type (1=irrigated) is positive and statistically significant in the intensity regression.

H3: Rainfall risk hypotheses

H3a: *Low average rainfall leads to less use of fertilizer.* The implication is that the coefficient of mean rainfall is positive and statistically significant in both the probability and intensity models.

H3b: *High rainfall variability leads to low fertilizer use.* The implication is that the coefficient of rainfall variability is negative and statistically significant in both the probability and intensity regressions.

H4: Irrigation and rainfall risk interaction hypotheses

H4a: *Irrigation stimulates greater fertilizer use in low rainfall areas than in high rainfall areas*. The implication is that the interaction effect of irrigation and rainfall (*rainfallirr*) on fertilizer use is negative. Thus, the marginal benefit of irrigation investment is lower in high rainfall areas. Its effect on fertilizer adoption is less there as well.

H4b: *Irrigation stimulates greater fertilizer use in areas with high rainfall variability relative to areas with low rainfall variability.* The implication is that the interaction effect of irrigation and rainfall variability (*cvirr*) on fertilizer use is positive and significant.

H5: Food deficit impact hypotheses

H5a: *The probability of food self-sufficiency is positively associated with fertilizer use.*

H5b: *Households predicted to have a food deficit use less fertilizer than households that do not have a food deficit.* This is because such households are less able to bear *ex-post* consumption fluctuations and fund fertilizer use (Dercon and Christiaensen, 2007).

H5c: *Food deficit households use more fertilizer than other households in order to reduce their food deficit* (Finkelshtain and Chalfant, 1991).

The Study Area and Data

The data used in this paper came from a large rural household sample survey targeting small-scale irrigation projects in the Tigray region, northern Ethiopia. Our study area covers six communities/Tabias[‡], each consisting about four villages. These sites were selected to represent different agro-ecological settings, water typologies (source of irrigation water), irrigation water distribution and management systems.

The sample was established through a three-stage stratified random sampling process. First, all Tabias in the region with irrigation projects were identified based on the type of irrigation technology. Altitude, size of irrigable land and experience (years since irrigation was started) were also used as a basis for stratification. Among the six sites, two of them use micro-dam, and two use river diversion, as a source of irrigation water. The remaining two use ground water, while one of them is using pressurized tube irrigation infrastructure. At the second stage, all farm households in each Tabia were stratified based on their access to irrigation.

In the final step, we selected 100 sample households from each Tabia, with the exception of Kara-Adishawo (in Raya Azebo), from which we have 113 sample households. The number of households with and without access to irrigation was determined based on the proportion of total farm households that have and have not access to irrigation in each Tabia. This approach enabled us to have households with and without irrigated plots, with the second group serving as a counterfactual. In this paper, we dropped rented in and rented out plots. Hence, we used 1782 owner-operated plots, of which 1419 and 363 are rain-fed and irrigated, accounting for 79.6 and 20.4% respectively[§]. A plot is defined as a distinct management unit based on the type of crop planted during 2004/2005 agricultural season.

Data on plot characteristics include soil type, land quality and slope (as perceived by the farm households) and recall data on inputs and output from the past harvest season[**]. Plot size was not physically measured, but farmers were asked to report the size of the plot in the local measurement unit (*tsimdi*[††]). Size was subsequently converted into hectares. Since farmers have land certificates indicating the size and boundaries of their plots, we trust that the size of plots that they reported is quite accurate.

Descriptive Statistics

Table 1 presents a summary of variables used in the regression. We see that about 77% of the sample households are headed by males. Households with access to irrigation have higher shares of female labor. About 62% of pure rain-fed cultivating and 66% of irrigating households have access to credit. The overall average plot size is about 1.2 ha and the average size of rain-fed and irrigated plot is 1.4 and 0.41 ha, respectively. On average, about 22, 20, 23 and 35% of rain-fed plots, and 17, 33, 27 and 24% of irrigated plots are found in Baekel (Cambisol), Walka (Vertisol), Hutsa (Leptosol) and Mekayhi (Luvisol) soils, respectively (for soil characteristics see Appendix 2). On the other hand, about 9% of irrigated and 19% of rain-fed plots are found in plain area, while farmers believe that about 82% of their irrigated and 60% of rain-fed plots are of good quality. Overall, average fertilizer use is about 10.5 Kg/ha, about 18.2 and 8.5 Kg/ha on irrigated and rain-fed plots, respectively. Finally, we see no statistical difference in the village level variables, except that 28% of rain-fed plots and 35% of irrigated plots are found in lowland (Kola) areas.

Estimation Methods

In order to test the effects of households' food self-sufficiency and actual food deficits on households' fertilizer adoption, we first ran a probit model to predict the probability that households were food self-sufficient. We had data whether a farm household had sufficient food at the beginning of the rainy season (June), but this variable was likely endogenous and dependent on structural characteristics (such as household wealth, composition and general agro-climatic conditions). It may also be affected by potential community-wide shocks (like droughts) or individual household (like health problems affecting the labor force during the production season). The results of the probit model are presented in Appendix 1.To capture shocks in households' food availability and examine the effect of a food deficit on households' fertilizer use, we used the residual (= dummy for actual food self-sufficiency minus the predicted food self-sufficiency) to generate two dummy variables. The first of these (*D1foodaversi*) was set equal to one if the value of the residual is greater than -0.5 and less than 0. This captures food deficit households that were predicted to

[‡] Tabia is the lowest administrative unit in the structure of the Regional Government of Tigray.

[§] Most farm households in the study are own more than one plot, which may consist of rain-fed and irrigated plots

[**] Data collection was carried out during October-December, 2005

[††] Four tsimdi is approximately equal to one hectare.

Table 1. Summary statistics of variables.

Variable	Description	Total owner operating households	Households who have no access to irrigation	Households who have access to Irrigation	t-test
	Household level Variables				
Jnenough	Household has enough food in June (1=yes)	0.436 (0.021)	0.4160 (0.030)	0.455 (0.030)	-0.897
Hhage	Household age	46.813 (0.657)	46.814 (0.928)	46.811 (0.933)	0.002
Hheadsex	Household sex (1=male)	0.765 (0.018)	0.766 (0.026)	0.764 (0.026)	0.059
Litrate	Literate household members	1.375 (0.062)	1.223 (0.079)	1.524 (0.096)	-2.418**
Femwl	Household member female labor	1.585 (0.039)	1.561 (0.054)	1.607 (0.058)	-0.582
Mamwl	Household member male labor	1.426 (0.044)	1.431 (0.064)	1.422 (0.062)	0.106
Oxen	Oxen ownership	1.246 (0.045)	1.197 (0.067)	1.295 (0.061)	-1.079
Totaltlu	Livestock ownership (tlu)	3.131 (0.143)	3.002 (0.227)	3.257 (0.176)	-0.887
Farasso	Household's access to credit (1=yes)	0.638 (0.021)	0.617 (0.030)	0.658 (0.029)	-0.996
Adueqcoworo	Adult equivalent consumer worker ratio	1.561 (0.039)	1.508 (0.055)	1.613 (0.054)	-1.369
Farmzpadu	Owner operated land holding per adult equivalent (ha)	1.125 (0.038)	1.318 (0.061)	0.936 (0.042)	5.195***
Obs.	Number of households	544	269	275	
	Plot level variables	**Total plots**	**Rain-fed plots**	**Irrigated plots**	
Plottype	Plot type (1=irrigated)	0.204 (0.010)	----	----	-----
Plotsize	Plot size in ha.	1.198 (0.025)	1.400 (0.029)	0.409 (0.008)	19.545***
Yhat	Predicted probability of food availability in June	0.464 (0.004)	.469 (0.005)	0.443 (0.010)	3.256***
D1foodaveresi	Food deficit households predicted to be so	0.384 (0.012)	.384 (0.013)	0.383 (0.026)	0.180
D2foodaveresi	Food deficit households predicted to be food self-sufficient	0.144 (0.008)	.145 (0.009)	0.140 (0.018)	-0.668
Baekel	Soil type, 1=baekel)	0.210 (0.010)	0.222 (0.011)	0.165 (0.020)	3.481***
Walka	Soil type (1=walka)	0.224 (0.010)	0.198 (0.011)	0.325 (0.025)	-4.598***
Hutsa	Soil type (1=hutsa)	0.240 (0.010)	0.233 (0.011)	0.270 (0.023)	-2.896***
Mekayhi	Soil type (1=mekayhi)	0.325 (0.011)	0.347 (0.013)	0.240 (0.022)	3.808***
Slope1	Slope of plot (1=plain)	0.168 (0.009)	0.189 (0.010)	0.088 (0.015)	4.805***
Landqual1	Plot quality (1=good, 0=poor)	0.646 (0.011)	0.601 (0.013)	0.824 (0.020)	-7.985***
Ferzuse	Fertilizer has bee applied (1=yes)	0.311 (0.011)	0.315 (0.012)	0.298 (0.024)	0.059
Fertzperha	Fertilizer used (Kg/hectare)	10.476 (0.565)	8.513 (0.475)	18.152 (2.016)	-8.542***
	Village level variables				
Mktwalkdis	Walking distance to all weather roads	0.935 (0.006)	0.937 (0.006)	0.926 (0.014)	
Popdensi	Population density (Km^2)	104.514 (1.058)	105.296 (1.220)	101.455 (2.049)	0.852
Degua	Agro-ecology, 1=highland, 0=otherwise	0.221 (0.010)	0.228 (0.011)	0.190 (0.021)	1.209

Table 1.Cont'd

Wdegua	Agro-ecology, 1=mid-altitude, 0=otherwise	0.488 (0.012)	0.495 (0.013)	0.463 (0.026)	0.897
Kola	Agro-ecology, 1=lowland, 0=otherwise	0.291 (0.011)	0.277 (0.012)	0.347 (0.025)	-2.064**
Rainfall	Average annual rainfall (mm)	779.535 (2.972)	781.150 (3.349)	773.223 (6.436)	0.920
Cv	Coefficient of rainfall variability	0.334 (0.003)	0.334 (0.004)	0.331 (0.007)	-0.287
Rainirri	Rainfall-irrigation interaction	141.226 (6.799)	0 (0)	693.290 (7.691)	-20.028***
cvirri	Rainfall variability-irrigation interaction	0.068 (0.003)	0 (0)	.331 (0.007)	-18.599***
loca1	Tabia (1=Adis Alem)	0.1765 (0.016)	0.160 (0.022)	0.193 (0.024)	-1.005
Loca2	Tabia (1=Kara-Adishawo)	0.175 (0.016)	0.234 (0.026)	0.116 (0.019)	3.657***
loca3	Tabia (1=Laelay Agulae)	0.127 (0.014)	0.052 (0.014)	0.2 (0.024)	-5.308***
loca4	Tabia (1=Adi-Ha)	0.175 (0.016)	0.1450 (0.022)	0.204 (0.024)	-1.804*
loca5	Tabia (1=Adidedena)	0.182 (0.017)	0.227 (0.026)	0.138 (0.021)	2.690***
loca6	Tabia (1=Maiadrasha)	0.165 (0.016)	0.182 (0.024)	0.1491 (0.022)	1.037
popdensi	Population density (people/Km^2)	100.118 (1.821)	96.539 (2.725)	103.619 (2.410)	-1.949*
Obs.	Number of plots	1419	363	1782	

* Significance level is 10%, ** significance level is 5%, *** significance level is 1%, Figures in parenthesis are standard errors.

be in food deficits. The second (*D2foodaversi*) was set equal to one if the value of the residual is less than -0.5 and captures food deficit households that were predicted to be food self-sufficient. Therefore, their actual food deficit may be attributable to a shock. For a clear exposition of how the two dummy variables were generated, see Table 4.

The more negative the residual is, the less likely the household is facing food deficit; that is, such households are wealthier and subsequently food self-sufficient. We use both variables in the fertilizer adoption models to test whether food deficits are expected to affect farm households' ability to invest in fertilizer as a strategy to become food self-sufficient.

In our sample data, fertilizer use has been reported in about 30% of irrigated and 32% of rain-fed plots (Table 1). In such conditions, estimating the parameters using OLS regression fails to account for the qualitative difference between zero and continuous observations and leads to biased estimates. This is sometimes referred to as "substantial bias" (Franklin, 2006; Smits, 2003). On the other hand, restricting the analysis to observations where fertilizer has been applied (that is, $f > 0$) will yield biased and inconsistent parameter estimates. This is known as "heterogeneity bias" (Smits, 2003) because it ignores the process that generated the observed fertilizer use (Yilma and Berger, 2006).

We assessed whether it is appropriate to use a one-shot or two-stage model for fertilizer use by comparing the results of a censored Tobit model and a Cragg (double hurdle) model. In the double hurdle model, we first estimated the probability that the farm household adopts fertilizer. We estimated the intensity of fertilizer use in the second stage. We performed a likelihood ratio test

Table 2. Probability of fertilize use.

Variable	Variable description	Coefficient	Std. Error
hhaccirr	Household has access to irrigation (1=yes)	0.118*	0.070
plottype	Plot type (1=irrigated)	2.101***	0.450
hhage	Household age	-0.018***	0.004
hheadsex	Household sex (1=male)	0.822***	0.128
litrate	Literate household members	0.080***	0.025
femwl	Household member female labor	0.044	0.042
mamwl	Household member male labor	0.031	0.035
oxen	Oxen ownership	0.163**	0.066
totaltlu	Livestock ownership (tlu)	0.050*	0.027
farasso	Household's access to credit (1=yes)	-0.048	0.097
plotsize	Plot size (ha)	0.077*	0.046
farmzpadu	Owner operated land holding per adult equivalent (ha)	0.033	0.060
yhat	Predicted probability of food availability in June	-2.875***	0.959
D1foodaversi	Food deficit households predicted to be so	-0.290***	0.091
D2foodaversi	Food deficit households predicted to be food self-sufficient	-0.066	0.103
landqual1	Plot quality (1=good, 0=poor)	0.080	0.081
slope1	Slope of plot (1=plain)	-0.220**	0.101
Baekel	Soil type, 1=baekel)	-0.302**	0.120
Walka	Soil type (1=walka)	-0.038	0.124
Hutsa	Soil type (1=hutsa)	-0.093	0.124
rainfall	Average annual rainfall (mm)	0.026***	0.003
cv	Coefficient of rainfall variability	-14.711***	1.874
rainirri	Rainfall-irrigation interaction	-0.002***	0.001
cvirri	Rainfall variability-irrigation interaction	-1.114	0.758
Degua	Agro-ecology, 1=highland, 0=otherwise	4.133***	0.425
Wdegua	Agro-ecology, 1=mid-altitude, 0=otherwise	1.346***	0.193
mktwalkdis	Walking distance to all weather roads	-0.059	0.149
cons	Constant	-16.390***	1.499
	Number of observation	1782	
	Log likelihood	-859.800	
	Wald chi2(27)	1257.790	
	Prob > chi2	0.000	
	Pseudo R2	0.222	

to see whether the censored Tobit model nests the two-stage model. The likelihood ratio test rejected the censored Tobit model in favor of the Double hurdle model ($\chi^2_{(22)} = 316.75,\ prob = 0.000$).

Given our two-stage model, there is also a risk of selection bias related to clustering at zero due to selection rather than censoring. A Heckman selection test was used to test for selection bias. We found no significant selection bias in the Heckman selection model and hence present only the results from the Cragg (double hurdle) model.

Results and Discussion

We found that households with access to irrigation are significantly (at 10% level) more likely to use fertilizer than households without access to irrigation. Our first hypothesis (**H1**) stated that farmers are more likely to use fertilizer on their irrigated plots than on rain-fed plots. We see from Table 2 that farm households were significantly (at 1% level) more likely to use fertilizer on irrigated plots than on rain-fed plots. Furthermore, our second hypothesis (**H2**) stated that access to irrigation enhances fertilizer intensity. We found that farm households' use

Table 3. Intensity of Fertilize use.

Variable	Variable description	Coefficient	Std. Error
Hhaccirr	Household has access to irrigation (1 = yes)	8.517	8.246
Plottype	Plot type (1 = irrigated)	163.562***	60.259
Hhage	Household age	0.824	0.563
Hheadsex	Household sex (1 = male)	-9.795	13.736
Litrate	Literate household members	0.102	2.844
Femwl	Household member female labor	1.068	4.669
Mamwl	Household member male labor	5.193	3.515
Oxen	Oxen ownership	-11.969	8.369
Totaltlu	Livestock ownership (tlu)	-0.073	3.246
farasso	Household’s access to credit (1 = yes)	-12.054	12.181
Plotsize	Plot size (ha)	-64.328***	12.220
farmzpadu	Owner operated land holding per adult equivalent (ha)	-17.430**	7.878
Yhat	Predicted probability of food availability in June	120.973	117.566
D1foodaversi	Food deficit households predicted to be so	43.402***	12.930
D2foodaversi	Food deficit households predicted to be food self-sufficient	14.178	8.727
landqual1	Plot quality (1 = good, 0 = poor)	13.851	8.512
Slope1	Slope of plot (1 = plain)	-17.063	12.598
Baekel	Soil type, 1 = baekel)	1.050	12.174
Walka	Soil type (1 = walka)	-18.946*	10.291
Hutsa	Soil type (1 = hutsa)	-13.093	11.023
Rainfall	Average annual rainfall (mm)	0.860**	0.368
Cv	Coefficient of rainfall variability	-592.664**	246.848
Rainirri	Rainfall-irrigation interaction	-0.228**	0.104
Cvirri	Rainfall variability-irrigation interaction	147.986*	88.269
Degua	Agro-ecology, 1 = highland, 0 = otherwise	112.454**	54.475
Wdegua	Agro-ecology, 1 = mid-altitude, 0 = otherwise	12.659	25.451
Mktwalkdis	Walking distance to all weather roads	4.970	17.206
Cons	Constant	-571.251***	217.913
	Number of observation	555	
	Log likelihood	-2396.732	
	Wald chi2(27)	85.400	
	Prob > chi2	0.000	

significantly (at 1% level) higher amounts of fertilizer on irrigated plots than on rain-fed plots (see Table 3).Therefore, we are clearly not in a position to reject these hypotheses, contrary to earlier findings in this part of Ethiopia. One possible explanation may be that there is a learning curve in relation to production on irrigated land, as it is a relatively new technology, and the advantages have become stronger in our more recent data. Another explanation is that we have better quality data, allowing us to do a more rigorous test than was possible in earlier studies.

Hypothesis three (**H3a and H3b**) stated that fertilizer adoption is lower in areas with low rainfall and in areas with high rainfall variability. We found that the probability of fertilizer use was significantly (at 1% level) higher in areas with higher average rainfall and lower rainfall variability (*cv*), in line with our hypotheses. Similarly, the intensity of fertilizer use is significantly (at 5% level) higher in high rainfall and low rainfall variability areas (Tables 2 and 3). The results imply that rainfall risk is an important constraint to fertilizer adoption in Tigray.

Hypothesis four (H4a, H4b) stated that irrigation stimulates greater fertilizer use in low rainfall and high rainfall variability areas relative to areas with high average annual rainfall and low rainfall variability. To test these hypotheses, we use the interaction effect of irrigation with average annual rainfall (*rainirr*) and rainfall variability (*cvirr*). From Table 2, the significance (1% level) of the first interaction variable indicates that the effect of irrigation on the probability of fertilizer use is higher in low rainfall areas than in high rainfall areas, while the second interaction variable was insignificant. Both interaction variables were significant (at 5% and 10% levels) with negative and positive signs in the

Table 4. Two dummy variables.

	Food availability in June (Y)	
	Yes = 1	No = 0
Predicted food availability (yhat)	Y-yhat = (+)	Y-yhat = (-), D1=1 if 0>D1>-0.5
	Y-yhat = (+)	Y-yhat = (-), D2=1 if D2<-0.5

intensity model (Table 3). This provides clear evidence of the higher importance of irrigation availability for fertilizer adoption in low rainfall areas and weak evidence of more fertilizer use in areas with more rainfall variability. These findings imply that irrigation is more important for fertilizer adoption in drought-prone areas than in areas with sufficient precipitation. This may have policy implications for where to allocate irrigation investments, but it must be combined with overall cost-benefit analyses where investment costs, crop productivity effects and transportation costs are taken into account.

Hypothesis five (**H5a, H5b, H5c**) stated that food deficits may affect fertilizer adoption positively or negatively and that expected (predicted) food deficits may have a different effect than actual food deficits (for example, due to shocks). From Table 2, we see that the higher probability of households' being food self-sufficient (*yhat*) was negatively related to the probability of fertilizer adoption (significant at 1% level). This indicates that expected food deficits stimulate fertilizer adoption as a means to reduce the deficit. However, food deficit households predicted to be so (*D1foodaversi*) were significantly (at 1% level) less likely to use fertilizer. This may indicate that particularly poor households experiencing a food deficit may be forced to use scarce resources to buy food to satisfy current consumption, rather than to invest in fertilizer adoption to reduce future food deficits.

On the other hand, in regards to the intensity of fertilizer use (Table 3), food deficit households predicted to have a food deficit used significantly (at 1% level) higher amounts of fertilizer than food self-sufficient households. The food deficit may not have come as a shock to these households;but they may be less liquidity constrained and thus appear to try to reduce future food deficits by using higher levels of fertilizer. We should remember that the sample size here has been restricted to those using fertilizer, meaning that those who were unable to buy fertilizer due to poverty/liquidity constraints have been eliminated from the sample. These finings are in line with the model of Finkelshtain and Chalfant (1991) and Fafchamps (1992), showing that net buyers of food respond differently to risk than net sellers (Sandmo (1971). This adds empirical evidence to the presumed effect of consumption risk on technology adoption in general and fertilizer, in particular.

There are some additional observations that presented in Tables 2 and 3. Households with more livestock (oxen and other livestock) and households with more literate members were significantly more likely to use fertilizer, demonstrating significant market imperfections causing wealth to affect production decisions. Households with older household heads were significantly less likely to use fertilizer. This could have several explanations. Old age could imply lower working capacity, less capacity to access fertilizer, poorer knowledge about the use of fertilizer and more skepticism towards fertilizer use. This is in line with findings in Malawi (Franklin, 2006). We see also that female-headed households were significantly (at 1% level) less likely to use fertilizer than male-headed households. This can be related to cultural norms that female labor in Ethiopia is not used for cultivation, except for weeding and harvesting. Moreover, female-headed households are among the poor households (Croppenstedt et al., 2003) that lack access to resources to invest in fertilizer. We refrain from commenting on the remaining significant control variables.

Conclusion

The Northern Ethiopian highland is drought prone area where agricultural production risk is prevalent leading to low adoption of improved agricultural input mainly fertilizer use. Apart from moisture stress, lack of capital and consumption smoothing mechanisms may also limit households' investment in production enhancing agricultural inputs, possibly leading into poverty trap. Previous studies in the Tigray region (our study area) have reported mixed results some of them differing from findings from other parts of the world. On the other hand, the effect of production risk and food deficit on technology adoption in general and fertilizer use in particular is mixed in the literature, which our study area and data represent an excellent opportunity to test this.

In analyzing both the effect of irrigation and food deficit on fertilizer, we used a simple theoretical framework and drew on relevant theory for behavior of producer-consumer households that produce for their own consumption and may be net sellers or net buyers of food. We used theory to derive relevant hypotheses to test the effects of investment in irrigation, rainfall and rainfall variability and food self-sufficiency and food deficits on adoption and intensity of fertilizer use on irrigated and rain-fed land.

We found strong positive effects for adoption and intensity of fertilizer use on irrigated land, contrasting with earlier studies that did not find such a positive effects of irrigation. Our study is based on more solid data, and we think that these new results provide evidence of significant positive effects of irrigation investment on fertilizer use.

We found that production risk due to adverse climatic conditions (rainfall scarcity and variability) is an important determinant of farmers' fertilizer adoption. We also found that predicted food self-sufficiency was negatively related to fertilizer adoption, indicating that expected food deficits had a positive effect on fertilizer adoption. This contrasts the prediction of the pure producer model of Sandmo (1971), but it is in line with the predictions of the producer-consumer household model of Finkelshtain and Chalfant (1991), indicating that risk averse net buyers of food may respond to higher risk by producing more (through use of more inputs). We also assessed the effects of actual food deficits, whether they were expected or not, and found a contrasting effect on adoption of fertilizer vs. intensity of fertilizer use. Food deficit households predicted to be in food deficits were less likely to use fertilizer, possibly due to liquidity constraints and the need to buy food to meet urgent food needs rather than reducing future food deficits. However, when assessing the fertilizer use of those households that still managed to buy fertilizer, we found that they used significantly more fertilizer than other households. These households are likely to be less cash constrained and therefore, more able and willing to use fertilizer to reduce future expected food deficits, a sign of their high relative risk aversion (Finkelshtain and Chalfant 1991). Overall, we may conclude that liquidity or credit constraints may inhibit fertilizer adoption of food deficit households. However, the covariance between income and price risk may cause the risk premium to be negative for food deficit households and induce them to adopt and use more fertilizer to reduce their future food deficits. Furthermore, both investment in irrigation and provision of credit can be important policy instruments to enhance food security in semi-arid and drought-prone areas like the one in our study, where fertilizer can enhance food self-sufficiency.

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Appendix 1. Probability of food availability in June (Probit model).

Variable	Variable description	Coefficient	Std. Error
hhage	Household age	-0.010**	0.004
hheadsex	Household sex (1=male)	0.184	0.154
litrate	Literate household members	-0.010	0.046
femwl	Household member female labor	0.036	0.067
mamwl	Household member male labor	-0.039	0.067
oxen	Oxen ownership	0.111	0.078
totaltlu	Livestock ownership (tlu)	0.069**	0.027
farasso	Household's access to credit (1=yes)	-0.163	0.122
adueqcoworo	Consumer worker ratio (adult equivalent)	-0.060	0.083
farmzpadu	Owner operated land holding per adult equivalent (ha)	0.076	0.074
loca1	Tabia (1=Adis Alem)	-0.030	0.205
loca3	Tabia (1=Laelay Agulae)	-0.987*	0.599
loca4	Tabia (1=Adi-Ha)	-0.584	0.550
loca5	Tabia (1=Adidedena)	0.279	0.201
loca6	Tabia (1=Maiadrasha)	-1.041	1.178
popdensi	Population density (people/Km^2)	0.013	0.011
cons	Constant	-1.012	0.754
	Number of observation	544	
	Log likelihood	-344.833	
	Wald chi2(16	47.950	
	Prob > chi2	0.000	
	Pseudo R2	0.074	

Appendix 2. Classification of soils in Tigray.

Local name	Scientific name	General characteristics
Baekel	Cambisol	Normally found in moderately steep slope, good drainage, poor fertility, low compaction, Easy to plough (good workability)
Walka	Vertisol	Normally found in valley bottom, good soil depth, rich in chemical soil minerals, poor drainage, difficult to plough (tough workability)
Hutsa	Leptosol	Extremely poor soil fertility, found in steep slope (susceptible to erosion), high drainage, low water absorbing capacity, shallow soil depth and easy to plough.
Mekayhi	Luvisol	Found in moderate slope, deep soil, well drained, moderate fertility, easy to plough (good workability)

Source: (Nyssen *et al.*, 2007).