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An analysis of net farm income to guide agricultural policies in the Ethiopian highlands

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Abstract

Background: As part of a larger food security project under Ethiopia's Agricultural Growth Program (CASCAPE), 928 farms in the Ethiopian Highlands were surveyed between 2012 and 2017. The aim was to determine whether the Net Farm Income (NFI) is a relevant indicator that drives food security at the household and the farm level, and to determine its drivers across six study regions of Ethiopia (i.e., Addis Ababa, Hawassa, Haramaya, Bahir Dar, Jimma, and Mekelle). The effect of different socio-economic and environmental drivers on NFI was determined using descriptive statistics, correlation analysis, k-means clustering and comparison of high and low NFI quartiles per region.

Results: The average annual NFI in Ethiopia was just below 1000 US$ per farm household, with Addis Ababa region leading. Jimma and Bahir Dar were just above average, and the others were at the lower end. In the correlation analysis, NFI was best explained by farm size, net cash flow and the use of nitrogen fertilizer. Male-headed households earned considerably more than female-headed households. The k-means clustering yielded two major farm types on the basis of significant differences in rainfall, farm size, education level, crop diversity, cash flow and N fertilizer use. An analysis of richest 25% versus poorest 25% per region showed Addis Ababa, Bahir Dar, Jimma and Mekelle regions all had significant differences between the two quartiles in farm size, crop diversity and N fertilizer use, whereas Hawassa and Haramaya regions seem more homogeneous.

Conclusions: The survey results present new entry points for informed decision making through targeted, area-specific food security policies in the Ethiopian Highlands by virtue of insight in the regional spread of NFI and its driving forces. Important deductions from the results are policy actions that are obtainable from the results. For example, the farm-size variable provides an indicator on the type of policy action that is required to determine the farm sizes that generate sufficient returns on the overall farming investment. Next, cash-flow is a variable that speaks to the idea on the amount of hard-cash needed by a household to enable it get meaningful returns on cash invested on farming, or a guaranteed minimum return on any specific crop(s) or animal production. Nitrogen fertilizer as an analysis variable is predominantly a crop productivity indicator. In order for the farming to be sustainable, there is need for policy articulation on the amount of nitrogen required for specific yields and crops. Finally, location and rainfall parameters require recommendations on location specific crop management policies that correspond to the rainfall amount, soil types, ecological zones and distance from the markets as maybe gleaned from the results.

Keywords: Farm inventory, Farming system, Fertilizer, Gender, Net farm income, Ethiopian highlands

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Background

Ethiopia is the second most populous nation in Africa after Nigeria with a population of about 115 million people, out of which over 90 million live in the rural areas. It is expected that the population will further grow to 170 million by the year 2050. Out of these, approximately 33 million people receive a daily income of less than 1.9 US$ per day, which is the international poverty line. Out of the 17 million rural households, only 3.5 million have access to improved seeds, compared to 14.5 million who have access to fertilizers. Some 10,5 million households have average land holdings below 0.6 ha, with each household having an average of 5 family members [6, 30].

The country is blessed with extensive highlands that generally have young fertile, volcanic soils [12], which respond well to fertilizer applications if applied according to soil and agro-ecological characteristics [13]. Although it is technically possible to increase productivity and production by a good margin, this depends a lot on national agricultural policies and on farm households preparedness and support to invest in agriculture. However, agricultural technology adoption rates have been disappointing in many developing countries, the highlands of Ethiopia not being an exception [1, 3, 14, 21, 22, 24, 33]. A historic survey revealed that until some decades ago, there has not been a lot of effort in Ethiopia to take peasant agriculture to higher levels of development [5]. There has been a status quo for a long time, where farm households obtaining their food through ox-plough driven smallholder farming continue to dominate the farming landscape. The International Food Policy Research Institute (IFPRI) s executed its first major Ethiopia Rural Household Survey in 1989, which has been used for many follow-up studies and agricultural modeling. One such study found positive impacts of agricultural extension services on poverty reduction and consumption growth [8].

In the last 2 decades, the Ethiopian rural development policy has been directed at developing efficient use of modern agricultural technologies for increased production and productivity. Based on this focus, the government implemented the second phase of its Growth and Transformation Plan (GTP II) and has now launched a follow-up 2021–2030 national development plan [25]. Part of GTP II is the Agricultural Growth Program (AGP) which invests heavily in infrastructure, but also in the national extension system and services in the high- and medium-potential parts of the Highlands. Meanwhile, there is increasing evidence that participation in the AGP has contributed to an increase in food security as a result of both technical change and increased efficiency of available technology, and underpinned the need for investment in research and extension [27].). From 2010 onward, the Dutch-funded project CASCAPE (Capacity building for scaling up of evidence-based best practices in agricultural production in Ethiopia) has assisted AGP develop effective pathways for participatory technology development, and subsequent scaling through a Training of Trainers capacity building program. CASCAPE worked in six AGP areas, operating from universities and agricultural research centers in these regions. For this work to be effective and relevant, a large multi-year household survey was carried out in the regions (2012–2017), that were meant to help target interventions and technologies on a regional basis, and on the basis of different resource endowments among farm households. Aware of the fact that choosing food security indicators is a delicate affair based on subjective measurement decisions [31], Net farm income (NFI) was generally seen as a key indicator that could be used to turn data into information, and information into wisdom and policy recommendations. NFI measures the reward to the farm family for its labor as well as management input and the returns to all the capital invested in the farm whether borrowed or not. Off-farm income is not included in the definition of NFI. This paper provides an analysis of a large multi-annual survey centered on the NFI as a key indicator highlighting important productivity differences across regions and households. The objectives, therefore, are (i) to provide insight and explain differences in NFI across the Ethiopian Highlands, (ii) explain NFI by the bio-physical and socio-economic data obtained during the survey using different statistical tools, and (iii) make policy recommendations that follow from this research.

Materials and methods

Study area and data collection

The study focused on smallholder subsistence farms in the Ethiopian highlands. Out of a total of 30 intervention woredas (districts) throughout the Ethiopian Highlands (Fig. 1), two districts were selected in 6 cluster areas: Addis Ababa, Bahir Dar, Haramaya, Hawassa, Jimma, and Mekelle. A total of 928 households was surveyed

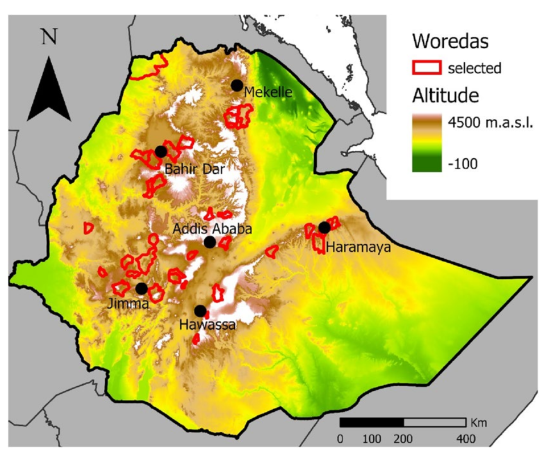

Fig. 1 Sampled districts (woredas) in the 6 study regions

from 2012 to 2017. Households were selected based on their biophysical settings (agro-ecological zone, geology, soils) and farm typologies (resource-rich, medium, poor), and male versus female-headed households. Households were visited twice a year—at the start of the season for farm input data and at the end of the season for production (output) data. Interviews of roughly 2.5 h followed the MonQIt methodology (previously MonQI) (https://www.MonQI.org/features/description ; references). The use of resource endowment as a means of stratification was based on the approach by the national extension system who work with the concept of 'model' farmers. As in retrospect, it turned out to be difficult to find objective grounds for coining a household as 'model' or 'non-model', this approach has not been maintained in this analysis. Moreover, by avoiding this, the categorization of the farms based on NFIs come out after the analysis rather than being built as an a priori classification attribute that precedes the analysis, living up to the adagium 'first calculate, then aggregate'. The MonQIt methodology conceptualizes the farm or agricultural enterprise in land units, the household, and the external environment. The activities on the farm are subdivided into land use activities, animal activities, redistribution activities, storage activities and other activities (Fig. 2). The standardized survey instrument aims to characterize the various components (land units, household, and external) and includes detailed questions on the various activities.

The MonQIt approach stems from an earlier Farm-NUTMON (farm-nutrient monitoring) data collection toolbox that was originally designed to quantify soil nutrient balances (N, P, K), and their relationships with farm-level soil fertility management and farm level economic performances [7, 26, 32]. Similar network approaches were developed later on [2]. The toolbox includes a structured questionnaire, a database, and two simple empirical static models (NUTCAL for calculating nutrient flows and ECCAL for calculating the economic parameters). The farms are treated as distinct physical systems with concrete boundaries. This is important for goods and flows that enter the farm, leave the farm, and are rerouted among components of the farm. The selected farms were interviewed using the standardized questionnaire of MonQIt Farm management data on household composition, fields and farm characteristics and nutrient management data including use of inputs for the different crops and livestock activities, flows between activities, crop yields, animal production, sales, input and output prices were collected using the MonQIt model questionnaire. MonQIt is a tool for monitoring the management and performance of small-holder farming systems to understand and pave the ways for improvement in social, economic, agricultural and environmental conditions of farming systems (www.monqi.org; https://research.wur.nl/en/publications/monqi-toolbox-for-monitoring-and-evaluating-the-management-and-pe). Data entered into the MonQIt model, combines the farm data with the background data on, e.g., nutrient contents of products, conversion factors from farmer used units (e.g., head loads) to SI units, etc. Data on nutrient (e.g., N, P and K) contents of crops, crop residues, milk and manure are obtained from literature [32] and included in the background database of the model.

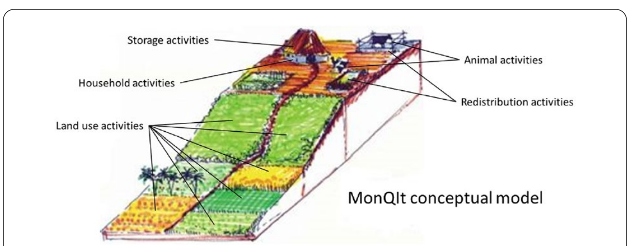

Fig. 2 MonQIt conceptual model with the various activities in the household

Data processing

Data processing was conducted using the SPSS statistical package. Descriptive statistics, correlation analysis and cluster analyses were the predominant statistical analysis methods used. Descriptive statistics provided the computed values of the measured variables. Correlation analyses were used correlate the net farm income (NFI) with the collected data values of the observed variables. Cluster analysis was used to cluster the farms based on their NFI values and subsequently differentiating them into different income categories based on their resource endowments.

Before the statistical analysis, the data were cleaned for obvious data collection errors. Most of data were continuous data, whereas some were discrete data (Table 1). The Net farm income was computed based on the gross margins of the farming activities and sales. The gross margin (GM) is an indicator of the profitability of the farming activity and is calculated as the difference between the intrinsic gross value of all expenses compared to farm income (regardless of whether they were sold or not) and the variable cost of all inputs (excluding family labour) The net farm income (NFI) was thus calculated as

$$\begin{aligned}\mathrm{NFI} &= \mathrm{GM}_{\mathrm{LA}} + \mathrm{GM}_{\mathrm{AA}} + \mathrm{GM}_{\mathrm{RA}} + \mathrm{GM}_{\mathrm{S}} \\ &\quad + \mathrm{GM}_{\mathrm{OA}} - \mathrm{FIXCOST}\end{aligned}$$

where LA = land use activity, AA = animal activity, RA = redistribution activity, S = storage activity, OA = other activities (Fig. 2). FIXCOST refers to the costs associated with a product which are fixed over a number

Table 1 Farm characteristics that were registered during the MonQIt surveys in the 6 regions

Measured variable	Variable description	Measurement Units
Economic performance		
NFI_tot	Total net farm income of the farm	ETB/yr
NFI_lu	Net farm income per labor unit	ETB/yr
Site description		
S_loc	Location and zone of the collected household data (i.e., Addis Ababa/Jimma/Bahir Dar/Mekelle/Haramaya/Hawassa)	–
S_prec	Precipitation (rainfall amounts in specific locations)	mm/yr
S_dist	Distance to market	Km
Farm architecture		
A_tot	Total area of farm	m^2
A_own	Total area owned by the farmer	m^2
A_mngd	Total area managed by the farm owner	m^2
A_rentI	Total area rented in from other farms	m^2
A_rentO	Total area of the farm rented out	m^2
C_div	Number of crops on the farm	# crops
L_tlu	Tropical livestock units (a standard measurement unit that allows the aggregation of the various categories of livestock to enable them to be compared)	# TLU
Household characteristics		
H_gend	Household head gender	
H_age	Household head age	Years
H_edu	Household head level of education (Number of years in school)	Years
H_size	Household size (number of persons in the household)	#
H_cons	Consumer units (number of people fed on the farm)	#
H_lab	Labor units (number of labour days provided by an adult)	#
Economic characteristics		
E_Lval	Livestock value in the farm	ETB/yr
E_ncf	Net cash flow of the farm	ETB/yr
E_ofi	Off-farm income (external income)	ETB/yr
E_ri	Land rent income (income from rented land on farm)	ETB/yr
Environmental characteristics		
N_fert	Nitrogen Fertilizers input in crops	Kg/yr
N_bal	Nitrogen balance in the soil based on nitrogen inputs and outputs calculated from the sol harvests	Kg/yr

ETB Ethiopian Birr; *Kg/yr* Kilograms per year; *mm/yr* rainfall amount in millimeters per year; # number of

of units produced. NFI can be interpreted as the return to labor, since family labor was excluded from its calculation. After data cleaning and discarding farm households with incomplete data sets, 928 households were included in the survey. Interviews were held between one and five times, between 2012 to 2017. Data were aggregated over the various years for the households that were visited more than once. From the larger database, data were extracted describing the economic performance of the farm and descriptive variables on farm architecture, household, management, N fertilizer use and soil nutrient balances. (Table 1).

Statistical analysis

The variation in NFI is analyzed by means of descriptive statistics and the cumulative distribution function to indicate the width of the distribution and to indicate the important tails of the distribution. To indicate whether the variation is local or whether the variation is the result of large-scale agro-ecological variation, the analysis was also carried out after stratifying the area over the six regions. A common element that was considered important in agricultural development was the difference in performance between female- and male-headed households. The difference in NFI between these two groups was tested through a student *t* test.

A large variation in farm household characteristics was expected, also due to the dropping of the 'model' versus 'non-model' farmer selection approach. The survey describes this variation in terms of the wide range of variables listed in Table 1. The variation in these characteristics is described by summary statistics and their interactions are evaluated through a correlation analysis and diagram. To summarize the variation in all the properties, a k-means cluster analysis was carried out to see whether specific farm types could be identified [16]. In a subsequent step, differences in NFI between these farm types were tested using summary statistics and a student *t* test. An alternative, second approach then followed in line with the central postulation of the CASCAPE project that agricultural development can be achieved by specifically looking at the most successful farmers in a region and to identify the specific characteristics and management that may have led to their success. Therefore, the farms in the lower and upper quartile of the NFI per region were statistically compared and evaluated [19].

Table 2 Presentation of the results of the descriptive analysis of the farm variables from Table 1

	Mean	Median	St.Dev	C.V
NFI_tot	21482	16193	43406	202
NFI_lu	6593	5647	14347	218
S_prec	971	1010	298	31
S_dist	0.9	0.4	2.8	321
A_tot	18960	15000	15883	84
A_own	16035	12156	14468	90
A_mngd	18193	14,347	15432	85
A_rentI	2904	0	6430	221
A_rentO	745	0	3756	504
C_div	4.9	5.0	2.1	44
L_tlu	9.9	2.1	167.0	1693
H_gend	1.2	1.0	0.4	35
H_age	43.1	42.0	11.3	26
H_edu	3.3	2.0	3.4	105
H_size	6.4	6.0	2.2	35
H_cons	4.9	4.9	1.8	36
H_lab	3.2	3.0	1.3	41
E_lval	22,626	15,975	26,634	118
E_ncf	8095	1793	61,369	758
E_ofi	840	0	3763	448
E_ri	337	0	2533	752
N_fert	67	46	70	104
N_bal	− 64	− 1	264	− 412

Results and discussion

Summary statistics

Table 2 shows the summary statistics of the entire survey. The data confirm the considerable variation that can be found in the Ethiopian highlands which is particularly visible in the large coefficients of variation. Net farm income in the Ethiopian highlands averaged 21,482 ETB with a standard deviation of 43,406 ETB. Large differences between the mean and median of rented land, number of animals, cash flow, fertilizer use and the nutrient balance indicated skewed distribution. This implied that a small percentage of the total number of farms had much rented land, many animals, high cash flow and fertilizer use, and a high extraction rate of soil nutrients. The median value of 'total area' was 1.5 ha, which is at the high end when compared to national averages, mentioned in the Introduction. The average household size of the sample is a bit larger than national averages [5].

Figure 3 shows the distribution of NFI across the sampled farms, showing that 50% of the farms have a net farm income below 16,193 ETB, at an average household size of 6.4 members with 3.2 labor units (Table 2). Against an average ETB to US$ rate of 22.5 to 1, this would mean that 50% of farmers earn less than US$ 720 from farming, which is close to US$ 2/day and also close to the international poverty line of US $ 1.9/day. A negative net farm income was observed for 12.5% of the surveyed households. Off-farm income should make up for this in order for farm households not to become safety-net dependent. Reported off farm income (E_ofi in Table 2) of 840 ETB/year, however, does not fill this gap. It is assumed that farmers may have other off-farm income sources and remittances that did not come out clearly from the survey. This is partly due to the focus in this study on income from agriculture, and partly because it is a sensitive issue to discuss and might have needed different national census-type survey approaches. Hence, off-farm income is still largely agriculture-related off-farm income.

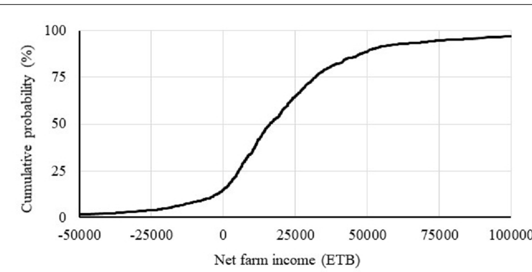

Fig. 3 Cumulative distribution of net farm income

Table 3 Average net farm income (in 000 ETB) in the six study regions

	Average*	St.dev	Median	%NFI < 0	%NFI > 40
Addis Ababa	45[a]	73	27	5.9	36.6
Bahir Dar	24[b]	21	22	3.7	14.3
Haramaya	12[c]	33	9	25.8	11.6
Hawassa	3[c]	25	4	41.9	7.5
Jimma	24[b]	24	17	3.4	20.5
Mekelle	8[c]	34	12	21.5	7.4

* Different letters indicate significant differences ($p < 0.01$)

NFI by region

For policy interventions it is important to further break down the variation in NFI and to identify sources of variation. The six regions that were included in the survey showed significant differences in NFI ($p = 0.00$) as illustrated in Table 3. The study regions explained 10% of the total variation in net farm income in the Ethiopian highlands. Major differences were between Hawassa, where incomes are lowest with almost 40% of the households dealing with a negative NFI, and the Addis Ababa region, where almost no households had a negative NFI. For the latter region, average NFI was more than twice the overall average, but the median value was closer to the overall average. Hence, a smaller, more well-off (in terms of agriculture) group was part of the Addis Ababa sample. Their way of farming at the same time may set an example for other farms and areas.

Correlating NFI with other characteristics

When correlating NFI with the other characteristics of Table 2, it is observed that NFI correlates moderately well (correlation coefficients above 0.25) with net cash flow, farm area, and the use of nitrogen fertilizer (Table 4). Other correlations show that older heads of household appear to have a lower level of education, larger households appear to have more livestock, and larger farms have more livestock, apply more N-fertilizer but also have more negative N balances, which is probably caused by the increased extraction of nitrogen due to higher crop production.

Going by the above, it is possible to assess and establish the land sizes needed to generate above-poverty line NFIs or above. This can guide land size fragmentation policies. Cash-flow is another element of importance: without cash, there is no investment. Farm subsidy or credit to the farmer would go a long way in making them obtain higher net farm incomes and hopefully plough that back into the purchase of fertilizers and other ways to sustain or increase productivity. Livestock is related moderately well with the area under crops, which may relate to the dependence of the animals on crop residues during part of the year, and the land to be tilled. Animal manure may also explain the correlation, but in some regions, dried manure is often sold as a fuel.

Table 5 shows the distribution of NFI by gender. Net farm income of the male-headed households exceeds those of the female headed households (approximately 46,000 versus 41,000 ETB), but the differences are not significant ($p = 0.068$).

Farm types created by k-means cluster analysis

To better understand the variation in farm characteristics in the Ethiopian highlands, a k-means cluster analysis on the farm characteristics was performed, including all characteristics except NFI itself. This resulted in two clear farm type clusters as presented in Table 6, a 'richer' one of 213 households and a 'poorer' one of 720 households. Most characteristics differ significantly between the two farm types, notably total rainfall, farm size, number of animals, education level, net cash flow, nitrogen fertilizer use and (in a negative way) soil nutrient mining. Distance to market, however, does not come out as significant, which may be due to the entire sample being relatively close to markets, or to lack of clarity at the start on what is considered a 'market'. Remarkably also, farm type 2 has higher off-farm derived cash flow, which makes sense as NFI is not enough to make a living. One might argue that this approach brings back the notion of 'model' and 'non-model' farmer categories, but in an objective way. This has not been verified though.

Afterward, average NFI for the two farm types were determined by independent sample *t* test for equality of means not assuming equal variances. Averages were approximately 47000 ETB and 14000 ETB, respectively (bottom of Table 6). This shows that NFI of farm type 1 (approximately 25% of the sample) has NFI that is more than twice the average NFI for the entire survey group, but the large farm type 2 (approximately 75% of the sample) has NFI that is even below the overall median figures of Table 2 and Fig. 3, and below the poverty line of 1.9 US$/day, if only looking at income from agriculture.

Comparison of upper and lower quartiles per region and characteristic

An alternative way of looking at the among and within-regional variability and identify which characteristics make a farm successful or not in terms of its NFI is to compare characteristics across the regions and to see how farms in the upper and in the lower quartile of the NFI within regions differ. The latter can then again be compared across regions. The upper quartile corresponds with farm type 1 in Table 6.

Table 7 shows the results of the analysis. The highlighted cells show, where upper and lower quartiles differ

Table 4 Correlation analysis of the farm characteristics

	NFI_tot	*NFI_lu*	*S_prec*	*S_dist*	*A_tot*	*A_own*	*A_mngd*	*A_rentI*	*A_rentO*	*C_div*	*L_tlu*	*H_gend*	*H_age*	*H_edu*	*H_size*	*H_cons*	*H_lab*	*E_lval*	*E_ncf*	*E_ofi*	*E_ri*	*N_fert*	*N_bal*
NFI_tot	1.00																						
NFI_lu	0.92	1.00																					
S_loc	-0.22	-0.23																					
S_prec	0.11	0.12	1.00																				
S_dist	-0.02	-0.02	0.07	1.00																			
A_tot	0.30	0.21	0.18	-0.01	1.00																		
A_own	0.26	0.17	0.19	-0.02	0.91	1.00																	
A_mngd	0.30	0.21	0.18	0.00	0.97	0.87	1.00																
A_rentI	0.15	0.14	0.02	0.04	0.41	0.01	0.43	1.00															
A_rentO	0.05	0.06	0.03	-0.02	0.23	0.27	0.00	-0.03	1.00														
C_div	0.09	0.10	0.11	0.13	0.15	0.10	0.15	0.15	0.03	1.00													
L_tlu	0.15	0.12	0.30	0.10	0.35	0.32	0.33	0.14	0.14	0.20	1.00												
H_gend	-0.05	-0.01	-0.06	-0.08	-0.13	-0.08	-0.14	-0.15	0.02	-0.17	-0.24	1.00											
H_age	0.14	0.13	0.03	0.03	0.13	0.18	0.13	-0.07	0.01	0.08	0.05	0.04	1.00										
H_edu	0.02	0.02	0.02	-0.01	0.13	0.11	0.13	0.09	0.03	0.05	0.18	-0.29	-0.29	1.00									
H_size	0.14	0.04	-0.01	0.02	0.20	0.19	0.19	0.08	0.09	0.18	0.31	-0.32	0.14	0.10	1.00								
H_cons	0.18	0.06	0.02	0.02	0.21	0.20	0.20	0.09	0.08	0.20	0.31	-0.31	0.18	0.07	0.94	1.00							
H_lab	0.16	0.02	0.08	0.03	0.11	0.10	0.11	0.05	0.03	0.20	0.19	-0.18	0.22	-0.10	0.65	0.74	1.00						
E_lval	0.12	0.10	0.18	0.09	0.30	0.27	0.28	0.14	0.13	0.25	0.84	-0.24	0.02	0.19	0.35	0.33	0.19	1.00					
E_ncf	0.35	0.36	0.05	-0.02	0.07	0.07	0.07	0.03	0.03	0.04	0.00	-0.01	0.03	-0.01	0.05	0.07	0.06	-0.01	1.00				
E_ofi	-0.11	-0.08	-0.03	0.02	-0.07	-0.06	-0.07	-0.03	0.00	-0.03	0.00	-0.03	-0.01	0.01	0.05	0.05	0.08	0.00	-0.02	1.00			
E_ri	-0.01	-0.01	0.02	-0.02	0.09	0.02	0.07	0.16	0.06	-0.02	-0.01	0.02	-0.03	0.01	0.00	0.00	-0.01	-0.02	0.02	-0.03	1.00		
N_fert	0.39	0.34	0.25	0.06	0.45	0.39	0.45	0.24	0.04	0.17	0.34	-0.11	0.06	0.11	0.16	0.18	0.14	0.25	0.06	-0.02	0.05	1.00	
N_bal	-0.15	-0.12	-0.20	0.00	-0.34	-0.35	-0.34	-0.04	-0.03	-0.11	-0.33	0.11	-0.06	-0.17	-0.14	-0.14	-0.01	-0.27	-0.05	0.05	0.03	-0.22	1.00

Table 5 Average net farm income in six regions in the Ethiopian highlands divided over male and female-headed households (in 000 ETB; standard deviation between parentheses)

	Male headed		Female headed		Difference
	Average	St.dev	Average	St.dev	(*p* value)
Addis Ababa	46286	(81756)	41471	(40521)	0.600
Bahir Dar	26170	(20694)	18777	(19495)	0.040
Haramaya	13583	(35862)	5187	(18797)	0.068
Hawassa	3784	(25129)	− 7936	(17593)	0.368
Jimma	25584	(25321)	17628	(13243)	0.023
Mekelle	11333	(38917)	3435	(22129)	0.104
All	22925	(46653)	16983	(29443)	0.028

significantly. The three regions that have higher rainfall (Addis Ababa, Bahir Dar, Jimma regions) show similar patterns of significance: farm size, crop diversity, and fertilizer use are markedly higher in the upper quartile than in the lower quartile. Haramaya and Hawassa regions have very few significant differences between the quartiles and can, therefore, be regarded as rather homogenous. Mekelle region, however, has significant differences for almost every characteristic, showing that the upper 25% is a lot more well-off than the lower 25%. On cash flow, all regions show significant differences between the two quartiles. Distance to markets again shows no significant differences, and for the registered off-farm income, all low quartiles have larger values than the high quartiles, apart from Mekelle, where the low quartile seems to meet with stubborn poverty problems, also testified by the highly negative NFI.

The spread shown in Table 7 shows the need to make policy interventions i. specific for regions, but also ii. on the basis of the heterogeneity of the farming community, and iii. on the characteristics that amplify this heterogeneity across resource endowment groups. Low or unpredictable rainfall may be countered by irrigation (if the option exists) or adopting drought-tolerant crops or varieties, farm size getting too small is a challenge given ongoing land fragmentation in the country, cash-flow enhancement through credit facilities or other means of case transfer is a clear divider between rich and poor in all regions. In the Addis Ababa region, both quartiles use more than 100 kg of nitrogen fertilizer on their land, implying it is probably effective and may even

Table 6 Characteristics of two farm types identified with a k-means cluster analysis. Differences in means and standard deviation between the two farm types are tested with a *t* test and *f* test, respectively

	Farm type 1 (*n* = 213)		Farm type 2 (*n* = 720)		Differences	
					Means (*t* test)	StDev.(*f* test)
S_prec	1080	(285)	939	(295)	0.000	0.525
S_dist	1.04	(2.86)	0.83	(2.81)	0.354	0.695
A_tot	36965	(20841)	13621	(8637)	0.000	0.000
A_own	30757	(20417)	11663	(8074)	0.000	0.000
A_mngd	35587	(20226)	13034	(8484)	0.000	0.000
A_rentI	6208	(10718)	1930	(3947)	0.000	0.000
A_rentO	1377	(6487)	559	(2396)	0.073	0.000
C_div	5.7	(2.2)	4.6	(2.0)	0.000	0.221
L_tlu	8.0	(6.0)	2.2	(2.5)	0.000	0.000
H_gend	1.1	(0.3)	1.2	(0.4)	0.000	0.000
H_age	45.4	(9.9)	42.4	(11.6)	0.000	0.007
H_edu	4.5	(3.8)	2.9	(3.3)	0.000	0.009
H_size	7.3	(2.3)	6.1	(2.1)	0.000	0.135
H_cons	5.7	(1.9)	4.7	(1.7)	0.000	0.096
H_lab	3.6	(1.4)	3.1	(1.3)	0.000	0.008
E_lval	51475	(35929)	14,098	(14848)	0.000	0.000
E_ncf	18855	(43968)	2645	(23370)	0.000	0.000
E_ofi	505	(2202)	941	(4111)	0.043	0.000
E_ri	407	(1933)	316	(2687)	0.587	0.000
N_fert	119	(98)	52	(49)	0.000	0.000
N_bal	− 241	(485)	− 12	(94)	0.000	0.000
NFI_tot	46937	(65770)	13915	(30317)	0.000	0.000
NFI_lu	13791	(19392)	4455	(11672)	0.000	0.000

Table 7 Characteristics of farms within the lower and upper quartile of NFI in the study regions

	S_prec	S_dist	A_tot	A_own	A_mngd	A_rentI	A_rentO	C_div	L_tlu	H_gend	H_age	H_edu	H_size	H_cons	H_lab	E_lval	E_ncf	E_ofi	E_ri	N_fert	N_bal
Addis Abeba																					
low	1137	0.7	16860	14892	16307	1968	553	2.9	4.5	1.3	41	3.9	5.6	4.1	2.3	18622	-7784	978	1873	73	-202
high	1084	0.4	39497	34646	37157	4851	2340	4.6	5.5	1.2	48	3.3	7.5	5.9	3.6	30840	44996	427	883	183	-369
P	*0.01*	*0.07*	*0.00*	*0.00*	*0.00*	*0.11*	*0.26*	*0.00*	*0.45*	*0.81*	*0.00*	*0.52*	*0.00*	*0.00*	*0.00*	*0.04*	*0.00*	*0.25*	*0.44*	*0.00*	*0.16*
Bahir Dar																					
Low	1195	1.4	11833	10729	11583	1104	250	4.7	3.1	1.4	43	2.2	5.3	4.1	3.1	15754	-4448	2446	0	67	11
High	1184	2.5	27496	20096	27496	7400	0	6.7	4.2	1.2	45	2.9	6.2	4.9	3.8	22510	21045	558	264	175	45
P	*0.63*	*0.44*	*0.00*	*0.00*	*0.00*	*0.00*	*0.21*	*0.00*	*0.23*	*0.01*	*0.56*	*0.25*	*0.07*	*0.09*	*0.06*	*0.13*	*0.00*	*0.06*	*0.32*	*0.00*	*0.00*
Haramaya																					
Low	835	0.7	8632	7286	8632	1346	0	4.5	1.5	1.3	42	2.4	6.7	5.2	4.0	14029	-2288	3985	285	41	12
High	807	0.6	8768	7662	8704	1106	64	5.1	3.0	1.1	41	3.7	7.6	5.9	4.2	32822	28950	918	34	58	-21
P	*0.21*	*0.78*	*0.92*	*0.68*	*0.96*	*0.72*	*0.32*	*0.11*	*0.00*	*0.06*	*0.49*	*0.09*	*0.07*	*0.09*	*0.57*	*0.00*	*0.00*	*0.17*	*0.18*	*0.07*	*0.04*
Hawassa																					
low	654	1.4	17902	14671	17558	3231	344	7.2	2.6	1.1	39	4.0	6.8	4.8	2.8	29154	-3882	892	281	34	-65
high	654	0.8	24085	19755	22065	4329	2020	6.6	4.8	1.0	42	5.6	7.2	5.5	2.6	50800	12977	557	27	56	-154
P	*1.00*	*0.15*	*0.13*	*0.11*	*0.26*	*0.61*	*0.19*	*0.38*	*0.02*	*0.16*	*0.33*	*0.14*	*0.58*	*0.14*	*0.49*	*0.03*	*0.00*	*0.51*	*0.26*	*0.09*	*0.10*
Jimma																					
low	1258	0.8	16017	13692	14163	2325	1854	4.4	2.3	1.1	42	2.8	5.9	4.4	3.0	14517	-3149	923	6	34	-17
high	1041	0.3	32456	29288	29175	3168	3281	5.8	4.8	1.1	43	4.5	7.4	5.7	3.7	30314	26763	162	11	72	-52
P	*0.02*	*0.00*	*0.00*	*0.00*	*0.00*	*0.37*	*0.28*	*0.00*	*0.02*	*0.51*	*0.43*	*0.01*	*0.00*	*0.00*	*0.01*	*0.02*	*0.00*	*0.12*	*0.66*	*0.00*	*0.09*
Mekelle																					
low	663	0.4	20668	18559	19982	1620	198	2.3	1.0	1.4	37	2.9	5.3	3.9	2.3	7479	-29614	1486	878	22	23
high	695	1.0	18303	10516	18054	7787	249	5.1	6.8	1.1	46	3.1	7.3	5.5	3.4	41925	3155	559	160	40	7
P	*0.32*	*0.00*	*0.60*	*0.02*	*0.67*	*0.01*	*0.76*	*0.00*	*0.00*	*0.02*	*0.00*	*0.76*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.28*	*0.42*	*0.01*	*0.23*

become more effective with proper measures and a conducive policy and import/export market environment, as suggested for wheat [13]. Addis Ababa, Hawassa (upper quartile farmers) and Jimma had the most negative nutrient balances, signaling soil nutrient mining. This may require remediation to restore soil quality, but it depends mostly on the total available nutrient stocks. If these are sufficiently large, intervention is less urgent as compared to a situation of low nutrient stocks, where nutrient depletion translates rapidly into production losses and deterioration of soil quality which is then hard to repair.

Further reflections

The CASCAPE project was meant to underpin choices of participatory technology testing and development in the Ethiopian highlands in support of AGP. It sheds light on relations between income from agriculture and a set of farm and environmental characteristics. Results differ in a way that allows partitioning the sample of 928 households into groups based on region and resource endowment. The technology interventions can be geared toward 'learning from the best group', for example, farm type 1 in Table 6, from marked differences between the poor and the rich (Table 7), from gender differences (Table 5), or from farm characteristics that seem most relevant and can be targeted by extension and technology development.

The study has some limitations. Distance to market does not come out clearly, which may be due to the non-random selection of farmers. This also holds for median farm size (1.5 ha), which is above average farm size, and for the difference between model and non-model farmers. Although this issue was circumvented by not using it as a means of analysis, the high standard deviations at the different levels of analysis may be due to the selection process. The two groups in Table 6 may well represent model and non-model farmers, but this has not been validated. At the same time, the perception that model farmers are examples to other farmers has recently been challenged [9]. New technologies for malt barley cultivation in Hawassa were not benefiting all farm households to the same level. There tended to be social and clan-based exchange mechanisms that were often invisible, even though they are of critical importance in driving access to the material and social components of modern agricultural technologies. This tends to widen the poverty gap rather than closing it.

Other rural surveys in the Ethiopian highlands are more local by nature, but reach conclusions that generally link well to the one described in this study. It was found, for example, that education levels, household size, presence of extension workers, and risk perception were key attributes toward the probability of acceptance of improved agricultural technologies in Tigray [3, 4]. A study into the adoption of integrated soil fertility management in

Oromia found that income from maize, teff and wheat increased in the humid areas, but the higher labor demand also led farmers to discontinue other economic activities, testifying to reallocation of scarce labor resources in drier areas [17]. Having observed that mineral N fertilizer use was linked to NFI shows that farmers tend to prefer this soil fertility management option rather than going for the laborious organic fertilizer way. Policy interventions could assist in addressing this constraint (i.e., access to mineral N fertilizers). The advantages that higher rainfall areas offer for agricultural profitability also come out clearly from the former East African Highlands program [24], for all moist highlands of Uganda, Kenya and Ethiopia. The authors applied an econometric model to the Ethiopian highlands to explore the determinants of economic, social and environmental sustainability in the region's agricultural sector. The study showed that farmers felt that farm size, market access, access to off-farm income, agricultural loans, and access to agricultural extension and demonstration plots are key drivers of agricultural sustainability at the farm-level. Differences in agro-ecological conditions and region-specific factors were also significant determinants of relative farm sustainability [23]. It was also found that adoption of a combination of technologies works best [15]. The positive influence of crop diversity on food security, for example, was also found in south-western Ethiopia [20]. Related to the present study, other authors [28] looked at decision variables influencing fertilizer adoption and optimal fertilizer rates. The intensity of use of fertilizers was influenced by education status of the household head, family size, access to credit, membership to cooperatives, annual income, number of farm plots owned, and agro-ecology. In a similar study on adoption of recommended crop extension packages, major differences were found between commodities [29]. Results demonstrated that agro-ecology and spatial variability, distance from homestead to farm plots, slope index of the farm, and (again) access to extension services, access to credit, and membership of a cooperative were all significant factors influencing technology adoption. Going by this review, access to credit and extension and membership of cooperatives could have been interesting additional interview components. At the same time, yield gap analysis in the country shows that apart from use of fertilizers, the adoption of high-yielding varieties is key to increased food security [4, 18], but was not employed directly in the current study. In addition, the psychological driver 'aspirations' turned out to be of importance in rural Ethiopia, and was different between male head-of-households and spouses, but was not employed in the current study [21].

Conclusions

Net Farm Income (NFI), although not covering off-farm incomes, turns out to provide a clear picture of differences in resource endowment, per region, per agro-ecological or other farm (household) characteristic, and for male and female-headed households. Average NFI is approximately 21,500 ETB (slightly below US$ 1000/year), but the median value is only 16000 ETB. Addis Ababa region has (on average) by far the highest NFI and Hawassa the lowest. NFI correlates best with farm size, cash flow and the use of N fertilizer. Male-headed households earn 5000 ETB more than female-headed households. Addis Ababa, Jimma and Bahir Dar clearly benefit from better rainfall totals. Two farm types that were derived from a machine-learning-based statistical approach (k-means) gave two farm types with significant differences in a number of characteristics: rainfall, farm size, education level, crop diversity, cash flow and N fertilizer use. Interventions have to take this on board. Farm size may pose the largest challenge, as there is no way to increase this unless cluster farming and mechanization are introduced at a larger scale. Irrigation, education, credit facilities and financial literacy, crop and fertilizer choice can all be dealt with in policy development.

An analysis of richest 25% versus poorest 25% per region showed, apart from the already observed regional differences, that the wetter Addis Ababa, Bahir Dar and Jimma regions all had significant differences in farm size, crop diversity and N fertilizer use. Hence, closing poverty gaps has to address these issues for those regions. For Mekelle, almost all characteristics studied showed significant differences, implying that poverty alleviation here has many intervention entry points. Hawassa and Haramaya seem more homogeneous and are better served by generic agricultural policies and interventions. All areas had significant differences between rich and poor on net cash flow. This is not surprising but shows there is a compelling lack of finance to invest in the agricultural sector of the Ethiopian highlands. Given the fact that it is one of the most fertile regions on the continent, there is ample room for improvement.

The past 10 years saw impressive agricultural growth and poverty reduction in Ethiopia, stemming in partly from substantial public investments in agriculture, including extension, through the GTP II program [27]. The International Food Policy Research Institute recently presented a forward-looking analysis of Ethiopia's agrifood system in the context of a rapidly changing economy, and conclude that sustained investment in the agricultural sector, also by the private sector, is needed to continue poverty reduction [5, 10]. In the most recent outlook on Ethiopia's development, however, it is expected that agricultural growth in 2021–2030 will be less than in the previous 10-year period, and agriculture will offer fewer jobs and constitutes a smaller part of export revenues. Most of the growth should come from manufacturing [25]. This shows that apart from policy interventions in the agricultural sector and technology testing and development, there is also a need to look into cross-sectoral development, and alternative employment opportunities, perhaps in the commercialization of agriculture or in developing a more booming midstream between producer and consumer. The majority of farmers in this survey can just eke out a living from agriculture, but will not be in a position to become producers of market surpluses unless their purchasing power increases substantially. This reality has to be taken on board when evaluating the agricultural growth in Ethiopia.

The survey results present new entry points for informed decision making through targeted, area-specific food security policies in the Ethiopian Highlands by virtue of insight in the regional spread of NFI and its driving forces. Important deductions from the results are policy actions that are obtainable from the results. Four entry points are singled out. First, the farm-size variable provides an indicator on the type of policy action that is required to determine the farm sizes that generate sufficient returns on the overall farming investment. Policy recommendations that match the farm-size with returns on investment is crucial for the sustainability of the farming enterprise. This is a difficult issue, because bigger farm-sizes require extra investments which the farmer may sometimes not have or alternatively, that the government stimulates the growth of industries to remove people from unproductive farming to work in the factories or cities. For example, land policy in Algeria is at the heart of agricultural development. The model of land policy adopted here since the 1980s was inspired by the Eastern European countries, i.e., relocation of state lands. Since then, privatization has been adopted to achieve higher agricultural returns but ownership of land remained in the hands of the state, whereas land tenants have only usufruct rights [11]. This policy has also been a condition to improve competitiveness in the process of trade liberalization and WTO negotiations. The Government of Kenya and Partners [14] conducted a study on land fragmentation and its impacts on food security and recommended that the Ministry of Agriculture jointly with respective County Governments, in collaboration with the Ministry of Lands and National Land Commission should establish the minimum viable agricultural land sizes in all Counties for sustainable land use. The report further highlights factors that need to be taken into account while coming up with the minimum viable agricultural land sizes.

Second, cash-flow is a variable that speaks to the idea of the amount of hard-cash needed by a household to enable it get meaningful returns on cash invested on farming, or a guaranteed minimum return on any specific crop(s) and/or animal production. Required is a policy that provides the minimum number and types of farm operations, their costs, labour investment, farm-gate selling prices, etc., that are necessary to generate acceptable benefit-to-cost ratios (BCRs) for any selected crop or other farming activities. BCRs greater than 1 are desirable as they show positive returns on the type and number of investments made. Third, nitrogen as an analysis variable is predominantly a crop productivity indicator. It is a major crop growth and yield generator. In order for the farming to be sustainable, there is need for policy articulation on the amount of nitrogen needed for specific yields and crops. The amount of nitrogen applied should ensure that the crop produces yields that return sufficient higher yields based on the level of investment made in the purchase of the nitrogen fertilizers. When making policy recommendations, there is a need for economic computations to put numerical values on these key indicators that inform relevant policy articulation and evidence. Furthermore, to realize the desired results, there is need to consider subsidy for crop production in terms of inputs provision for balanced crop nutrition and their access by farmers that cannot afford them. Finally, the location and rainfall parameters require recommendations on location specific crop management policies that correspond to the rainfall amount, soil types, ecological zones and distance from the markets as maybe gleaned from the results showing that higher NFI occur in farms that are closer to the major urban centres in the country including: Addis Ababa, Bahir Dar and Jimma.

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Author contributions
The program was initiated and launched by EE and CvB. The fieldwork and data collection was led by AB, MT, MM, YG and HH. The latter also took charge of data management. Statistical analysis was done by PO and JS, who had lead roles in turning raw data sets into a scientific manuscript. ES initiated the write-up and edited the manuscript several times. All authors read and approved the final manuscript.

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Availability of data and materials
The data sets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

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Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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