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Analysis

Seeds for livelihood: Crop biodiversity and food production in Ethiopia

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ABSTRACT

This paper uses a farm level panel data from Ethiopia and a comprehensive empirical strategy to investigate the contribution of crop biodiversity on food production. We find that increasing the number of crop variety increases production. This result is stronger when rainfall level is lower. Moreover, the productivity analysis is complemented with the study of the determinants of farm level crop biodiversity. Empirical results suggest that rainfall, tenure security and household endowments tend to govern crop diversity decisions at the farm level.

1. Introduction

Crop biodiversity is the foundation of food production and supply. Farmers and breeders use biodiversity to adapt crops to different and changing production environments. Maintaining diverse plant varieties on farmers' fields, *in-situ*[1] conservation, *vis-a-vis* storing germplasms in gene banks, is increasingly regarded as an effective way of conservation of plant genetic resources (Benin et al., 2004; Bezabih, 2008). At the heart of whether *in-situ* conservation could be pursued as a fruitful strategy of keeping important germplasms alive is whether it generates farm level benefits that are internalized by farmers. Benin et al. (2004) observed that on farm conservation of crop diversity poses obvious policy challenges in terms of the design of appropriate incentive mechanisms and possible trade-offs between conservation and productivity.[2] There is evidence, however, of that crop biodiversity is very important for both the functioning of ecological systems and the generation of ecosystems' services (e.g., Tilman and Downing, 1994; Tilman et al., 1996; Wood and Lenné, 1999; Loreau and Hector, 2001; Naeem et al., 1994).

Growing multiple species makes possible the productive exploitation of synergies among crops and niche partitioning (Di Falco and Chavas, 2009). This has been reported in a series of experimental studies that have shown that plant biomass is an increasing function of diversity (Tilman and Downing, 1994; Tilman et al., 1996; Lehman and Tilman, 2000) and that higher diversity systems give greater yields than lower ones (Tilman et al., 2005). These results can be stronger in a setting where agro-ecological heterogeneity and harsh weather conditions may increase positive interactions among plants. Plants can exhibit a greater reliance on positive synergies and display facilitation (rather than competition).[3] The implication is that conserving diversity in the field delivers important productive services and allows farmers to mitigate some of the negative effects of harsh weather and agro-ecological conditions (Walker et al., 1999; Di Falco and Chavas, 2009).

Besides the evidence based on experimental analysis, a growing body of applied economics literature focusing on the same research question, but using different methods, found similar evidence. The role of biodiversity on food production is found to be positive and not negligible (e.g. Di Falco et al., 2007; Smale et al., 1998). These findings are based on two different empirical approaches: aggregate panel data and farm level cross section analyses. The aggregate panel data analysis makes use of regional or district level data to estimate aggregate production functions where biodiversity is typically modelled as an input in the production process (e.g. Smale et al., 1998; Widawsky and

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[1] Conservation of genetic resources *in-situ* refers to the continued cultivation and management by farmers of crop populations in the open, genetically dynamic systems where the crop has evolved.

[2] Smale et al. (2003) noted that there is a fundamental problem that affects the design of policies to encourage on farm conservation. Crop genetic diversity is an impure public good, meaning that it has both private and public economic attributes.

[3] Bertness and Callaway (1994), Callaway (1995), Callaway and Walker (1997), and Vandermeer (1989).

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Rozelle, 1998). These studies exploit the benefits of fixed effects panel data in terms of removing time invariant unobserved heterogeneity. However, the scale of these analyses does not allow controlling for farm agro-ecological characteristics and implicitly assumes that the underlying theoretical model can be scaled up at a macro level. The second approach of using farm level cross section analysis, while overcoming the aggregation problem, has the obvious shortcoming of neglecting dynamics (Di Falco and Chavas, 2009).

In this paper we build upon these previous contributions and assess the contribution of crop diversity to farm level productivity using farm level panel data from the Central Highlands of Ethiopia. The dataset was formed from a survey of 1500 farm households in Ethiopia collected in 2002 and 2005 The adoption of a farm level panel data, besides helping in dealing with endogeneity, allows us to address the issue of time invariant heterogeneity at the household level (i.e. farmers ability, or farm specific unobserved characteristics). Compared to the existing literature, this will provide further (and more robust) empirical evidence on the relationship between productivity and crop biodiversity. The study is conducted in a setting where environmental conditions are difficult due to poor soil quality and challenging weather conditions. The drought-prone and moisture-stressed production environment of Ethiopia. This is a rain-fed production environment. Therefore, of special interest is the impact of rainfall abundance on productivity and its interplay with crop biodiversity. To this end, we matched the farm level data with data on the current and lagged levels of rainfall. To our knowledge no farm level panel has investigated the productive implications of the interaction between biodiversity and weather.[4] We employ a comprehensive empirical strategy that both assesses the relationship between productivity, diversity and rainfall, and addresses the possible endogeneity of diversity in productivity. We first estimate two separate equations representing farm productivity and the determinants of biodiversity, respectively. This entails the assumption that diversity is not endogenous in the productivity equation. Second we adopt a pseudo-fixed effects approach to control for possible endogeneity of diversity and time invariant unobserved heterogeneity. Third, we jointly estimate the diversity and productivity equations, to address the possible endogeneity of diversity due to factors other than time invariant unobserved heterogeneity and to further probe the robustness of our findings. Moreover the first stage regression provides useful information on the determinants of crop biodiversity at the farm level including tenure security. The availability of data regarding both past and current rainfall can also capture the role of expected and observed weather on crop choice and shed light on the way farmers use *in-situ* diversity (Van Dusen and Taylor, 2005; Benin et al., 2004) in food production.

The rest of the paper is organized as follows. In Section 2, we provide a brief background. Section 3 provides information about the Ethiopian agriculture and agro-biodiversity in the country. The estimation methodology along with some considerations in the estimation procedure is provided in Section 4. Section 5 details the survey design and data employed in the empirical analysis. Section 6 presents the empirical findings and Section 7 concludes the paper.

2. Background

Screening both ecological and resource economics literature, three mechanisms have been identified that relate crop biodiversity to agro-ecosystem functioning and productivity. First, biodiversity increases the level at which certain ecosystem services are provided. Compared to a single species (or a less diverse) ecosystem, in diverse ecosystems there is a greater likelihood that key species that have large impact on the performance of an ecosystem would be present in the system. This is known as the 'sampling effect' or the 'selection probability effect' (Aarssen, 1997; Huston, 1997; Loreau, 2000; Tilman et al., 2001). Second, diversity enhances the possibility of species complementarities. Complementarities among crop species imply an efficient use of total available resources both in time and space (Trenbath, 1974; Harper, 1977; Ewel, 1986; Vandermeer, 1989; Loreau, 2000). Multiple crop species can also reduce the implication of price and production risk (Baumgärtner and Quaas, 2008; Di Falco and Chavas, 2009) and allows farmers to market their produce several times throughout the year. Third, diversity increases facilitative interaction among species by ensuring the presence of species with different sensitivities to suite environmental conditions (Bertness and Callaway, 1994; Mulder et al., 2001). Since certain species can buffer against harsh environmental conditions or provide a critical resource for other, the probability that some of these species can react in a functionally differentiated way to external disturbance of the system and changing environmental conditions increases with increasing number of functionally different species. Therefore, biodiversity can act as an insurance in carrying out ecological processes (Borrvall et al., 2000; Elton, 1958; Chapin and Shaver, 1985; Hooper et al., 1995; Lawton and Brown, 1993; MacArthur, 1955; Naeem, 1998; Naeem and Li, 1997; Petchey et al., 1999; Trenbath, 1999; Baumgärtner and Quaas, 2009).[5]

The level of complementarity and inter-specific facilitation between species is, however, dependent on the extent of both spatial and temporal heterogeneity in the system. Tilman et al. (2005), for instance, demonstrate that under homogeneous environment, a single species best adapted to the environmental condition will produce greatest biomass. With heterogeneous habitats, however, diversity tends to be more beneficial. Norberg (2001) present a similar but a more comprehensive approach of multispecies competition that relates aggregate biomass, average phenotype (a measure of environmental responsiveness) and environmental variability. The framework developed by Norberg (2001) suggest that phenotypic variance within functional groups is linearly related to their ability to respond to environmental changes. As a result, the long-term productivity for a group of species with high phenotypic variance may be higher than for the best single species.

Whatever the sources of the value of crop biodiversity we test the hypothesis that the correlation between diversity and productivity is positive. In order to control for environmental conditions, rainfall and other source of observed farm specific heterogeneity (e.g. slope of the plots or fertility) are inserted into the analysis. We also include some interaction terms between biodiversity and the variables representing these conditions. This, for instance, allows to understand the interplay between biodiversity and rainfall and tests the hypothesis that the productive benefits of biodiversity are more important when rainfall is lower, thus the amount of environmental stress is larger.[6]

We extend the set of tested hypothesis by providing an analysis of the determinants of farm diversity. Understanding the drivers of on farm diversity is very important for the policy standpoint. It has been found that in the presence of market imperfections, farmers' choice on

[4] Some evidence has been provided at more aggregate level, see Di Falco and Chavas (2008).

[5] For a comprehensive assessment of the contribution of diversity to ecosystem functioning, see Hooper et al. (2005).

[6] Based on crops grown in Ethiopia, a number of agronomic and other biophysical studies show that different crops respond differently to moisture availability. Using geospatial rainfall estimates and seasonal water balances, Senay and Verdin (2003) show that teff, maize and sorghum respond differently to moisture availability. In their study of responsiveness of alternative durum wheat cultivars, Simane et al. (1993) found that the variation in moisture stress led to significant differences in yield measures. In addition, Yadeta and Bejiga (2004) highlight differences in drought responsiveness among 482 genotypes of chickpea evaluated for differences in drought responsiveness. In Sinebo (2005), sixteen barley genotype grain yields were shown to interact differently with different experimental environments. The effect of mixtures of cultivars on yield and risk distribution in four maize cultivars grown at four different population levels also indicated biomass production differs with rainfall availability (Tilahun, 1995). Kefale and Ranamukhaarachchi (2006) show that three maize varieties respond negatively but differently to moisture deficit.

the number of crop species to be grown can be influenced by household endowments (i.e. land), distance to market, access to infrastructures, agro-ecological characteristics of the operated plots, as well as farmers' socioeconomic characteristics (Benin et al., 2004; Bezabih, 2008; van Dusen and Taylor, 2005). We therefore add another estimating equation for the determinants of farm diversity where we test the role of rainfall pattern, heterogeneity and other relevant variables, in the determination of the number of crop species grown by farmers in moisture-stressed and ecologically fragile agricultural system. Addressing this issue also allows us to undertake a very important methodological issue, the potential endogeneity of the diversity metrics in the productivity analysis. We tackle endogeneity via the adoption of a Three Stages Least Squares Estimator. A more detailed presentation of the issues related to the empirical analysis will be provided in Section 4.

3. Agricultural Production and Crop Biodiversity in Ethiopia

Agriculture is the mainstay of the Ethiopian economy. The agricultural sector accounts for about 40% of national GDP, 90% of exports, and 85% of employment. Ethiopian agriculture is largely of low external-input nature i.e. low fertilizer, improved seeds and irrigation inputs. A considerable proportion of seed inputs are derived from local planting materials and the country's seed resources are critical to the performance of agriculture. While Ethiopia is not one of the mega-diversity centres comparable with Central American, Southeast Asian or Central African countries, the country displays a considerable wealth of diversity in food crops and their wild relatives (Gebregziabher, 1991). Indeed, owing to its large altitudinal variation,[7] Ethiopia is a home for a number of food crop varieties suited to the dry and high temperature conditions of the lowlands and the wet and cooler temperature conditions of the highlands. Ethiopia is also recognized as a global centre of genetic diversity for several crops, including barley and durum wheat (Vavilov, 1949; Harlan, 1992).

The country's agricultural performance has been extremely modest. Real agricultural GDP and per capita cereal production has been falling over the last 40 years with cereal yield stagnant at about 1.2 tons per hectare (World Bank, 2005). This is further exacerbated by extreme land shortages in the highlands—per capita land area has fallen from 0.5 ha in the 1960s to only 0.2 ha by 2005 (World Bank, 2005).[8]

In an effort to curb the challenges facing the agricultural sector and achieve faster agricultural growth and food security, the Government of Ethiopia (GoE, hereafter) did launch a new development strategy—Agriculture Development Led Industrialization (ADLI)—in 1991. Subsequently, agriculture has become the main focus of the GoE's poverty reduction strategy, which includes the Sustainable Development and Poverty Reduction Program (SDPRP) approved in 2002, the 2004 Food Security Strategy (FSS), and, most recently, the 2006 Plan for Accelerated and Sustained Development to End Poverty (PASDEP) (MoFED, 2002, 2006). The core goal of all these strategies was to increase yields through a centralized extension-based service focusing on technological packages that combined credit, fertilizers, improved seeds and better management practices. Overall, so far the programs' reach has been somewhat limited. Official estimates from the Central Statistical Authority show that uptake of improved seed has been fairly modest: less than 5% of farmers.

Ethiopian agriculture[9] is mostly rain-fed. Therefore, rainfall is a very critical factor in both determining crop yields and shaping farmers' crop species choices.[10] Ethiopia has experienced at least five major droughts since 1980, along with several other sporadic droughts. Cycles of drought create poverty traps for many households, constantly thwarting efforts to build up assets and increase income. Between 1999 and 2004 more than half of all households in the country experienced at least one major drought shock.

4. Empirical Strategy

In this section we present the empirical models and variables used in estimating both the determinants of crop diversity and its role on food production using panel data from the Ethiopian highlands. The central focus of this study is to investigate the impact of crop diversity on farm level crop productivity, where crop diversity measured by a diversity index enters a standard household production function, Y_{ht}, as specified in Eq. (1).

$$Y_{ht} = f\left(L_{ht}, M_{ht}, W_{ht}, D_{ht}, \Omega^{\mathrm{F}}_{ht}, \gamma\right) + \xi_{ht} \tag{1}$$

Where for household h and time t, L_{ht} is a measure of inputs such as household labour, land, M_{ht} captures other inputs such as fertilizer, seeds, manure and improved seeds; W_{ht} is a measure representing climatic factors such as rainfall D_{ht} is a measure of crop diversity; and Ω^{F}_{ht} represents farm characteristics (such as soil fertility and slope). γ is a vector of parameters, and ξ_{ht} is household specific random error term.

In the empirical model a flexible quadratic functional specification is adopted.[11] All the other independent variables enter the production function linearly. This specification is particularly suited for the study of yield response (which exhibits a maximum) and allows for zero values in the set of inputs. The choice of the explanatory variables in the production function follows a standard production theory where production is a function of production inputs. Socioeconomic and physical farm characteristics are also included. Based on our hypothesis set out in Section 2 on the role of diversity in productivity and the interactions between diversity and rainfall in determining the level of productivity, we have adopted a count index as a measure of diversity, current and lag year annual rainfall and the diversity–rainfall interactions as determinants of productivity. We also included an interaction between diversity and other farm specific characteristics. The count index is a measure of species richness and is defined as the number of crops grown per farm. For instance, a count index of 6.1 implies that the average number of crops grown on a farm was 6.1. The choice of a diversity index is always difficult and largely affected by data availability. The lack of information of the spatial distribution of crop species prevented us from using spatial indices. Nevertheless, the count index is very appropriate when “diversity is apparent to farmers” (Meng et al., 1998).[12] This is, indeed, an important characteristic of the cereal crops grown in Ethiopia. Their genetic

[7] Ethiopia has more than half of the total highland and mountain area of Africa which dissipates the arid and semiarid climate that it would have had due to its location in the Sahel Zone.

[8] Seasonality of production in agriculture implies unevenness in the utilization of resources such as labour. While at certain times of the year, the employment of labour would contribute to nothing (i.e. labour has zero marginal product), at other seasons, labour is fully utilized and thus has a high marginal product (Gill, 1991). The observation of zero (very low) marginal productivity of labour stems from averaging productivity of labour over long slack seasons (as is the case with rain-fed, non irrigated agriculture) and short peak seasons.

[9] Inadequate, erratic and/or untimely rainfall has arguably been the most important reason causing frequent crop failures in Ethiopian agriculture. Hence, the productivity is highly dependent on the availability of adequate and timely rainfall.

[10] Agriculture is almost entirely rain-fed with only about 2% of the total arable land under irrigation (World Bank, 2005).

[11] We explored alternative functional forms, and based on appropriate statistical tests, we found a quadratic production function more robust.

[12] Besides the count index (which measures species richness in a farm), other indices have appeared in the literature. These include: the Margalef Index (which is very similar to the count); the Shannon Index (which measures richness and relative abundance); the Berger Parker Index (which measures relative abundance). Bezabih (2008) compares Shannon and count index measures using the same dataset used in this paper. It has been found no significant difference in their impact on productivity.

diversity is reflected in the morphogenetic trait of the crop. A count index also suits the second empirical model. Farmers make decisions regarding the number of crops to be grown, thus determining the level of diversity existing in the farm.

The crop diversity model, which is likely to be endogenous in the productivity equation, is given by:

$$D_{ht} = D\left(\Omega_{ht}^{HH}, \Omega_{ht}^{F}, \Omega_{ht}^{R}, \Omega_{ht}^{C}; \beta\right) + \eta_{ht} \tag{2}$$

where D_{ht} is crop biodiversity for household h at time t, and Ω_{ht}^{HH}, Ω_{ht}^{F}, Ω_{ht}^{R}, Ω_{ht}^{C} are household endowments (such as land and labour), farm characteristics (soil fertility and slope), location specific characteristic (such as distance to plots), and climatic factors (such as rainfall), respectively. β is a vector of parameters, and η_{ht} is household specific random error term. Our choice of the determinants of diversity closely follows from previous works assessing factors affecting farm level diversity particularly in developing countries. Benin et al. (2004) argue that in countries like Ethiopia where both input and output markets are imperfect, household endowments are important drivers of crop biodiversity choices. Accordingly, Di Falco and Chavas (2009) identify the use of improved inputs, labour inputs draught power, and plot characteristics. Similarly, Bezabih (2008) uses the socioeconomic characteristics of age, gender of the household head, education, livestock ownership, and physical farm characteristics such as soil color and slopes. Land tenure security is included in the analysis as stronger security is found to have significant impact on land investment decisions including crop biodiversity (Nkonya, 2004). Rainfall in its current and lagged level is inserted to see if farmers are considering crop biodiversity as one adaptation strategy in response to climatic changes.

A Poisson regression is adopted to estimate determinants of crop diversity as specified by Eq. (2). The choice of Poisson estimation is primarily based on the characteristic of our diversity metrics. The panel structure of the database makes the use of a standard fixed effect model possible. Therefore the error term takes the form $\xi_{ht} = \mu_h + v_{ht}$. The fixed effect has an obvious advantage over random effect and other non-linear models (such as Tobit or truncated regressions). It enables to control for time invariant unobserved heterogeneity (μ_h) that might be correlated with observed explanatory variables and therefore it produces consistent parameter estimates. However, standard fixed effect models rely on data transformation (i.e. transforming the variables in deviations from their means of first differences) that removes the individual effect (μ_h) as well as time invariant variables (such as gender). Moreover this transformation can be implemented in linear models but not in non-linear models (i.e. Poisson regression). An alternative (but equivalent) approach is the one suggested by Mundlak (1978), referred to in the literature as pseudo-fixed effect model. This approach relies on the assumption that unobservable effects are linearly correlated with the explanatory variables. Therefore the right hand side of the pseudo-fixed effect regression equation includes the mean value of the time-varying explanatory variables (Mundlak's, 1978). Thus, the unobserved effects (η_h) are defined by:

$$\mu_h = \bar{x}\alpha + \pi_h, \pi_h \sim \text{iid}\left(0, \sigma_\mu^2\right) \tag{3}$$

where $\bar{x}$ is the mean of the time-varying explanatory variables within each household (cluster mean) such as average values for fertilizer, manure, oxen, labour and plot size, α is the corresponding vector coefficient, and π is a random error unrelated to $\bar{x}$s. The vector α will be equal to zero if the observed explanatory variables are uncorrelated with these effects. This procedure can be employed in both production model and Poisson regression, which is unique in this study.

One can also use the pseudo-fixed effect model to address the potential endogeneity bias due to the inclusion of the diversity variable in the right hand side of the food production model. This is, however, under the assumption that the endogeneity bias (or also a selection bias) is due to time invariant unobserved factors, such as household heterogeneity (Wooldridge, 2002). To illustrate the problem of endogeneity, we first implemented a Wu–Hausman test for the presence of endogeneity bias due to the use of biodiversity variable as one of our right hand side variable in the production model. We found a p-value of 0.12. This implies a non-rejection of the null hypothesis of exogeneity. The test procedure implemented after the inclusion of the pseudo-fixed effect provided a p-value of 0.38. This indicates that after controlling for time invariant unobservables, our choice of pseudo-fixed effect approach has corrected the endogeneity bias that otherwise would have prevailed in other alternative estimation procedures.

To further consolidate the robustness of our result and address the possible endogeneity of the diversity variable sufficiently, we employed a three stage instrumental variable estimation procedure. We first checked for the availability and validity of instruments, to justify the use of Instrumental Variable (IV) estimation. In our setting, there are three variables that are key explanatory variables of Eq. (1) (diversity model) but not relevant in the estimation of Eq. (2) (the production model). These are land tenure security, distance between plots and the farm, and gender. To scrutinize our choice of instruments we tested for their relevance by using an F test of the joint significance of the excluded instruments. We rejected the null hypothesis, indicating that the instruments are relevant. We also tested the overidentification restrictions using a Sargan Hansen test of over-identifying restrictions. It was implemented for our model estimated with instrumental variables in which the number of instruments exceeds the number of covariates and therefore we have an overidentified equation. The joint null hypothesis is that the excluded instruments are valid instruments. We failed to reject the null hypothesis so the instruments appear to be uncorrelated with the error term and correctly excluded from the estimated equation. The results of the test are reported at the bottom of Table 4a.

Next, we examine the existence of any potential correlation between the diversity model (Eq. (1)) and the food production model (Eq. (2)) to justify the use of Three Stage Least Square Instrumental Variable (3SLS) estimation procedure. If the correlation between the error term and crop biodiversity would not happen exclusively via the individual effect, removing or controlling for time invariant unobservable characteristics may still not provide consistent parameter estimates. Thus a Three Stages Least Squares estimator should be adopted. The appropriate implementation of the estimator requires that the set of explanatory variables that are used as instruments would not be correlated with the error term in Eq. (2) but correlated with the endogenous variables. As further robustness check we also considered the situation in which all the variables in Eq. (2) could be correlated with the remaining (random) component of the error term. Given the two year panel nature of our data, this could be addressed using a first differenced IV approach. In first difference IV, we take the difference between a variable in two rounds to remove unobserved heterogeneity (basically obtaining the same results as in the Mundlak approach). Then, we adopt the lagged variables as instruments for the first differenced variables. Our results from first difference IV are fairly consistent with the results of 3SLS presented in Table 2. The results of the first difference IV estimation are available from authors upon request.

5. Survey and Data Description

The basic socioeconomic, physical farm characteristics and production data was collected from two rounds (2002 and 2005) of household surveys conducted on 1500 farm households in 12 villages

Table 1
Description of variables used in the regressions.

Variables	Description
Socioeconomic and farm characteristics	
Female	Gender of the household head (1 = female; 0 = male)
Labour	The number of working-age family member household
Oxen	The number of oxen
Flat slope plot[a]	Proportion of plots with flat slope
Fertile plot	Proportion of plots with fertile soil
Land size	Land size (ha)
Distance	Average Distance of the plot from the farm (walking time in minutes)
Production inputs	
Fertilizer	Amount of fertilizer applied (kg)
Manure	Amount of manure applied (kg)
Improved seed	Amount of improved seed used applied (kg)
Tenure security	
Security	Whether the household expects increase, no change or decrease in the land size in the coming five years (1 = decrease 2 = no change 3 = increase)
Climatic variables	
Rainfall	Mean annual rainfall, averaged over monthly mean observations
Lag rainfall	Lagged value of mean annual rainfall
Dependent variables	
Productivity	The amount of production (kg)
Diversity	Richness measured in terms of Count index

[a] Respondents were given three choices in defining the elevation of each of the plots in their farm: flat, medium-slope and steep. Similarly, respondents characterized the fertility of their plots as fertile and infertile.

Table 2
Descriptive statistics on the variables used in the regressions.

Variable	Year 2002		Year 2005	
	Mean	Std. dev.	Mean	Std. dev.
Gender	1.12	0.33	1.13	0.34
Labour	5.70	2.17	6.20	2.15
Oxen	1.12	0.86	1.22	0.87
Training	1.83	0.38	1.82	0.39
Fertility	0.41	0.36	0.48	0.39
Flat slope	0.68	0.32	0.63	0.35
Land size	1.18	0.80	1.19	0.86
Fertilizer	30.19	55.06	30.92	59.84
Manure	78.39	140.04	136.35	166.19
Distance	4.1	10	3.9	8.61
Improved seed	4.47	45.72	3.93	29.94
Security	1.11	0.81	1.07	0.79
Rainfall	1194.39	169.77	997.20	219.55
Lag rainfall	1331.99	205.88	1097.20	173.56
Production	2202.00	1371.71	2590.65	2335.92
Diversity	5.30	2.13	6.10	2.23

located in two districts of the Amhara National Regional State of Ethiopia. The region encompasses part of the Northern and Central Highlands of Ethiopia. This household survey data was complimented by the rainfall data, collected by the Ethiopian Meteorology Authority from local meteorological stations. Average annual rainfall values were assigned for each village using the data taken from stations that are closer to each village.[13]

The resulting data consists of details of socioeconomic and physical farm characteristics of the households, major production inputs, a measure of tenure security, and climatic variables. Since farming technology is homogenously rudimentary in rural Ethiopia, inputs such as irrigation and equipment are not included in the analysis. Factors like extension services are not directly measured in the survey. The composition of most of the physical farm characteristics remained virtually unchanged over our study periods (2002–2005) due to limited opportunities that characterize the village life in rural Ethiopia. While average annual rainfall has also fallen over the study periods, farm level crop diversity and average productivity has increased by a modest 2% over the three year period. Comparing the levels of diversity in 2002 and 2005, the level of diversity has slightly increased. This indicates that, in our particular case, diversity loss is not experienced. Nevertheless, as discussed in Section 2, given the push for high external-input agriculture, the country's agro-biodiversity resource is under threat and assessing the role of diversity in agricultural productivity remains a vital undertaking.

Description of the variables used in the regression and the basic descriptive statistics of the variables used in the regression are presented in Tables 1 and 2, respectively. The crop types grown by the sample households are presented in Table 3. The dependent variables in our analysis are the level of production and farm level diversity, which is treated as an endogenous variable. Our measure of production captures all cereal and pulse crops grown by a farm household in a particular year, where each crop variety grown covers a plot and the level of diversity and productivity is computed at a farm level. Perennial crops such as fruits and spice trees as well as vegetables are excluded from the analysis as they are difficult to aggregate into cereal crop production figures. As discussed in the previous section, diversity is measured as a count index.

The standard determinants of productivity such as labour and oxen power are included in the analysis. An additional determinant of productivity in our analysis is rainfall availability, measured as mean annual rainfall and its interaction with diversity. As Ethiopia's agriculture is virtually totally rainfall dependent, production is clearly dependent on moisture availability, which makes rainfall a justifiable factor in our productivity equation. The interaction between diversity and rainfall is one of the key variables of interest in our productivity analysis. As argued in Section 2, a number of ecological studies put a strong argument forward that the contribution of diversity to productivity is conditional on the environmental factor (rainfall in our case), which makes the benefit of diversity situation specific and hence calls for investigation of the role of diversity on productivity conditioned on the availability of rainfall.

Table 3
Crop types grown by households in percentage.

Small and large cereals		Pulses, oil seeds and spices	
White teff	55.6	Broad beans	26.5
Mixed teff	26	Cow peas	5.8
Black/red teff	35.7	Garden peas	0.13
Wheat	51.53	Lentil	3.26
Barley	27.2	Soya bean	0.13
Sorghum	25.53	Vetches	13.9
Millet	17.93	Kidney beans	0.13
Oats	10.13	Chick peas	7.93
Dagussa	1.46	Common bean	1.33
Rice	0.3	Nigerseed	13.6
Sinar/gerima	13.73	Sesame	0.06
Maize	10.6	Linseed	3.06
Gibto	2.9	Black pepper	0.06
Other cereals	10.6	Fenugreek	3.46

Note: The crop names in italics are local names. White, mixed, and black/red teff are varieties of teff (*Eragrostis teff*), a small cereal and a staple for Ethiopians. Gibto (*Lupinus termis* Forssk) is a maize-like large cereal. Chat (*Collomia linearis*) is a mild stimulant commonly grown in the highlands of East Africa.

[13] Since rainfall variables are constructed based on observations from local meteorological stations, rainfall measure is likely to be correlated with village level effects that vary across villages. Factors that are bundled up in these measures include access to markets, access to inputs and technology as well as agro-ecological variations.

Table 4a
Empirical results—food production model.

	OLS	Fixed effects	3SLS and fixed effects
	A	B	C
Fertility	179.5	149.9	−60.45
	(239.8)	(235.6)	(206.9)
Flat slope	−32.65	31.18	−158.4
	(247.8)	(243.8)	(208.3)
Labour	62.65	17.26	18.62
	(77.43)	(97.42)	(87.03)
$Labour^2$	4.755	4.101	5.801
	(5.781)	(5.680)	(5.216)
Land	1405.1***	830.4***	1064.3***
	(154.1)	(161.9)	(142.4)
$Land^2$	−70.30***	−55.75***	−74.06***
	(9.037)	(8.999)	(8.511)
Oxen	118.5***	98.51***	65.94***
	(23.17)	(22.90)	(18.01)
$Oxen^2$	−0.152***	−0.126***	−0.0846***
	(0.0296)	(0.0292)	(0.0232)
Fertilizer	0.481***	0.425***	0.643***
	(0.103)	(0.102)	(0.189)
$Fertilizer^2$	−0.0000140***	−0.0000119***	−0.0000392***
	(0.00000385)	(0.00000378)	(0.0000149)
Manure	0.00396	0.0103	−0.0167
	(0.00943)	(0.0113)	(0.0247)
Rainfall	1.058**	0.755	0.692
	(0.483)	(0.475)	(0.438)
Lagged rain	−0.0740	0.00341	0.289
	(0.232)	(0.228)	(0.190)
Improved seeds	0.276	0.322	0.277
	(0.381)	(0.374)	(0.270)
Biodiversity	403.4***	383.3***	438.6***
	(131.7)	(129.5)	(110.4)
Biodiversity*Rainfall	−0.320***	−0.315***	−0.384***
	(0.100)	(0.0987)	(0.0858)
Biodiversity*Flat slope	54.70	40.09	62.84
	(61.04)	(60.02)	(50.46)
Biodiversity*Fertility	43.24	53.46	66.64
	(62.59)	(61.61)	(53.07)
Training	82.70	100.5	142.7
	(106.3)	(104.4)	(95.07)
Time dummies	Yes	Yes	Yes
Fixed effects	No	Yes	Yes
Constant	−163.3	−212.1	42.05
	(448.6)	(443.9)	(412.2)

N: 1798. Tests of endogeneity of biodiversity (Wu–Hausman *F* test): 2.5 *P*-value = 0.12. Test for excluded instruments $F(3, 1770) = 4.75$; Prob > $F = 0.0026$. Sargan statistic (overidentification test of all instruments): 0.985 Chi-sq(2) *P*-val = 0.6. Standard errors in parentheses. Significance code: *$p<0.10$, **$p<0.05$, ***$p<0$.

Table 4b
Empirical results—the determinants of crop Biodiversity.

	Poisson	Poisson and fixed effects	3SLS and fixed effects
	(A)	(B)	(C)
Fertility	−0.0390	−0.0409	−0.171
	(0.0356)	(0.0358)	(0.113)
Flat slope	−0.0363	−0.0394	−0.116
	(0.0373)	(0.0374)	(0.121)
Labour	0.0207***	0.00541	0.0114
	(0.00565)	(0.0205)	(0.0686)
Land	0.104***	0.0679***	0.477***
	(0.00893)	(0.0133)	(0.0624)
Oxen	0.000379	0.000490	0.00166
	(0.000335)	(0.000577)	(0.00174)
Fertilizer	0.0000113	−0.00000298	−0.0000305
	(0.0000188)	(0.0000200)	(0.0000786)
Manure	0.0000187***	0.0000138**	0.0000895***
	(0.00000649)	(0.00000688)	(0.0000289)
Improved seeds	−0.0000716	−0.0000651	−0.000292
	(0.000112)	(0.000112)	(0.000320)
Rainfall	0.000603***	0.000545***	0.00217***
	(0.0000642)	(0.0000663)	(0.000228)
Rainfall lagged	−0.000221***	−0.000203***	−0.000790***
	(0.0000689)	(0.0000693)	(0.000220)
Gender	−0.153***	−0.139***	−0.426***
	(0.0393)	(0.0395)	(0.117)
Training	−0.0406	−0.0386	−0.165
	(0.0329)	(0.0329)	(0.113)
Tenure	0.109***	0.0928***	0.420***
	(0.0262)	(0.0265)	(0.0908)
Distance	−0.0213***	−0.0207***	−0.0234***
	(0.00244)	(0.00244)	(0.00335)
Time dummies	Yes	Yes	Yes
Fixed effects	No	Yes	Yes
Constant		2748	1.926***
		0.282	(0.355)

Standard errors in parentheses. Significance code: *$p<0.10$, **$p<0.05$, ***$p<0$.

6. Results and Discussion

Tables 4a and 4b report the estimation results of both the production model (Eq. (1)) and crop biodiversity model (Eq. (2)) respectively. These tables report the results of three different estimation methods: OLS, Pseudo-fixed effects and Three Stages Least Squares with fixed effects for the model (1) and Poisson, Poisson with fixed effect and Three Stages Least Squares for (2). We first comment the results from the determinants of productivity across and then discuss the results corresponding to the determinants of diversity.

The results in Table 4a show that physical farm characteristics, such as plot slope and fertility are not significant in the food production equation. The conventional inputs display the expected signs with the impact of fertilizer on productivity being significant. Manure is not significant, however. In addition, the quadratic term shows that fertilizer at excessive levels may not be beneficial to productivity. This indicates the need for farmers' training on applications of optimal levels of fertilizer. The use of improved seeds is also not a significant determinant of productivity.

The interaction between biodiversity and other physical farm characteristics such as plot fertility and plot slope is also not significant. On the other hand, land size is a positive and significant determinant of crop production. However, the quadratic land term is negative and statistically significant. Labour is found to be not a significant positive determinant of productivity. However, the number of oxen, an indicator of traction availability, is a positive and significant determinant of productivity.

The estimated coefficient for diversity is positive and significant across the different estimation procedures, indicating that more biodiversity delivers important pay offs in terms of production. This result is consistent with the other findings in the literature (e.g. Di Falco and Chavas, 2009). This indicates that keeping more varieties in the field can be a viable strategy to support agricultural production in the highlands of Ethiopia. As mentioned earlier novel in this study is the inclusion of the interaction term between rainfall and biodiversity. The estimated coefficient for the interaction between diversity and rainfall is negative and statistically significant. This implies that the marginal contribution of diversity to production is sensitive to the level of rainfall. To illustrate consider two alternative situations in which the level of rainfall is low (i.e. 800 mm per year) and high (i.e. 1500 per year). The marginal contribution of diversity is 0.35 and −0.1 respectively, implying that the payoffs from crop biodiversity are much stronger in moisture-stressed and ecologically fragile agricultural systems than other agro-ecologies. This result is robust to different econometric specifications.

Table 4b presents the results of the diversity regression that correspond to the three different econometric specifications of the diversity equation. As discussed in Section 4, the decision to increase crop diversity is assumed to be a function of plot characteristics (i.e. plot size, slope, color and fertility of the soil, and overall land size), household characteristics (i.e. gender, age, household assets such as livestock and land size), use of farm technology (i.e. fertilizer and manure), tenure security, distance of plots from the homestead and past experience in terms of rainfall availability.

The results suggest that the level of rainfall and household land endowments tend to govern crop diversity decisions. The choice of the number of crop species is correlated with rainfall both in its lagged and current levels. The availability of information on rainfall both in the current and in the past season allows to disentangle two effects. First, how the decision concerning the number of crops farmers grow is affected by the current level of rainfall. For instance, if farmers observe more rain, will they respond by planting more species? Second, how rainfall expectation, captured by last year rainfall affect this very same decision. The results are qualitatively different. Past rainfall is negatively correlated with the number of the crop species grown. When farmers expect harsher environmental conditions, they use more diversity to reduce the risk of crop loss and maintain productivity of their agro-ecosystem. Current level of rainfall is, instead, positively correlated with the number of crops. This seems to indicate that when more rain is available the possible set of crops that can be grown can be expanded. Given, that the time dimension of our panel is very limited, we need to be cautious in the interpretation of these results. Labour is a positive and significant determinant of diversity only in the first estimator. Households with larger availability of manure maintain more diversity. Larger both tenure security and distance display expected (statistically significant) signs. More tenure security is associated with larger level of diversity, while the estimated coefficient for distance of farm plots from farm is negative.

7. Conclusions

Understanding farmers' incentives to grow diverse varieties and local cultivars are critical to the success of *in-situ* conservation. As opposed to *ex-situ* conservation, which involves storage and preservation of germplasm samples in gene banks (Cohen and Williams, 1991), *in-situ* conservation is the conservation of plant materials in surroundings where they have developed their distinctive properties. Since *in-situ* conservation takes place on farmers' fields, it is viable only if it generates sufficient farm level benefits. Hence, determining the appropriate cost and benefit of keeping species on farmers' fields is an important step in designing *in-situ* conservation efforts. Assessing the contribution of crop biodiversity to productivity is thus one way of measuring this benefit. The issue is of particular importance in countries like Ethiopia. Ethiopia is characterized by large dependence on rain-fed agriculture, large crop biodiversity and inadequate rainfall. In this environment enhancing agricultural productivity is in an utmost priority in order to achieve food security and reduce the chronic dependence on external food aid.

This paper investigated the contribution of crop biodiversity to farm level productivity in Ethiopia with a special focus on the implications of rainfall and farm level heterogeneity. Differently from the existing literature, we used a farm level Panel Dataset and set different estimators that also control for both farm unobserved heterogeneity and the possibility of endogeneity bias. We find that increasing the number of crop variety increases production. This result is stronger when rainfall is lower. Henceforth, this result provides further (and more robust) empirical evidence on the relationship between productivity and crop biodiversity. This indicates that in a challenging production environment farmers' reliance on crop biodiversity is very important. The productivity analysis was complemented with the study of the determinants of farm level crop biodiversity. Results suggest that the rainfall and household endowments tend to govern crop diversity decisions. The choice of the number of crop species is correlated with rainfall both in its lagged (capturing rainfall expectations) and current levels. Rainfall expectations are negatively correlated with the number of the crop species grown. When farmers expect harsher environmental conditions, they use more diversity to reduce the risk of crop loss and maintain productivity of their agro-ecosystem. Current level of rainfall is, instead, positively correlated with the number of crops. This seems to indicate that if more rain is available in season the possible set of crops that can be grown can be expanded. It should be noted, however, that the time dimension of our panel is very limited. We therefore need to be cautious in the interpretation of the dynamic implications of rainfall pattern. Tenure security seems to play a very important role in determining farm level diversity. Policies aiming to strengthen tenure security may therefore foster *in-situ* conservation of resources; resources that are crucial to improve the productivity of food crops.

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References

Aarssen, L.W., 1997. High productivity in grassland ecosystems: affected by species diversity or productive species? Oikos 80, 183–184.
Baumgärtner, S., Quaas, M.F., 2008. Managing increasing environmental risks through agro-biodiversity and agri-environmental policies. University of Lüneburg Working Paper Series in Economics, Working Paper No. 80. March 2008 (available at http://ssrn.com/abstract=1104956).
Baumgärtner, S., Quaas, M.F., 2009. Agro-biodiversity as natural insurance and the development of financial insurance markets. In: Kontoleon, A., Pascual, U., Smale, M. (Eds.), Agrobiodiversity, Conservation and Economic Development, Routledge, London, pp. 293–317.
Benin, S., Smale, M., Pender, J., Gebremedhin, B., Ehui, S., 2004. The economic determinants of cereal crop diversity on farms in the Ethiopian highlands. Agricultural Economics 31, 197–208.
Bertness, M.D., Callaway, R.M., 1994. Positive interactions in communities. Trends in Ecology and Evolution 9, 191–193.
Bezabih, 2008. Agrobiodiversity conservation under an imperfect seed system: the role of community seed banking schemes. Agricultural Economis 38 (1), 77–87.
Borrvall, C., Ebenman, B., Jonsson, T., 2000. Biodiversity lessens the risk of cascading extinction in model food webs. Ecology Letters 3 (2), 131–136.
Callaway, R.M., 1995. Positive interactions among plant. Botanical Rev. 61, 306–349.
Callaway, R., Walker, L., 1997. Competition and facilitation: a synthetic approach to convention on biological diversity. WEB site: http:www.cbd.int.
Chapin, F.S., Shaver, G.R., 1985. Individualistic growth response of tundra plant species to environmental manipulations in the field. Ecology 66, 564–576.
Cohen, J., Williams, D., 1991. Ex situ conservation of plant genetic resources: global development and environmental concerns. Science 23, 866–872 Vol. 253. no. 5022.
Di Falco, Chavas, J.-P., 2008. Rainfall shocks, resilience and the dynamic effects of crop biodiversity on the productivity of the agroecosystem. Land Economics 84 (1), 83–96.
Di Falco, S., Chavas, J.-P., 2009. On crop biodiversity, risk exposure and food security in the highlands of Ethiopia. American Journal of Agricultural Economics 91(3).
Di Falco, Chavas, J.-P., Smale, M., 2007. Farmer management of production risk on degraded lands: the role of wheat variety diversity in the Tigray region, Ethiopia. Agricultural Economics 36 (2), 147–156.
Elton, C.S., 1958. Ecology of Invasions by Animals and Plants. Methuen, London.
Ewel, J.J., 1986. Designing agro-ecosystems for the humid tropics. Annual Review of Ecology and Systematics 17, 245–271.
Gebregziabher, T., 1991. Diversity of the Ethiopian Flora. In: Engels, J.M.M., Hawkes, J.G., Worede, Melaku (Eds.), Plant Genetic Resources of Ethiopia. University Press, Cambridge.
Gill, G., 1991. Seasonality and Agriculture in the Developing World: A Problem of the Poor and Powerless. Cambridge University Press.
Harlan, J.R., 1992. Crops and Man. American Society of Agronomy, Madison, WI. 2nd Edition.
Harper, J.L., 1977. Population Biology of Plants. Academic Press, London and New York.
Hooper, D., Hawksworth, D., Dhillion, S., 1995. Microbial diversity and ecosystem processes. In: United Nations Environment Programme (UNEP) (Ed.), Global Biodiversity Assessment. Cambridge University Press, Cambridge, UK, pp. 433–443.
Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., Setala, H., Symstad, A.J., Vandermeer, J., Wardle, D.A., 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecological Monographs 75 (1), 3–35.
Huston, M.A., 1997. Hidden treatments in ecological experiments: re-evaluating the ecosystem function of biodiversity. Oecologia 110, 449–460.
Kefale, D., Ranamukhaarachchi, S.L., 2006. Response of maize varieties to drought stress at different phenological stages in Ethiopia. Tropical Science 44 (2), 61–66.

Lawton, J.H., Brown, V.K., 1993. Redundancy in ecosystems. In: Schulze, E.-D., Mooney, H.A. (Eds.), Biodiversity and Ecosystem Functions. Springer, Heidelberg, pp. 255–270.
Lehman, C., Tilman, D., 2000. Biodiversity, stability, and productivity in competitive communities. The American Naturalist 156, 534–552.
Loreau, M., 2000. Biodiversity and ecosystem functioning: recent theoretical advances. Oikos 91, 3–17.
Loreau, M., Hector, A., 2001. Partitioning selection and complementarity in biodiversity experiments. Nature 412, 72–76.
MacArthur, R.H., 1955. Fluctuations of animal populations and a measure of community stability. Ecology 36, 533–536.
Meng, E.C.H., Smale, M., Bellon, M.R., Grimanelli, D., 1998. Definition and measurement of crop diversity for economic analysis. In: Smale, M. (Ed.), Farmers, Gene Banks, and Crop Breeding. Kluwer, Boston, pp. 19–31.
MoFED (Ministry of Finance and Economic Development), 2002. Ethiopia: Sustainable Development and Poverty Reduction Program. MoFED, Addis Ababa.
MoFED, 2006. Ethiopia: Building on Progress: A Plan for Accelerated and Sustained Development to End Poverty. MoFED, Addis Ababa.
Mulder, C.P.H., Uliassi, D.D., Doak, D.F., 2001. Physical stress and diversity–productivity relationships: the role of positive interactions. Proceedings of the National Academy of Sciences of the United States of America 98 (12), 6704–6708.
Mundlak, Y., 1978. On the pooling of time series and cross-section data. Econometrica 46, 69–85.
Naeem, S., 1998. Species redundancy and ecosystem reliability. Conservation Biology 12, 39–45.
Naeem, S., Li, S., 1997. Biodiversity enhances reliability. Nature 390, 507–509.
Naeem, S., Thompson, L.J., Lawler, S.P., Lawton, J.H., Woodfin, R.M., 1994. Declining biodiversity can affect the functioning of ecosystems. Nature 368, 734–737.
Nkonya E. 2004. Strategies for Sustainable Land Management and Poverty Reduction in Uganda. International Food Policy Research Institute Washington, DC.
Norberg, J., 2001. Phenotypic diversity and ecosystem functioning in changing environments: a theoretical framework. Proceedings of the National Academy of Sciences of the United States of America 98 (20), 11376–11381.
Petchey, O.L., McPhearson, P.T., Casey, T.M., Morin, P.J., 1999. Environmental warming alters food-web structure and ecosystem function. Nature 402 (6757), 69–72.
Senay, G., Verdin, J., 2003. Characterization of yield reduction in Ethiopia using a GIS based crop water balance model. Canadian Journal of Remote Sensing 29 (6), 687–692.
Sinebo, W., 2005. Trade off between yield increase and yield stability in three decades of barley breeding in a tropical highland environment. Field Crops Research 92 (1) 14: 35–52.
Simane, B., Tanner, D.G., Tarekegne, A., Asefa, T., 1999. Agro-ecological decision support systems for wheat improvement in Ethiopia: climatic characterisation and clustering of wheat growing regions. African Crop Science Journal 7 (1), 9–19.
Smale, M., Hartell, J., Heisey, P.W., Senauer, B., 1998. The contribution of genetic resources and diversity to wheat production in the Punjab of Pakistan. American Journal of Agricultural Economics 80, 482–493.
Smale, M., Meng, E., Brennan, J.P., Hu, Ruifa, 2003. Determinants of spatial diversity in modern wheat: examples from Australia and China. Agricultural Economics 28.
Tilahun, A., 1995. Yield gain and risk minimization in maize (*Zea mays*) through cultivar mixtures in semi-arid zones of the rift valley in Ethiopia. Experimental Agriculture 31, 161–168.
Tilman, D., Downing, J.A., 1994. Biodiversity and stability in grasslands. Nature 367, 363–365.
Tilman, D., Wedin, D., Knops, J., 1996. Productivity and sustainability influenced by biodiversity in grassland ecosystems. Nature 379 (6567), 718–720.
Tilman, D., Reich, P.B., Knops, J., Wedin, D., Mielke, T., Lehman, C., 2001. Diversity and productivity in a long-term grassland experiment. Science 294 (543), 843–845.
Tilman, D., Polasky, S., Lehman, C., 2005. Diversity, productivity and temporal stability in the economies of humans and nature. Journal of Environmental Economics and Management 49 (3), 405–426.
Trenbath, B.R., 1974. Biomass productivity of mixtures. Advances in Agronomy 26, 177–210.
Trenbath, B.R., 1999. Multispecies cropping systems in India. In: Lefroy, E.C., Hobbs, R.J., O'Connor, M.H., Pate, J.S. (Eds.), Agriculture as a Mimic of Natural Systems. Kluwer, Dordrecht, pp. 381–405.
Van Dusen, M.E., Taylor, J.E., 2005. Missing markets and crop diversity: evidence from Mexico. Environment and Development Economics 10, 513–531.
Vandermeer, J.H., 1989. The Ecology of Intercropping. Cambridge University Press, Cambridge.
Vavilov, N.I., 1949. The origin, variation, immunity and breeding of cultivated plants. Chronica Botanica 13, 1–364.
Walker, B., Kinzig, A., Langdridge, J., 1999. Plant attribute diversity, resilience, and ecosystemfunction: the nature and significance of dominant and minor species. Ecosystems 2, 95–113.
Widawsky, D., Rozelle, S., 1998. Varietal diversity and yield variability in Chinese rice production. In: Smale, M. (Ed.), Farmers, Gene Banks, and Crop Breeding. Kluwer, Boston.
Wood, D., Lenné, J.M. (Eds.), 1999. Agrobiodiversity: Characterization, Utilization and Management. CABI, Wallingford.
Wooldridge, J.M., 2002. Econometric Analysis of Cross Section and Panel Data. The MIT Press.
World Bank, 2005. Ethiopia—Well-being and Poverty in Ethiopia: The Role of Agriculture and Agency Report No. 29468-ET. World Bank, Washington, D.C.
Yadeta, A., Bejiga, G., 2002. Evaluation of Ethiopian chickpea landraces for tolerance to drought. Genetic Resources & Crop Evolution 49, 557–564.