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FARM TYPOLOGY FOR DIGITAL GREEN AND FERTILIZER ETHIOPIA USE CASES

Farm Typology for Digital Green and Fertilizer Ethiopia Use Cases
| Version 1.0

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We acknowledge Excellence in Agronomy (EiA), a CGIAR Initiative to improve agronomic practices with the goal of increase productivity and quality of food of smallholders of farms, for funding this work.

As part of CGIAR, the Excellence in Agronomy (EiA) is an Initiative that focusses to generate impact on poverty reduction as a primary impact area, followed by Nutrition, health and food security, Gender equality, Climate adaptation and mitigation, and Environmental health and biodiversity as related impact areas. With an estimate of 80% of smallholding in the world's farms (CGIAR, 2023), the improvement of agronomic practices represents an opportunity to increase productivity and quality of food for many farming households. Research organizations involved in core partnership with Excellence in Agronomy Initiative are AfricaRice, Alliance Bioversity and CIAT, CIMMYT, CIP, ICARDA, ICRISAT, IFPRI, IITA, IRRI, IWMI and World Agroforestry. www.eia.cgiar.org

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PROJECT BACKGROUND

The CGIAR EiA Initiative is organized around Use Cases located in the Global South, including Cambodia, Colombia, Democratic Republic of the Congo, Egypt, Ethiopia, Ghana, Ivory Coast, Kenya, Malawi, Mali, Mexico, Morocco, Nigeria, Peru, the Philippines, Rwanda, Senegal, Uganda, Vietnam, Zambia and Zimbabwe (CGIAR, 2023). The lessons learned on each Use Case will provide evidence to develop lessons at global application. Each Use Case has been working on the co-creation of Minimum Viable Products (MVP) that provides agronomic advice at scale.

In order to maximize the impact potential of the MVP by each Use Case, a household survey has been performed at country scale, initially in Ethiopia to gain insights into relevant areas such as gender dynamics and farmer diversity that may affect adoption potential of the MVP. The collected data is the base to construct and analyse the different farm typologies across different geographies and commodities. To do the Farm Typology analysis of the Ethiopian Use Cases, EiA approached Plant Production Systems, group of Wageningen University (WUR), with the request to clean, process and analyse the collected data, elaborate a Farm Typology and socialize the methodology of this report in a format of protocol to be use by Use Case leaders.

This report involves three steps: 1) data analysis framework; 2) construction of the farm typology; and 3) presentation of a protocol to understand and execute the R scripts developed during the data analysis.

This document represents all three steps in a systematic manner. It starts with an introduction indicating the aims of the farmer segmentation and the used data framework (chapter 1), followed with the methods we used for the typology construction (chapter 2) and the outcomes of the analysis as results and discussion (chapter 3 and 4).

1. INTRODUCTION

Complexity of agro-ecological, socio-economic and resource endowment conditions is a major challenge for the characterization of farming systems. Temporal and spatial variability in smallholder communities is normally driven by opportunities and constraints that are linked to the diversity of landscape, culture, market, resources, agricultural and off-farm activities, land access, among others (Alvarez et al., 2018).

The construction of typologies is a process that summarizes variability of the existing households and farming systems. The process involves the selection, classification, description, comparison and interpretation of variables. However, the outcomes depend on the research questions and main purpose of the typology such as: identification of diversity and its underlying causes; analyse agricultural trajectories; or support development (selection of representative farms), implementation (scale-out appropriate interventions) and monitoring (scale-up of impact assessment) of agricultural projects (Alvarez et al., 2014; Kuivanen et al., 2016). Furthermore, farm typologies can be analysed at landscape, field or household level (e.g. resource endowment), leading to different approaches and methodologies to construct the typology (Alvarez et al., 2014; Kuivanen et al., 2016).

The EiA Initiative aims to generate actionable insights into farm diversity that can be used to increase impact potential of the Use Cases through a Minimum Viable Product (MVP), by informing the (re-)design and/or the scaling strategy of the MVP (EiA Standard Operating Procedure for farmer segmentation). The MVP for the Ethiopia Use Cases is described as a digital advisory tool, currently under construction, able to deliver advices on agronomic solutions for wheat, teff and sorghum to end users such as farmers, extension agents and agro-dealers. The agronomic advice is focused on unput (organic and inorganic) applications and climate information services relevant for farmers' biophysical and socio-economic context.

Hassall et al. (2023) illustrates the applications of structural and functional typologies. The first includes understanding farm differences based on their components, such as household composition, land, resources and capital assets. The second covers more nuances, understanding differences, for example, in household dynamics, livelihood strategies, attitudes, agricultural income and diversity between regions. Identification of farm types based on household opportunities and constraints, targeting agricultural interventions and innovations, are some of the outcomes when structural and functional typologies are combined (ibid).

Given the fact that the MVP is being developed, the construction of farm segmentation (combining structural and functional typologies) at landscape and farming system scale will be of a great support for the Use Case leaders to develop and scale the described innovation. Although all the Use Cases are aligned to the main goal of the EiA Initiative, it is important to note that each Use Case has specific objectives and contexts. Thus, the participation of the Use Case leaders in defining the specific objective of the farm typology and the selection of variables has been crucial for the farmer segmentation in this report. This process has been guided by a Standard Operating Procedure (SOP) for farmer segmentation in EiA that was developed by a team of experts in EiA and made available to the Use Cases (EiA Standard Operating Procedure for farmer segmentation).

The objective of this report is to provide a methodological approach to ***construct the Farm Typology analysis for Ethiopia, based on the interests and specific hypothesis of two Use Cases (Digital Green and Ethiopia-Fertilizer).***

In parallel with the construction of the typology, we aim ***to illustrate the process of statistical analysis of continuous and categorical variables as part of the typology***.

2.MATERIALS AND METHODS

1.1 TYPOLOGY CONSTRUCTION

1.1.1 Farm household survey

The data used in the typology construction was collected by the Fertilizer Ethiopia and Digital Green Use Case in Ethiopia as part of the Excellence in Agronomy Initiative of CGIAR. Field data was collected via a standardized and modular household survey tool based on the RHoMIS survey (EiA Standard Operating Procedure for farmer segmentation). Data has been collected using the Open Data Kid (ODK) Collect app, and the ONA data management platform. Consequently, two datasets were generated, differing in the number of surveyed households and districts, but sharing the same set of questions. The two datasets were combined to get household data of 889 households from Goba, Kewet, Lemo, Siyadebirnawayu and West Belessa districts. The survey was focused on the three most important crops in these regions: wheat, teff and/or sorghum. The survey was conducted in 2023 (2016 for Ethiopian calendar) including modules that are at farm and plot level.

1.1.2 Objectives and hypothesis

The wide application of typology constructions goes along with a pallet of different methods, depending on their objectives, the type of available data and size of the sample (Alvarez et al., 2018). Therefore, the results of the typology are largely influenced by the data collection, selection of variables, and methods for dimension reduction and clustering.

EiA has developed a Standard Operating procedure (SOP) for farmer segmentation (EiA Standard Operating Procedure for farmer segmentation) where the starting point is the "Use Case MVP", followed by "objective of farmer segmentation- selection of variables", "data collection-survey", "typology construction" to finally "redefine the MVP scaling strategies". The Use Cases defined their specific objectives before implementing the EiA household survey. They provided a list of desirable variables to tailor the design of the survey based on the selection of modules defined by EiA. During the exercise of this study the selection of variables for typology construction was performed after the data collection, following the interests of the Use Case leaders. Within the scope of this report, and the SOP provided by EiA, we translated the purpose of the typology to the implementation of the Use Case, i.e. to scale-out appropriate interventions.

Through interactive breakout sessions and consultations with Ethiopian Use Case leaders, we selected variables and developed objectives and hypothesis, providing results for two typologies:

First typology (T1): *<u>The objective</u>* was to classify farming households at the regional level, in order to support the development of the Use Case MVP based on their cropping system. The hypothesis was that agricultural households can be grouped according to their crop production system such as wheat, teff and/or sorghum.

After feedback from the Use Case leaders, the first typology was too general for implementation of the MVP. Hence, a second objective was set to explore the data further.

Second typology (T2): The objective was to differentiate farming households at the cropping system level (integrating the results from T1), in order to support the implementation of the Use Case MVP based on their resources, production orientation and use of agricultural inputs. The hypothesis was that farming households can be classified according to their resource endowment (TLU, farm size, access to technology) and production orientation.

The above-mentioned objectives align with EiA's SOP for farmer segmentation, which states: "The objective of conducting farmer segmentation in EiA Use Cases is to generate actionable insights into farm diversity that can be used to increase the impact potential of the Use Cases' MVP's and realise inclusive impact across different types of farmers".

The surveyed households are distributed across 5 districts, which are located in either highland or lowland agro-ecologies. The characteristics of each district are linked to the attributes of the landscape but also to the socioeconomic conditions. Therefore, the district variable was considered only for farm description in both typologies (T1 and T2).

1.2 FACTOR ANALYSIS ON MIXED DATA (FAMD)

1.2.1 Data cleaning and processing

Data on household, labour, livestock, income, production, agricultural inputs and access to technology was cleaned, processed and transformed for statistical analysis (Table 1).

Variables included in multivariate analysis

The raw dataset consisted of nested variables across the plot level and farm level. Farm size was calculated as the sum of plot sizes for each household. As the questionnaire was designed to collect information on ten plots only, farm sizes of households having more than ten plots is underestimated in the final calculation. The number of farm households with ten plots was inflated in the dataset suspecting that number 10 was entered in the ODK even though farmers had more plots (supplementary material). Tropical livestock unit (TLU) was calculated using the method by Jahnke (1982): cattle was assumed to be equivalent to 0.7 TLU, horses 0.8 TU, donkey and mules 0.7 TLU, goat and sheep 0.2 TLU, and chicken 0.01 TLU. Cattle ratio and small ruminant ratio (goat and sheep) was the ratio of their respective TLU and total household TLU. As the survey was focused on three crops, wheat, teff and sorghum, total production of only these three crops was considered. The number of adults in the household (age 15 and above) was considered as a proxy for household labour availability. Household head education was a categorical variable with multiple levels (no education, adult education, primary, secondary, post-secondary). This variable was converted to binary where low education was primary and below primary level, and high education was above primary level. Other categorical variables were binary and used as they were in the dataset (Table 1).

Variables used for farm description

Crop area proportions were calculated based on the area of plots under a specific crop for a farming household. In few cases, there were multiple crops per plots, thus such households were left out during this calculation. As most of the households were not geo tagged (no coordinates), district (woreda) names were used to assess their spatial distribution in Ethiopia. As the district name was a text input in the ODK, many typing errors during the data collection resulted in over 50 unique names. Each name was assessed based on the spelling errors and the cleaning resulted in five unique districts in three different regions in Ethiopia. Land slope profile per plot was a categorical variable at plot level with three levels (flat, slope and steep slope). To transform the variable to farm level, proportion of plot area under three levels of slope (flat, slope, steep slope) was calculated, hence, we got three variables corresponding to the three levels of slope. Agricultural training was a nested variable where answers were on three levels, i) training received 1 year ago, ii) training received 5 years ago, iii) never received training. This variable was transformed to binary where 1 was training received (either 1 year ago or 5 years ago) and 0 was never received training.

In this report we mostly worked on the modules that provided information at farm level, identifying more than 90 variables. A total of 28 variables were used in the typology analysis and 34 were used for the description of the farms. The reasons for excluding the rest of the variables from both typology and farm description were: no variation, incorrect units, had many NAs due to incomplete data collection or they were not relevant to the hypothesis (supplementary material). The type of data was mostly categorical, representing 83% of the variables, while continuous data represented 17% of the variables. In the dataset, some households lacked plot level information for farm characteristics. Thus, before the PCA and FAMD, the dataset was filtered for household with plot level information which resulted in 848 households from 889. Further, the dataset was filtered for NA in at least one of the selected variables for each household and the final number of households for analysis was 758.

Statistical analysis

Analysis consisted of four steps, i) Data exploration, outlier handling and transformation, ii) Correlation analysis and variable selection, iii) Multivariate analysis (PCA and FAMD), and iv) Clustering and farm description (Alvarez et al., 2014, 2018; Barba-Escoto, 2019; Shukla et al., 2019). All the statistical analysis and graphical output were obtained using R software (version 4.3.1) with RStudio using various packages (see below). Some limited amount of data handling was done using Microsoft Excel.

As distribution of the data is important for PCA, continuous variables were checked for normal distribution. Log and square root transformation was used to get the variables close to normal distribution as all the variables were skewed. Further, boxplots were created to check for outliers in the variables after transformation. Farm size, herd size and number of crops had few outliers for which the corresponding HHs were filtered out.

A correlation matrix was calculated for all the continuous variables using cor function from 'stats' package using Pearson's method. Variables with a correlation coefficient above 0.9 and variables without any significant correlation with any other variable were removed from the analysis (figures and tables in supplementary material). This step is necessary for dimension reduction as highly correlated or uncorrelated variables can create higher weightage or unnecessary noise (in terms of additional dimension) in the data respectively. For binary variables, percentages of the values (1,0) were calculated and variables with 90% of either 1 or 0 were removed from the analysis. This type of filtering of categorical variables improves the quality of the dataset by removing the variables with low variation. This prevents unnecessary noise in the dataset during analysis. Steps till now were repeated for all the typologies.

For the first typology, principal component analysis (PCA) was used as only continuous variables were selected. We used dudi.pca from 'ade4' package for PCA. For the second typology, we used a combined method with Principal Component Analysis (PCA) and Multiple Correspondence Analysis (MCA) called Factor Analysis for Mixed Data (FAMD) (Husson et al., 2008). This method allows using categorical variables along with continuous variables in their original format. For both the typologies, axes with eigenvalue more than one (as per the Kaiser criterion) were retained for clustering.

Hierarchical clustering was performed using Ward's method with a distance matrix generated in PCA and FAMD. Further, 'Nbclust' package was used to derive the optimal number of clusters using "ward.D2" and "kmeans" methods. This package provides a summary of 23 indices, and the cluster with the maximum number of indices was selected. If the highest number of indices indicates 3 clusters, then that specific number of clusters was chosen. This was further checked with subjective inspection of the dendrogram after which the number of clusters was finalised. After farm types were derived, Kruskal Wallis method was used to analyse the variance among farm types in continuous variables. Categorical variables were analysed for variation using percentages and heat map.

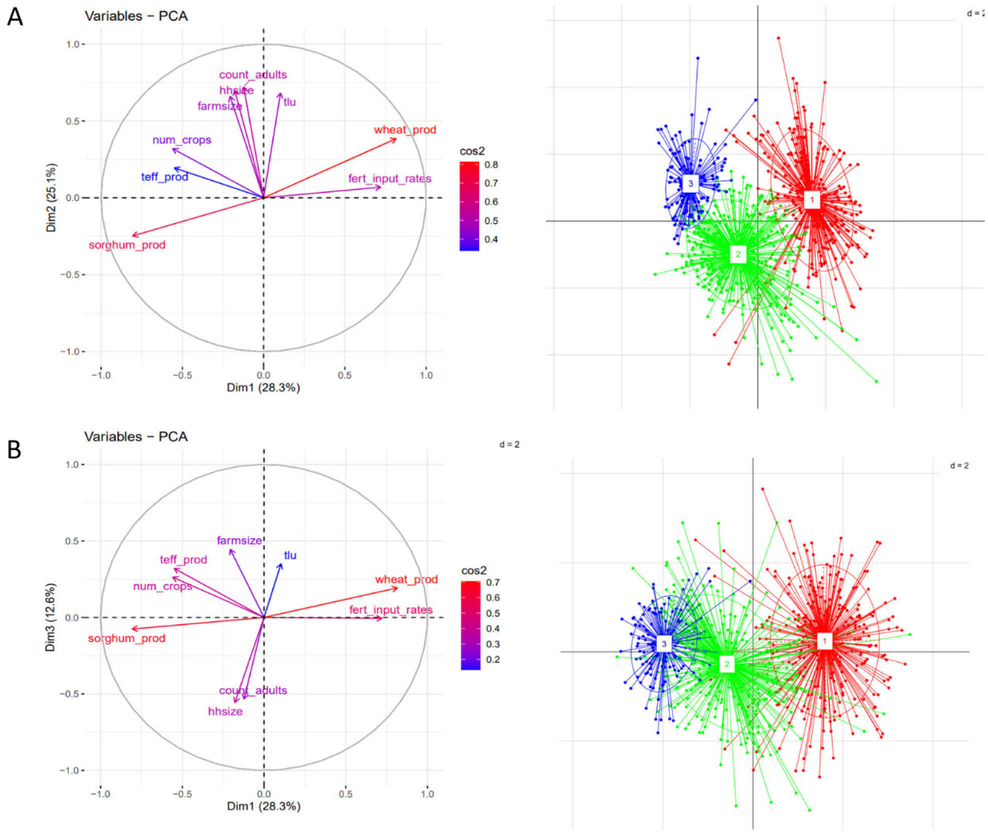
Table 1. *List of variables used for constructing typologies (T1 and T2) for two Use Cases in Ethiopia. Typology 1 resulted in three different farm types (HiW, MiS, LiS) that were subsequently used in T2. Continuous variables from T1 were retained for T2.*

Category	Variable	Code	Description	Unit	Data type	T1	T2		
							HiW*	MiS*	LiS*
Household	Household size	hhsize	Number of members in the household	number	continuous	x	x	x	x
	Education of household head	person_ education	Education level of household head	Binary	categorical		x	x	
Labour	HH labour availability	count_adults	Only adults are taken into account (from hh size)	number	continuous	x	x	x	x
	Homegarden	homegarden	Presence of homegarden in the farm	binary	categorical		x	x	x
	Oxen	oxenpair	Presence of draught power in the farm	binary	categorical			x	
Farm characteristics	Farm size	farmsize	Total area of the farm	ha	continuous	x	x	x	x
	Number of crops	num_crops	Number of crops on farm	number	continuous	x			
	Number of rent in plots	rent_in_land	Number of plots rented in	number	continuous		x	x	x
Livestock	Herd size	tlu	Total herd size	TLU	continuous	x	x	x	x
	Cattle	cattleratio	ratio cattle: total based on TLU	-	continuous		x		
	Small ruminant	smallrumratio	Ratio small ruminants: total based on TLU	-	continuous		x		
Income	Off farm income	offfarm_ income_any	hh members working outside the farm	binary	categorical		x	x	x
Main crops production	Teff production	teff_prod	Teff production	kg	continuous	x	x	x	x
	Sorghum production	sorghum_prod	Sorghum production	kg	continuous	x		x	x
	Wheat production	wheat_prod	Wheat production	kg	continuous	x	x		
Agricultural inputs and practices	Compost	compost	Use of organic fertilizer	binary	categorical				x
	Manure	manure	Use of manure	binary	categorical			x	x
	Pesticides	pesticides	Use of pesticides	binary	categorical		x	x	
	Hybrid seeds	hybridseeds	Use of improved seeds	binary	categorical		x	x	x
	Fertilizer input rates	fert_input_ rates	Chemical fertilizer inputs/ farm size	kg/ha	continuous	x	x	x	x
	Fertilizer on wheat	fertiliser_crops. wheat	Crops receiving fertilizer	binary	categorical				
	Fertilizer on teff	fertiliser_crops. teff	Crops receiving fertilizer	binary	categorical		x		
	Fertilizer on sorghum	fertiliser_crops. sorghum	Crops receiving fertilizer	binary	categorical			x	x
	Use of Urea	urea	Use of urea on farm	binary	categorical			x	x
	Use of NPS*	NPS	Use of NPS on farm	binary	categorical		x		
	Use of NPSB*	NPSB	Use of NPSB	binary	categorical		x	x	
Access to technology	Agricultural training	agtraining	Sum of hh members with training	binary	categorical		x	x	x
	Household membership	hh_ membership	Household having any membership	binary	categorical		x	x	x
Sample size (households)						**758**	**286**	**338**	**134**

**Note: HiW (High intensified Wheat), MiS (Medium intensified Sorghum), LiS (Low intensified Sorghum) farm types were identified in T1. Selection of variables in T2 included all the already selected variables in T1, with exception of "number of crops". NPS- Nitrogen, Phosphorus, Sulphur; NPSB- Nitrogen, Phosphorus, Sulphur, Boron.*

3.RESULTS

1.3 Typology 1 – Region level



Farm types were defined using PCA results in which 66% of the variability is explained by three principal components (Figure 1). The first dimension was related to the production of main crops (wheat and sorghum) and the fertilizer input rates, the second dimension was related to the characteristics of the farm (size of the farm, TLU), and the third dimension was related to the household (size of the household, number of adults). Teff production showed a lower variability among the dimensions than the other main crops, indicating that this crop is present in all types of farms but in variable proportions.

Figure 1. Typology 1- *Output of PCA and clustering analysis defined by three principal components (Dim 1, Dim2, Dim 3). A) PC1 and PC2, B) PC1 and PC3. The gradient from red to blue colour indicates the weight of the variable on the axes of the PC space.*

The three resulting farm types correspond to Farm type 1 (called HiW): highly intensified wheat farms in highlands, representing 38% of the 758 farms, Farm type 2 (called MiS): medium intensified sorghum farms in mixed altitudes, representing 45% of the total farms, and Farm type 3 (called LiS): low intensified sorghum farms in lowlands, representing 17% (Figure 1). Most of the HiW farms belong to Goba and Siyadebirnawayu districts, which are located in the highlands. MiS farms are in both high and lowland districts like Kewet, Lemo and West-Belessa. The third farm type, LiS, is mainly located in the West-Belessa district, which is a lowland area.

Highly Intensified Wheat (HiW) farms have high fertiliser input rates followed by MiS and LiS. Farms that are HiW have a higher proportion of highly educated household heads compared to MiS and LiS farms. HiW farm type has low proportion of farmers applying manure (13%) mainly due to focus on fertilisers. MiS farm type has 31% and LiS farm type has 63% farmers applying manure where higher number in LiS correlates with larger herd sizes and thus higher manure availability in this farm type.

In the entire dataset, all farmers apply fertilisers to their crops. In HiW, 97% apply to wheat followed by 61% to teff. For MiS and LiS, more proportion of farmers apply fertilisers on teff than sorghum. Compound fertilizers like NPS (19%N, 38% P2O5 and 7% S) and NPSB (18.9 % N, 16.4 % P, 6.95 % S, and 0.1 % boron) are common in HiW, but in MiS and LiS only NPSB. Urea is common in all farm types. Around 30% of farmers in each farm type have off-farm income sources and the proportion of off-farm income to total income is around 13%. Thus, selling farming products is the main income source for all the farmers in all farm types. Area proportion of crops other than wheat, sorghum and teff is significant (around 40%) and important in all the farm types, especially in MiS and LiS where wheat is less predominant (Table 3). Thus, even though the survey was designed for the three main crops, the farms are in general very diverse.

Recalling the hypothesis of this first typology (which suggest that agricultural households can be grouped according to their production system such as wheat, teff and/or sorghum), we confirm the clear definition of three farm types determined by elevation and production systems. This confirmation will greatly contribute in the development of the Use Case MVP, specifically focusing on the cropping systems. However, no variation among the farm types was observed in variables other than mentioned above which were selected for the farm description. This implies that the current grouping is very general, prompting the need for a more detailed typology within these farm types, hence the objective 2.

1.4 Typology 2 – Cropping system level

The general outcome of the initial typology demonstrates the collaboration of two distinct Use Cases operating in overlapping locations and farming systems. To further identify farm types that effectively support the implementation of the Use Case MVP, a second typology was executed. Typology 2 was performed using farm types identified in typology 1 and by adding more continuous variables related to the hypothesis of objective 2 and categorical variables for better detailed farm description (Table 1). Typology 2 was divided into 3 sections, corresponding to the already identified farm types of typology 1: i) Farm type 1 (HiW): high intensified wheat farms in highlands, ii) Farm type 2 (MiS): medium intensified sorghum farms in mixed altitudes, iii) Farm type 3 (LiS): low intensified sorghum farms in lowlands.

Based on the objectives, the farms in typology 2 were described based on resource endowment (RE) and production orientation. Farm size, herd size and oxen-pair ownership were considered for resource endowment. The thresholds for the levels of resource endowment are calculated through an iterative process with the local teams, in our case the Use Case leaders and studying the average and dispersion of the variables (Tittonell et al., 2010). The thresholds for the levels of ***resource endowment (low, medium and high)*** were calculated using three quantiles for each of the variables. For instance, 33% and 67% quantile was calculated for farm size in the whole dataset, and farmers in below 33% were Low Resource Endowment (LRE), between 33% and 67% were Medium Resource Endowment (MRE) and above 67% were High Resource Endowment (HRE). These quantiles are assumptions prior to the typology construction, validation of the boundaries is requested from the Use Case leaders.

Crop use (sold or consumed), land tenure status (renting-in land) and fertilisation were considered in production orientation. Based on ***production orientation***, farmers were categorised into three types: ***Market oriented***, ***mixed oriented*** and ***subsistence oriented***. Farm types were considered market oriented when they had relatively high proportion of crop sold in markets, a high proportion of land rented in, and high fertilisation rates, which is the case for some HiW farms. Mixed oriented farm types were farms who were mostly subsistence oriented but exhibited some market-oriented characteristics, as seen in farms like MiS and LiS situated in the West Belessa district, which cultivate sorghum and teff.

Figure 2 offers an overview of the various farm types identified in both typology 1 and 2. The labels used in the diagram remain consistent throughout this report.

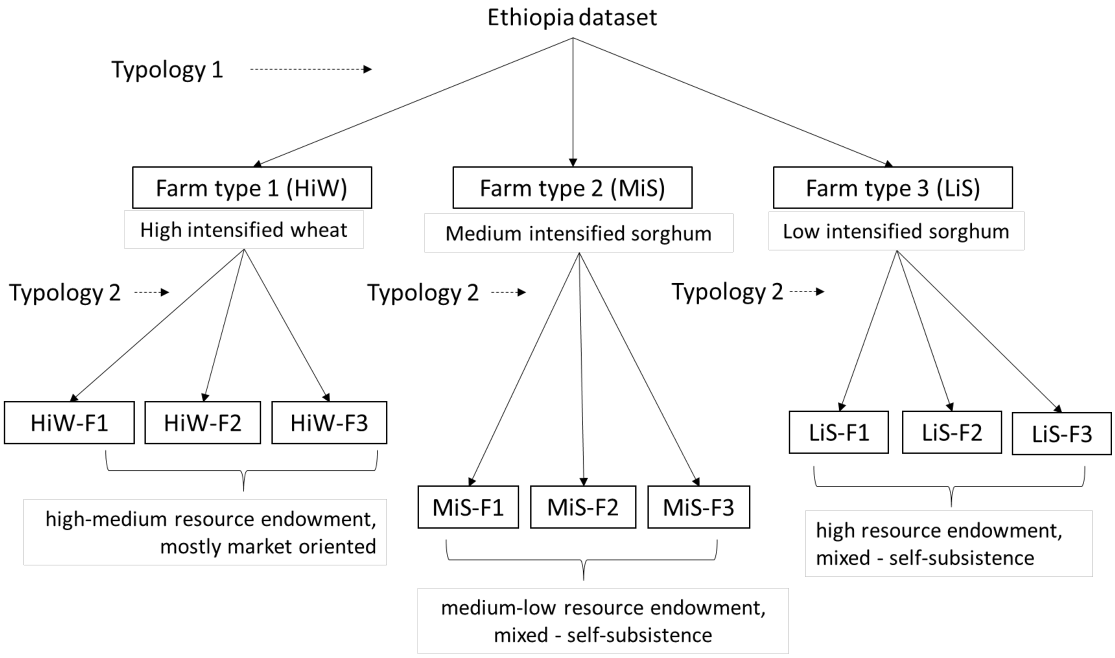


Figure 2. General overview of the identified farm types. In the first typology, intensification (high, medium and low) of the crop types (wheat and sorghum) were labelled accordingly. Farm types identified in typology 2, designed as F1, F2 and F3, were named uniquely based on the outcomes derived the typology 1.

1.4.1 High intensified wheat farms in highlands (HiW)

All continuous variables used in T1 were retained in this typology except sorghum production as the majority of the farmers were predominantly wheat and teff farmers. The selection of categorical variables was done based on the 10% variation rule mentioned above in the methods. For instance, over ~90% of household heads were male, did not use manure and compost, used urea and fertilized wheat with a type of fertiliser. Thus, categorical variables HH head gender, manure use, compost use, urea use and chemical fertiliser used on wheat were not included in the FAMD. The FAMD resulted in 7 dimensions explaining 65.9% of the data of which first two are represented in the Figure 3. Within FAMD, there are two analysis, one PCA for continuous variables and other MCA for the categorical variables. For PCA, first dimension was related to teff-production and second dimension related to farm size and TLU. For MCA, first dimension was related to fertilizer type applied and second dimension was related hybrid seeds and pesticides use. The clustering resulted in three farm types.

Type 1 (HiW-F1): High resource endowed, market oriented, wheat dominant farms (n=101)

This farm type is mostly present in Goba district. Features: The fertiliser type use is NPS rather than NPSB, high percentage of hybrid seed users, high percentage of memberships in social groups, 15% land rented-in, high proportion of wheat sold, households with high proportion of plots on slope have high fertiliser application rates compared to other farm types, similar pattern was observed by Desta et al. (2023).

Type 2 (HiW-F2): Medium resource endowed, mixed oriented, diverse farms (n=58)

This farm type is mostly present in Lemo district. Features: High proportion of home gardens and relying on off-farm income, low percentage of memberships in social groups and low hybrid seeds use, low percentage of rented-in land, high proportion of wheat consumed, around 48% of household face food shortage (highest compared to other types).

Type 3 (HiW-F3): High resource endowed and market oriented, high intensified, wheat-teff farms (n=127)

This farm type is mostly present in Siyadebirnawayu district. Features: highest fertiliser application rates, fertiliser type use is NPSB and Urea, high use of hybrid seeds and pesticides, high proportion of trained farmers and memberships in social groups, high proportion of wheat sold.

Overall, though the proportion of memberships in this type is high, most farmers of them are in social welfare groups, thus very few in social credit groups or cooperatives. For digital access, around 40-45% farmers in HiW-F1 and HiW-F2 have smartphones opposed to 22% in HiW-F3. Around 60-70% farmers have cell phones in all farm types.

In terms of dissemination of information preferences, most of the farm types prefer through government and relatives but HiW-F1 and HiW-F3 have other preferences like radio, TV.

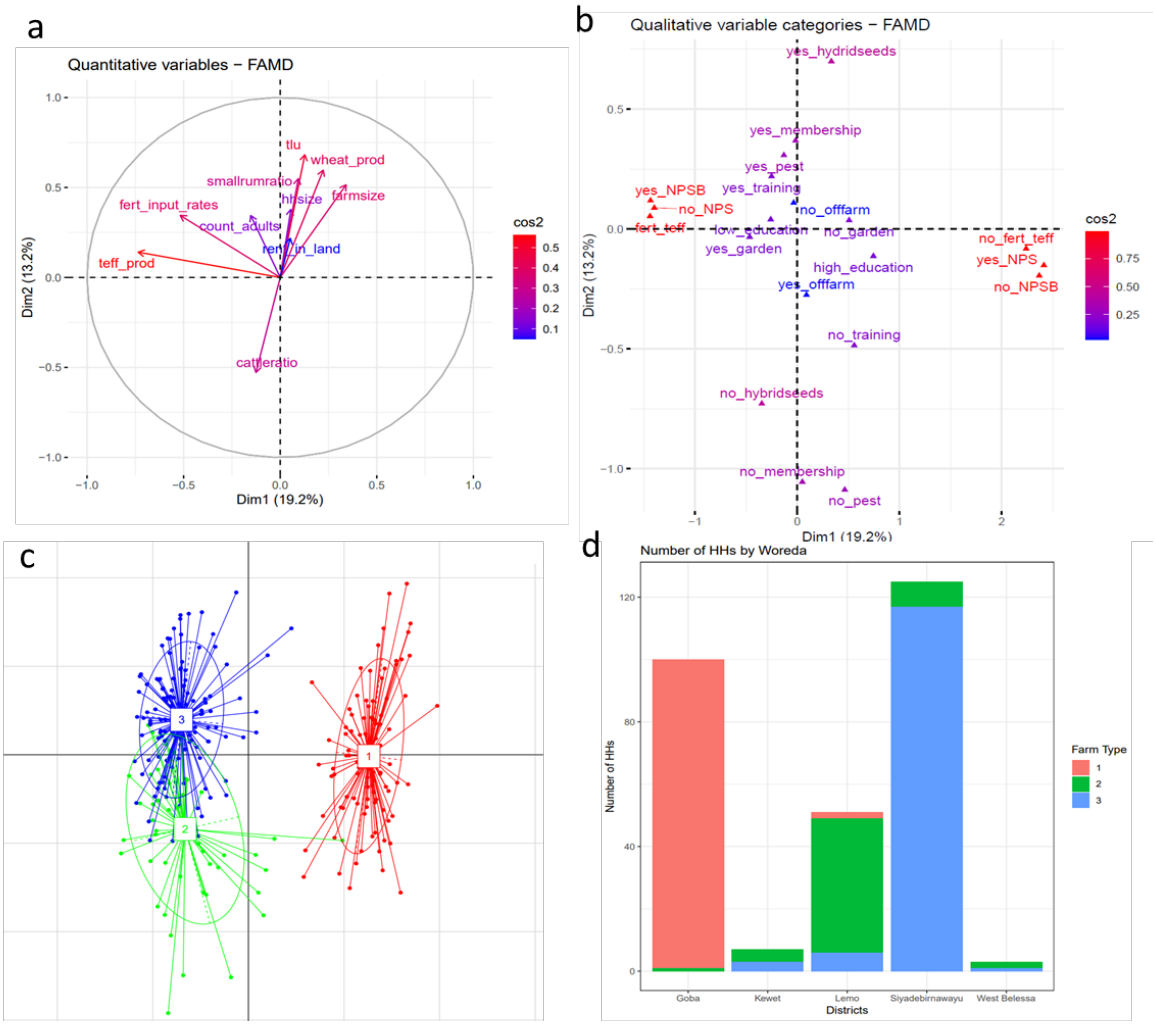


Figure 3. Typology 2 (HiW)- Output of PCA (a), MCA (b), clustering analysis (c) and the identified farm types (d) among high-intensified wheat farmers in highlands (HiW).

1.4.2 Medium intensified sorghum farms in mixed altitudes (MiS)

All continuous variables used in T1 were retained in this typology except wheat production as majority of the farmers were predominantly sorghum and teff farmers. The FAMD resulted in 8 dimensions explaining 62% of the variation (Figure 4). The first dimension was related to sorghum production and membership, and the second dimension was related to household size, HH labour availability, manure use and home garden ownership. Most of the sorghum and teff (60-70%) produced by these farms is consumed at home.

Type 1 (MiS-F1): Medium resource endowed and mixed oriented sorghum-teff farms (n=207)

This type of farms is mostly located in West Belessa and Kewet district. Features: High proportion of farms rent in land, have low fertiliser input rates but most apply manure and pesticides, over 75% of the farmers have memberships in social groups.

Type 2 (MiS-F2): Medium resource endowed and mixed oriented sorghum farms (n=75)

This type of farms is mostly found in Kewet. Features: Low proportion of farms rent in land, have high fertiliser application rates, high proportion of farmers have oxen pair, low manure application, 50% farmers have memberships.

Type 3 (MiS-F3): Low resource endowed and self-subsistence diverse farms (n=56)

This type of farms is mostly located in Lemo district. Features: Low fertilizer application rates, 30% area under teff and rest on other crops, higher proportion of households have homegarden, low membership, low manure use.

Even though MiS-F2 and MiS-F3 have significantly smaller farm sizes than MiS-F1, they have higher fertilisation rates. This suggests that the former types apply more fertiliser to overcome land constraints compared to the latter type. Overall, 50% of the households face food shortage where MiS-F3 which is LRE and subsistence-oriented have 64% farmers who face food shortage. Farms with high percentage of plots on slopes have low fertiliser application rates (MiS-F1), unlike what was observed in previous farm type such as HiW-F3. Most of the farmers did not use hybrid seeds in this group. Memberships in these farm types are in social welfare groups and social credit groups but very few in cooperatives and water committee. For digital access, around 25-40% farmers in all the farm types have smart phones and 60-70% have cell phones.

In terms of dissemination of information, 80% of farmers in MiS-F1 and MiS-F3 prefer through government compared to 60% in MiS-F2. 40-50% farmers prefer through relatives in MiS-F1 and MiS-F2, compared 22% in MiS-F3. Other modes are preferred by less than 10% of the farmers and thus, the preference for other modes is low.

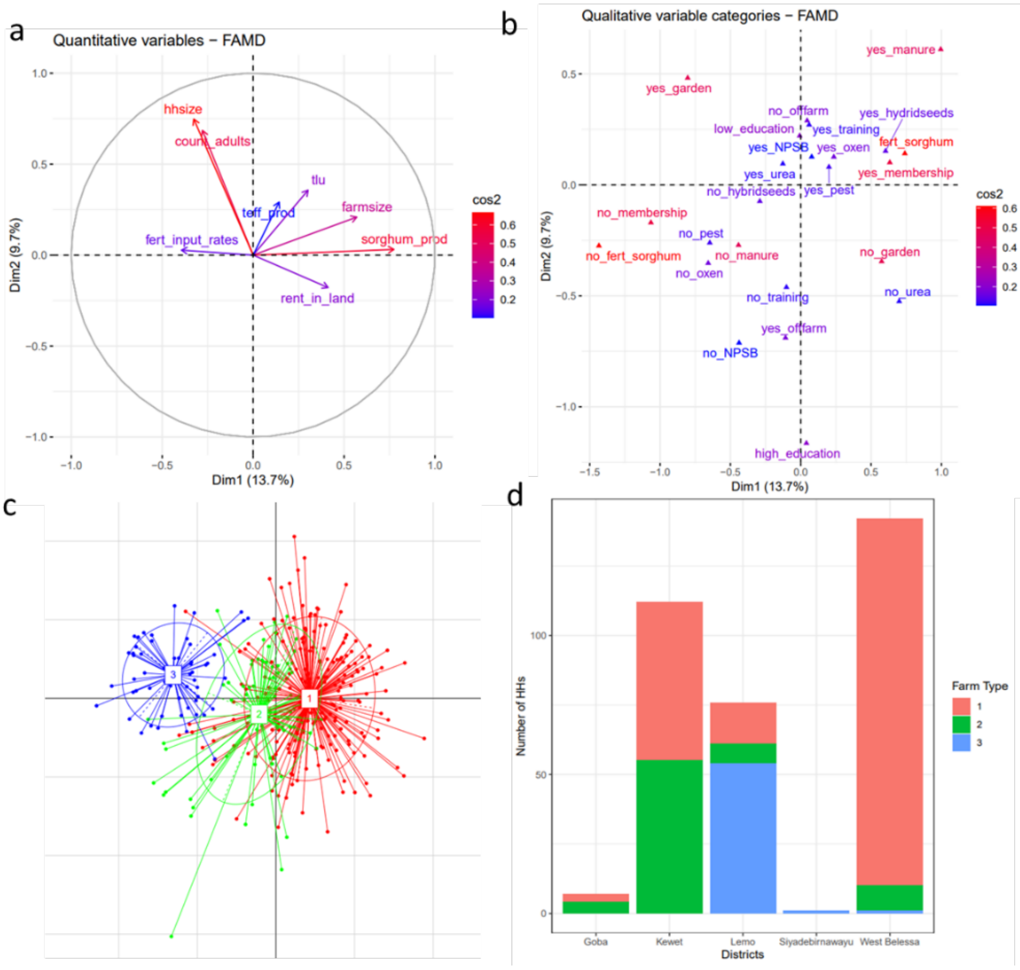


Figure 4. Typology 2 (MiS)- Output of PCA (a), MCA (b), clustering analysis (c) and the identified farm types (d) among medium-intensified sorghum farmers in mixed altitudes (MiS).

1.4.3 Low intensified sorghum farms in lowlands (LiS)

All continuous variables used in T1 were retained in this typology except wheat production as majority of the farmers were predominantly sorghum and teff farmers. The FAMD resulted in 7 dimensions, explaining 62% variation in the data (Figure 5). The first dimension is related to TLU, fertilizer application rates and second dimension is related to manure use, membership and sorghum production. Almost all the farm types are in West Belessa district.

Type 1 (LiS-F1): High resource endowed farms (HRE), self-subsistence sorghum-teff farms (n=85)

Features: High manure application rates, high proportion of farmers with memberships, 38% of farmers have homegarden, 60% farmers with hybrid seeds, low percentage of farms rented-in land and low proportion of produce sold in markets. They are HRE because of large farm size and herd size but self-subsistence because of low fertiliser application rates, low land renting-in and low proportion of crop produce sold in markets.

Type 2 (LiS-F2): High resource endowed farms (HRE), mixed oriented sorghum-teff farms (n=24)

Features: Low manure application rates, low proportion of farmers with membership, high percentage if farms rented-in land but low proportion of crop produce sold in the markets, low home gardens proportions. They are HRE because of high farm size and TLU. They are mixed oriented (self-subsistence and low input market oriented) because of low inputs but high land renting in which suggests strategy to increase production.

Type 3 (LiS-F3): High resource endowed farms, mixed oriented teff farms (n=25)

Features: Farms with the lowest fertiliser application rates in the entire survey region, less farms apply fertilisers on sorghum, high proportions of land renting and high proportion of households with home gardens. Similar to LiS-F2, these farms are HRE because of high farm size and TLU. They are mixed oriented (self-subsistence and low input market oriented) because of low application of inputs but high land renting in which suggests strategy to increase production.

Overall, 40% of the households face food shortage but lower proportion of farmers in LiS-F2 compared to LiS-F1 and LiS-F3. Memberships in these farm types are in social welfare groups and social credit groups but very few in cooperatives and water committee. For digital access, 16-20% farmers in LiS-F1 and LiS-F2 have smartphones, but only 8% farmers in LiS-F3 have smartphones. Most farmers in all the types have cell phones.

In terms of dissemination of information, 85-95% of farmers in all the farm types prefer through government, 30-50% farmers prefer through relatives. 17% in LiS-F3 prefer through traders and 26% in LiF-F3 prefer through radio. Rest all modes of dissemination are preferred by less than 5% of the farmers, hence negligible.

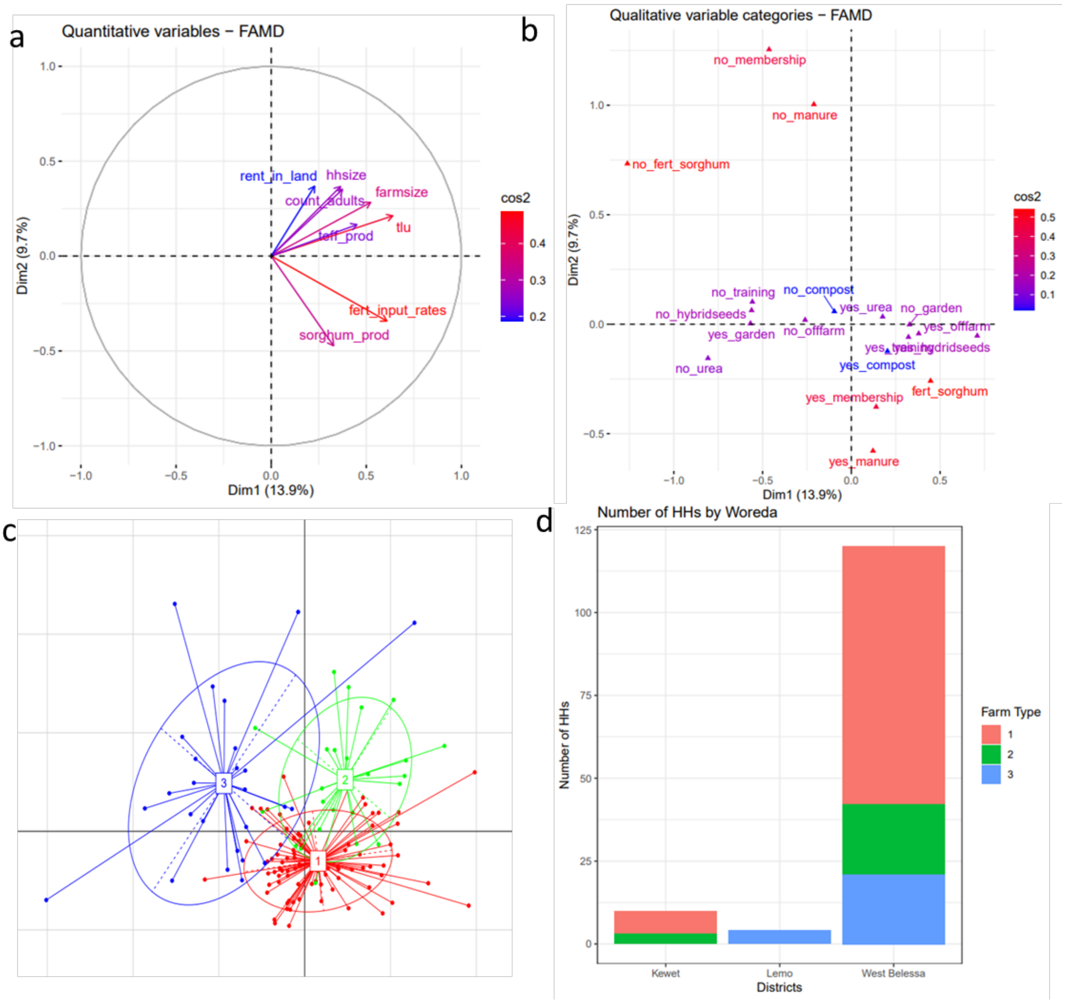


Figure 5. Typology 2 (LiS)- Output of PCA (a), MCA (b), clustering analysis (c) and the identified farm types (d) among low-intensified sorghum farmers in lowlands (LiS).

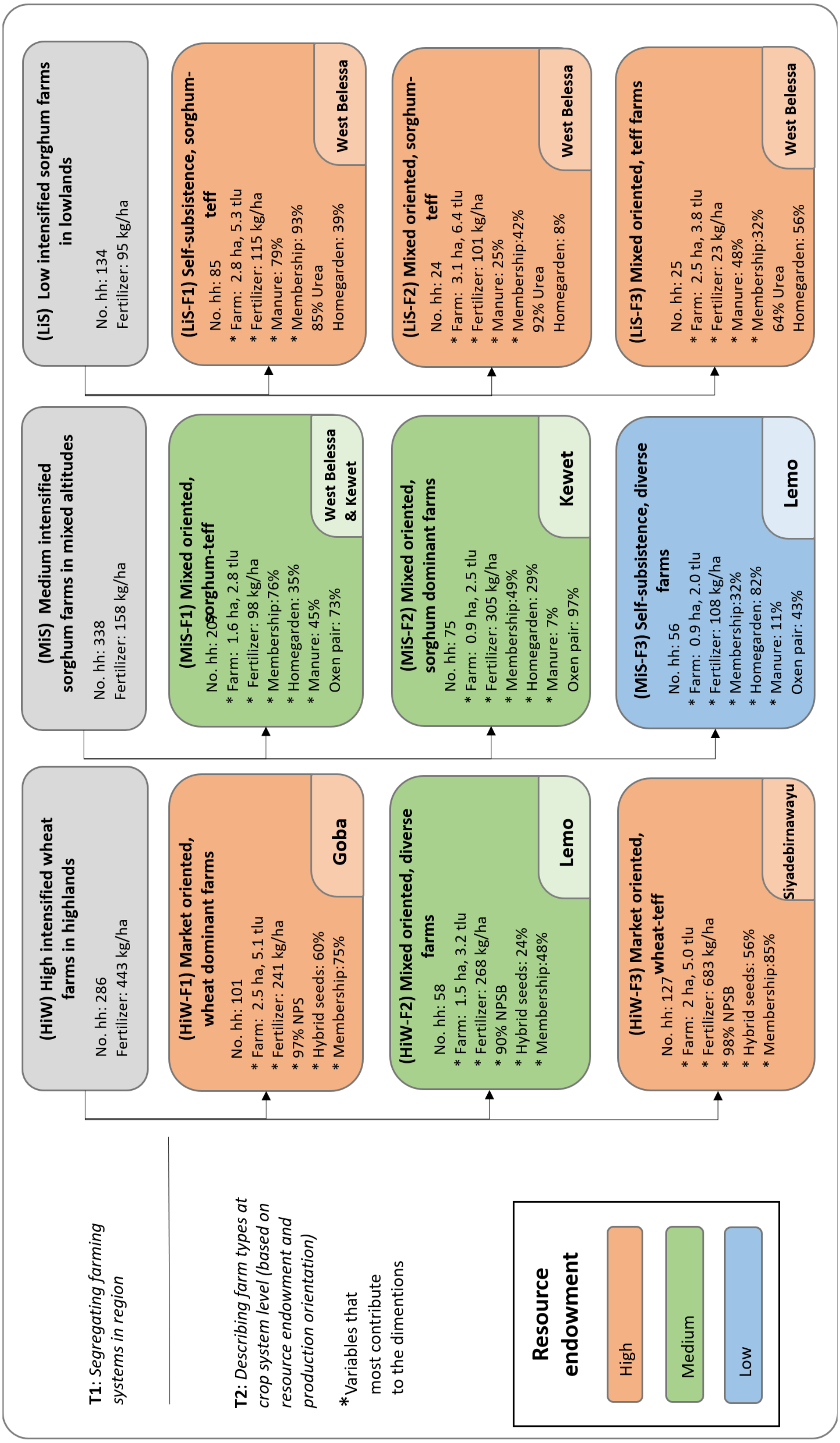


Figure 5. General overview of the outcomes of typologies 1 and 2. The grouping of the resulting farm types is represented in colours, according to their resource endowment. The production orientation and main crop(s) are indicated in the farm type name; the district where the farm type is mostly located is presented in the lower right corner; main farm type characteristics are listed.

4. DISCUSSION

Hypothesis based statistical farm typology is often used to segment farmers in a region based on their structural and functional characteristics (Alvarez et al., 2018). The variable selection depends on the scale of analysis, objective and the hypothesis of the local experts, in our case the leaders of Excellence in Agronomy (EiA), Ethiopia Use Cases. Usually, the survey questionnaire during data collection is designed based on the objective and the hypothesis of the typology. In this study, it was partially the case as the surveys were conducted in wheat, sorghum and teff growing regions, which were the Use Case locations, based on common objectives regarding farmer segmentation in the two Use Cases generalized. The data collection was generalized across various farm characteristics with a mix of structural and functional variables of continuous and categorical nature. To dive into the specific objectives of the Use Cases, exploratory analysis and segmentation of dataset was necessary to generate a meaningful typology of the system. Thus, two typologies were constructed, first on the entire dataset, at regional level, to slice the dataset into multiple sub-datasets and second typology for each of the sliced portions of datasets separately based on the farm types generated in typology 1.

Previous studies handled region level datasets by performing typologies by districts (Alvarez et al., 2018; Tittonell et al., 2010). In our case, the sample sizes per district were low to include all the relevant variables for the analysis and the agroecological difference was mostly on altitude differences (high and low), thus the district (woreda) variable was left out. The continuous structural and functional variables in the dataset were used to segment farms at regional level. Despite the exclusion of districts from the analysis, a distinct segmentation of farms based on agroecology was evident. Three distinct farm types were identified, aligning with three groups characterized by agroecological factors typical for their altitudinal location.

The categorical structural and functional variables provided a detailed description of farm characteristics. Using them initially along with the continuous variables in the first typology caused “masking” of the variation, and hence they were left out. Once the dataset was segmented based on the general variation among the continuous variables in typology 1, categorical variables proved vital to reveal the “hidden” differences among the farm types in typology 2.

Differences in farm types according to their resource endowment and production orientation

The first typology segmented the farms in two cropping systems, wheat dominant and sorghum dominant, and further segmented sorghum dominant systems in two groups: medium and low intensified based on fertilisation as wheat dominant system were high intensified due to highest fertiliser application rates. The association between resource endowment and cropping systems was not observed, as farmers engaged in both wheat and sorghum cultivation exhibited varying levels of resource endowment. Production orientation was associated to cropping systems as wheat farmers were either market oriented or mixed oriented (self-subsistence and market oriented). For wheat farmers, market and mixed orientation was mostly associated to high fertiliser application and high share of produce sold in market. For sorghum farmers, mixed orientation was mostly associated to farmers renting-in land, which can be seen as a strategy to expand production (Berre et al., 2019). Sorghum farmers exhibited low levels of market-oriented behaviour, as indicated by the minimal share of their products sold in the market and the low application of fertilizers.

The validation of these farm characterizations involved examining a subset of continuous and categorical variables. Home gardens play a crucial role in Ethiopian farms, contributing significantly to household food security. According to Motbainor et al. (2022) households with home gardens prioritise food security more than those without. Farm types categorized as mixed-oriented or self-subsistence-oriented exhibited a higher percentage of home gardens compared to market-oriented farm types. Notably, farmers exhibiting both medium-low resource endowment (RE) and predominantly self-subsistence orientation, as well as those who own home gardens within the same group, experience food shortage. Contrastingly, a lower proportion of farmers in farm types with market orientation and HRE experience food shortage with few exceptions like LiS-F1 and LiS-F3. Even though these are HRE farms, their low intensified system might be a main driver for their food insecurity. Overall, wheat dominant farms are more food secure than sorghum dominant farms. Memberships can be an indicator of social status. Similar patterns like in food shortage is observed for membership where HRE and market-oriented farms have high participation in social groups.

Engaging in off-farm activities implies that the household relies on income beyond what is generated from their farm produce (Berre et al., 2019). In the case of high intensified wheat (HiW), a greater proportion of mixed-oriented farmers had off-farm income compared to market-oriented farmers. Similarly, for high intensified wheat (HiW), greater proportion of farmers with market orientation used hybrid seeds compared to mixed oriented farmers. This pattern was not consistent for MiS and LiS as most of the farmers had self-subsistence orientation. Ownership of devices like smartphones and cell phones are also indicators of resource endowment (van den Brand, 2011)

In this study, there was no variation in ownership of devices among any of the farm types. Households with self-subsistence and mixed orientation had higher number of crops on the farm compared to farmers with market orientation. Mutyasira (2020) observed this crop diversification in low resource endowed farmers. In this study, this phenomenon is more associated with production orientation rather than resource endowment.

Differences in farm types within different districts

Farmers in Goba and Siyadebirnawayu are similar in terms of resource endowment with farmers in West Belessa. Due to different cropping system and production orientations, the former types are highly intensified and the latter are low intensified but have high potential of intensification.

There are two farm types in Lemo district, HiW-F2 and MiS-F3. These two farm types are both diversified and the proportion of crops other than wheat, teff and sorghum was high. Even though they are in the same district, there are striking differences in these two farm types. HiW-F2 are medium resource endowed with wheat as a main crop whereas MiS-F3 are low resource endowed farms with sorghum as their main crops. HiW-F2 has significantly higher fertiliser application than MiS-F3 and are mixed oriented as opposed to self- MiS-F3 being subsistence. This suggests that wheat farmers are more market oriented and their farms are intensified compared to sorghum farmers. In this case, production orientation is a driver of wealth, as found earlier in Malawi (Franke et al., 2014). This suggest that market-oriented farmers are more likely to adopt new production enhancing technologies compared to those oriented towards self-subsistence.

There are two farm types in Kewet district, sorghum-teff (MiS-F1) and sorghum dominant farms (MiS-F2). Both these farm types are medium resource endowed, where most of the farmers have oxen-pair, whose ownerships is associated with capital availability (Silva et al., 2019, 2021). Both these farm types are categorised as mixed oriented yet they have different strategies for production. Sorghum-teff farms are larger (1.5 ha) compared to sorghum dominant farms (0.9 ha) and increase production by renting-in land and mostly rely on manure from the cattle as inputs on farm. On the other hand, sorghum dominant farms apply more fertiliser rather than renting-in land and use less manure even though they have similar cattle numbers as the sorghum-teff farmers. Thus, sorghum dominant have high intensified production and sorghum-teff have high extensified production strategy. Previous studies report farming households facing land pressure tend to allocate their land to income-generating crops and increase intensification (Berre et al., 2019; Boere et al., 2016). At Kewet, technologies for sustainable intensification of these two farm types could include crop-livestock integration (fertilizers and manure management) to address production and land pressure.

West Belessa is distinguished from the other districts by having the largest farm size and TLU, despite maintaining the lowest rate of fertilizer input (Table 3). Variations between farm types in West Belessa mainly revolve around crop selection and production orientation. Those exclusively producing teff show significantly lower input rates and a higher proportion of home gardens compared to sorghum-teff producers. Furthermore, the degree of production orientation (from self-subsistence to market) is linked to the need to rent additional land for cultivation, as highlighted by Mutyasira (2020). These findings suggest a high production capacity and potential for intensification, particularly encouraging synergies between crop and livestock production across all farm types in West Belessa.

Limitation of the dataset for the analysis

The details on exclusion and limitations in variable selection are in the supplementary material, few examples are discussed here. Notably, the variable of labour utilization and hired human power (measured in human-hours per day or week) essential for assessing production orientation and resource endowment was absent in the dataset. This was a conscious choice by the survey designers as collecting data on human-hours is a lengthy process prone to errors, which would have increased the length of the survey significantly without guaranteeing quality data. We therefore used a proxy variable for labour, such as the presence of adults in the household. However, this proxy failed to provide a comprehensive depiction of the labour category in the typology as it highly correlated with household size.

Slope of the plots in the landscape was an important variable for one of the Use Cases in the study. It was collected at three levels (flat, slope, steep), which was inconsistent with how it was measured in the past (valley bottom, lower slope, middle slope, upper slope, plateau) in the same study regions (Desta et al., 2023). Further, fertiliser application was measured at farm level and not plot level. This caused loss of information in estimating the differences in fertiliser application by slope type and also crop type. When the slope information was included in the current form, the variables did not correlate significantly with any other variables in the dataset and hence were not included in the typology analysis but were used for farm description.

5. CONCLUSIONS

In this study, two typologies at different scales were used to identify farm types to customize MVP advisory in three regions of Ethiopia. Our method showed that typology using only continuous variables explaining general farm characteristics in the farming system may lead to blanket recommendations due to over generalization of the typology. Combined use of both continuous variables defining broad trends in the system and categorical variables at multiple scales is necessary for detailed farm characterization. In the region level typology, farm types were segmented primarily based on cropping system and fertilization intensity. In the farming system level typology, farms were segmented based on resource endowment and production orientation. Drawing upon the second typology hypothesis, which states that farming households can be categorized based on their resource endowment (measured by TLU and farm size) and production orientation, we affirm that three distinct farm types were derived within each initially segregated farms identified in typology 1. The nine farm types identified in five districts of Ethiopia differed in cropping system, land size and tenure status, capital availability based on livestock ownership and production orientation, all of which has an influence on their farm management and type of intervention/solutions necessary for intensification. We conclude that the wheat farmers mostly have high resource endowment and are market oriented with high social standing and high food security. Wealthy sorghum farmers are also similar to wealthy wheat farmers except production orientation is self-subsistence, thus have a high potential of intensification through targeted interventions. Dissemination through government and relatives is highly preferred by all the farm types irrespective of resource endowment and production orientation. Digital access was not correlated with resource endowment.

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7. APPENDIX

Table 2. Variables used for farm description

Category	Variables	Code	Description	Unit	Data type
Household	District	woreda	Location base on district names		categorical
	Age of household head	person_age	Age of the head of the household	years	continuous
	Gender	person_gender		binary	categorical
	Food shortage	food_security	Shortage of food at some point of a year	Binary	categorical
Farm charc.	Wheat area proportion	wheat_area_proportion	Percentage of the total operated area allocated for Wheat	%	categorical
	Teff area proportion	teff_area_proportion	Percentage of the total operated area allocated for teff	%	categorical
	Sorghum area proportion	sorghum_area_proportion	Percentage of the total operated area allocated for Sorgum	%	categorical
	Number of plots	num_plot	Number of plots on farm cultivated	number	continuous
Livestock	poultry	poultryratio	ratio from TLU	%	continuous
Technology	Smartphone access	smartphone	Score on the levels of access to smartphone	binary	categorical
	Cellphone access	cell_phone	Score on the levels of access to cellphone	binary	categorical
Dissemination	Government	government.1	Mode of dissemination of information to farmers	binary	categorical
	Private	private.1		binary	categorical
	Trader	trader.1		binary	categorical
	Association	association.1		binary	categorical
	Relatives	relatives.1		binary	categorical
	Other farmer	other_farmer.1		binary	categorical
	Radio	radio.1		binary	categorical
	TV	tv.1		binary	categorical
	Social media	social_media.1		binary	categorical
	App	app.1		binary	categorical
Water conservation practices	Soil stone bunds	soil_stone_bunds	Water conservation practices adopted by the households	binary	categorical
	Check dams	check_dams		binary	categorical
	Cut off drain	cut_off_drain		binary	categorical
	Ridge furrow	ridge_furrow		binary	categorical
	Contour ploughing	contour_ploughing		binary	categorical
	Terraces	terraces		binary	categorical
	Strip planting	strip_planting		binary	categorical
Membership	Social welfare	social_welfare	Memberships in various organizations/groups	binary	categorical
	Saving credits	saving_credits		binary	categorical
	Water committee	water_committee		binary	categorical
	Multi cooperative	multi_cooperative		binary	categorical
Slope	Flat land	flat_land_area	proportion of flat land area on farm	%	continuous
	Slope land	slope_land_area	proportion of slope land area on farm	%	continuous
	Steep slope land	steep_land_area	proportion of land area with steep slope on farm	%	continuous

Table 3. *Farm type description for farm typology 1. Letters in superscripts on values show significant difference.*

Category	Variable	Farm type (production system)*			
		HiW (Wheat)	MiS (Sorgum-teff)	LiS (Sorgum-teff)	Total
Household	Household size	5.6 (2.4)[b]	5.1 (1.8)[b]	6.8 (1.5)[a]	5.6 (2.1)
	Adult labour	3.5 (1.6)[b]	2.9 (1.2)[c]	4.1 (1.2)[a]	3.3 (1.4)
	HH head age (yr)	45.2 (13.2)	43.3 (13.0)	50.5 (10.6)	45.3 (12.9)
Farm characterization	Farm size (ha)	2.1 (1.1)[b]	1.3 (0.7)[c]	2.8 (1.1)[a]	1.9 (1.1)
	Fertilizer input rate (kg/ha)	443.1 (417.7)[a]	157.7 (258.5)[b]	95.4 (330.2)[c]	254.4 (369.7)
	Number of crops on farm	3.5 (1.4)[c]	4.0 (1.6)[b]	5.7 (1.4)[a]	4.1 (1.7)
	Number of plots on farm	4.3 (2.4)[b]	3.8 (2.0)[c]	6.7 (2.2)[a]	4.5 (2.4)
	Wheat production (kg)	4345.2 (4329.7)[a]	103.8 (351.3)[b]	71.3 (256.2)[b]	1698.4 (3372.7)
	Teff production (kg)	373.7 (572.9)[b]	296.6 (293.8)[b]	689.4 (539.3)[a]	395.1 (482.6)
	Sorghum production (kg)	26.2 (252.0)[c]	753.4 (683.3)[b]	1598.8 (3013.4)[a]	628.5 (1462.1)
	Wheat area proportion (%)	44.9 (27.8)[a]	3.3 (13.1)[b]	2.5 (6.3)[b]	18.9 (28.0)
	Teff area proportion (%)	17.0 (19.8)[c]	23.6 (24.0)[b]	26.6 (15.1)[a]	21.7 (21.4)
	Sorghum area proportion (%)	1.1 (6.4)[b]	25.6 (24.3)[a]	22.6 (13.3)[a]	15.8 (21.0)
	Other crops area proportion (%)	37.1 (30.1)[b]	47.5 (29.4)[a]	48.2 (18.2)[a]	43.7 (28.5)
Livestock	TLU	4.7 (2.3)[a]	2.6 (1.6)[b]	5.2 (2.6)[a]	3.8 (2.4)
	Cattle ratio	0.7 (0.2)[b]	0.8 (0.3)[a]	0.7 (0.2)[b]	0.8 (0.2)
	Small ruminant ratio	0.1 (0.1)[b]	0.2 (0.2)[b]	0.3 (0.2)[a]	0.2 (0.2)
	poultry ratio	0.0 (0.1)[b]	0.0 (0.1)[a]	0.0 (0.0)[a]	0.0 (0.1)
Land features	Rented in land	0.2 (0.3)[b]	0.1 (0.2)[b]	0.2 (0.2)[a]	0.1 (0.2)
	Area with flat land (%)	77.1 (31.1)[a]	75.5 (30.8)[a]	70.3 (26.0)[b]	75.2 (30.2)
	Area with slope land (%)	17.7 (27.5)[c]	22.9 (29.4)[b]	25.1 (22.8)[a]	21.3 (27.7)
	Area with steep slope land (%)	3.9 (13.7)[a]	0.8 (5.1)[b]	2.8 (8.5)[a]	2.3 (9.8)

*Most representative production system

Category	Variable	Farm type (district)*			
		HiW-F1 (Goba)	HiW-F2 (Lemo)	HiW-F3 (Siya-debirnawayu)	Total
	Household size	5.8 (2.6)^{ab}	6.1 (3.0)^{a}	5.2 (2.0)	5.6 (2.4)
Household	Adult labour	3.2 (1.5)b^{b}	4.4 (2.0)^{a}	3.4 (1.4)	3.5 (1.6)
	HH head age (yr)	42.6 (12.0)^{b}	50.4 (14.9)^{a}	44.9 (12.7)^{ab}	45.2 (13.2)
Farm characterization	Farm size (ha)	2.5 (1.3)^{a}	1.5 (0.8)^{c}	2.0 (0.9)^{b}	2.1 (1.1)
	Fertilizer input rate (kg/ha)	241.3 (294.9)^{b}	268.8 (207.7)^{b}	683.3 (448.6)^{a}	443.1 (417.7)
	Number of crops on farm	3.0 (1.3)^{b}	4.7 (1.7)^{a}	3.3 (1.1)^{b}	3.5 (1.4)
	Number of plots on farm	3.5 (1.7)^{b}	2.9 (1.6)^{c}	5.6 (2.5)^{a}	4.3 (2.4)
	Wheat production (kg)	5347.2 (4415.6)^{a}	1418.1 (2561.5)^{b}	4885.0 (4349.4)^{a}	4345.2 (4329.7)
	Teff production (kg)	0 (0)^{c}	369.0 (413.6)^{b}	673.0 (680.3)^{a}	373.7 (572.9)
	Sorghum production (kg)	0 (0)^{b}	119.0 (547.9)^{a}	4.7 (53.2)^{b}	26.2 (252.0)
	Wheat area proportion (%)	55.6 (28.3)^{a}	16.8 (22.5)^{b}	49.2 (20.3)^{a}	44.9 (27.8)
	Teff area proportion (%)	0.8 (5.7)^{c}	24.9 (25.7)^{b}	26.3 (15.4)^{a}	17.0 (19.8)
	Sorghum area proportion (%)	0 (0)^{b}	4.0 (12.1)^{a}	0.5 (4.5)^{b}	1.1 (6.4)
	Other crops area proportion (%)	43.7 (28.1)^{a}	54.3 (34.9)^{a}	24.0 (23.1)^{b}	37.1 (30.1)
	TLU	5.1 (2.7)^{a}	3.2 (1.7)^{b}	5.0 (2.0)^{a}	4.7 (2.3)
Livestock	Cattle ratio	0.7 (0.2)^{b}	0.9 (0.1)^{a}	0.7 (0.2)^{b}	0.7 (0.2)
	Small ruminant ratio	0.2 (0.2)^{a}	0.0 (0.1)^{b}	0.2 (0.1)^{a}	0.1 (0.1)
	poultry ratio	0.0 (0.1)	0.0 (0.0)^{a}	0.0 (0.0)^{a}	0.0 (0.1)
	Rented in land proportion	0.2 (0.3)^{ab}	0.1 (0.2)^{b}	0.2 (0.3)^{a}	0.2 (0.3)
Land features	Area with flat land (%)	82.6 (26.1)^{a}	86.7 (26.6)^{a}	68.5 (34.3)^{b}	77.1 (31.1)
	Area with slope land (%)	11.5 (23.0)^{b}	11.4 (23.0)^{b}	25.4 (30.6)^{a}	17.7 (27.4)
	Area with steep slope land (%)	4.2 (13.1)^{a}	1.8 (8.6)^{a}	4.6 (15.8)^{a}	3.9 (13.7)
	Wheat consumed (%)	37	55	39	41
Production use	Teff consumed (%)		71	61	63
	Wheat sold (%)	47	37	46	45
	Teff sold (%)		16	21	
Categorical variables	HH head high education (%)	38	29	15	27
	Pesticides use (%)	70	74	86	77
	Hybrid seeds use (%)	60	24	56	47
	Fertiliser use on teff (%)	1	90	95	62
	NPS fertilizer (%)	97	10	1	36
	NPSB fertilizer (%)	1	90	98	63
	Offfarm income source (%)	27	40	24	30
	Homegarden (%)	40	74	52	55
	Membership (%)	75	48	85	70
	Food shortage (%)	33	48	13	31
	Agricultural training (%)	58	67	78	68

Table 4. *Farm type description of farm typology 2 -HiW: F1, F2, F3.*

*Most representative district

Table 5: *Farm type description of farm typology 2 –MiS:F1, F2, F3*

*Most representative district

Category	Variable	Farm type (district)*			Total
		MiS-F1 (West-Belessa)	MiS-F2 (Kewet)	MiS-F3 (Lemo)	
Household	Household size	4.9 (1.7)^{b}	4.6 (1.6)^{b}	6.6 (1.7)^{a}	5.1 (1.8)
	Adult labour	2.7 (1.0)^{b}	2.8 (1.3)^{b}	3.6 (1.2)^{a}	2.9 (1.2)
	HH head age (yr)	41.7 (12.5)^{b}	43.2 (14.1)^{b}	49.7 (11.6)^{a}	43.3 (13.0)
Farm characterization	Farm size (ha)	1.6 (0.7)^{a}	0.9 (0.4)^{b}	0.9 (0.4)	1.3 (0.7)
	Fertilizer input rate (kg/ha)	98.1 (108.5)^{b}	305.3 (476.8)^{a}	180.1 (126.3)^{a}	157.7 (258.5)
	Number of crops on farm	4.3 (1.5)^{b}	2.8 (1.2)^{c}	4.9 (1.7)^{a}	4.0 (1.6)
	Number of plots on farm	4.7 (2.0)^{a}	2.6 (1.2)	2.2 (0.9)^{b}	3.8 (2.0)
	Wheat production (kg)	64.5 (338.7)^{b}	128.0 (371.8)	217.0 (347.4)^{a}	103.8 (351.3)
	Teff production (kg)	355.3 (285.0)^{a}	136.0 (254.4)	294.6 (299.3)^{a}	296.6 (293.8)
	Sorghum production (kg)	903.5 (662.0)^{a}	901.7 (625.3)^{a}	0.0 (0.0)^{b}	753.4 (683.3)
	Wheat area proportion (%)	2.1 (9.6)^{a}	5.7 (20.1)^{a}	4.5 (12.0)^{a}	3.3 (13.1)
	Teff area proportion (%)	24.0 (18.9)^{a}	15.9 (25.8)^{b}	32.7 (33.4)^{a}	23.6 (24.0)
	Sorghum area proportion (%)	28.3 (20.8)^{a}	35.7 (29.7)^{a}	1.6 (7.3)^{b}	25.6 (24.3)
	Other crops area proportion (%)	45.5 (23.5)^{b}	42.7 (34.4)^{b}	61.2 (37.6)^{a}	47.5 (29.4)
Livestock	TLU	2.8 (1.6)^{a}	2.5 (1.8)^{ab}	2.0 (0.9)^{b}	2.6 (1.6)
	Cattle ratio	0.7 (0.3)^{b}	0.9 (0.2)^{a}	0.9 (0.2)^{a}	0.8 (0.3)
	Small ruminant ratio	0.2 (0.3)^{a}	0.1 (0.2)^{b}	0.1 (0.2)^{b}	0.2 (0.2)
	poultry ratio	0.0 (0.1)^{a}	0.0 (0.1)^{b}	0.0 (0.1)^{ab}	0.0 (0.1)
Land features	Rented in land proportion	0.2 (0.2)^{a}	0.0 (0.1)^{b}	0.0 (0.0)^{b}	0.1 (0.2)
	Area with flat land (%)	71.5 (29.6)^{b}	79.1 (32.2)^{a}	85.3 (30.7)^{a}	75.5 (30.8)
	Area with slope land (%)	26.3 (27.8)^{a}	20.3 (32.3)^{b}	13.4 (29.4)^{b}	22.8 (29.4)
	Area with steep slope land (%)	1.1 (6.1)^{a}	0.0 (0.0)^{a}	0.6 (4.5)^{a}	0.8 (5.1)
Production use	Sorghum consumed (%)	70	78		73
	Sorghum sold (%)	14	12		13
	Teff consumed (%)	61	65	70	65
	Teff sold (%)	21	20	18	20
Categorical variables	HH head high education (%)	19	11	11	14
	Manure use (%)	45	7	11	21
	Pesticides use (%)	80	68	73	74
	Hybrid seeds use (%)	38	20	29	29
	Fertiliser use on sorghum (%)	75	84	9	56
	Urea use (%)	77	95	98	90
	NPSB fertilizer (%)	86	80	88	84
	Offfarm income source (%)	33	19	30	27
	Oxen pair (%)	73	97	43	71
	Homegarden (%)	35	29	82	49
	Membership (%)	76	49	32	52
	Agricultural training (%)	60	72	61	64
	Food shortage (%)	42	43	64	50

Table 6: *Farm type description of farm typology 2 – LiS: F1, F2, F3*

Category	Variable	Farm type (district)*			
		LiS-F1 (West-Belessa)	LiS-F2 (West-Belessa)	LiS-F3 (West-Belessa)	Total
Household	Household size	6.8 (1.5) [a]	7.3 (1.4) [a]	6.6 (1.4) [a]	6.8 (1.5)
	Adult labour	4.2 (1.2) [a]	4.1 (1.2) [a]	3.8 (1.1) [a]	4.1 (1.2)
	HH head age (yr)	50.9 (10.6) [a]	48.9 (9.2) [a]	50.8 (12.1)[a]	50.5 (10.6)
Farm characterization	Farm size (ha)	2.8 (1.1) [ab]	3.1 (1.0) [a]	2.5 (1.4) [b]	2.8 (1.1)
	Fertilizer input rate (kg/ha)	114.9 (402.3)[a]	101.5 (178.3) [a]	22.9 (23.5)[b]	95.4 (330.2)
	Number of crops on farm	5.8 (1.4) [a]	5.3 (1.3) [a]	5.4 (1.6) [a]	5.7 (1.4)
	Number of plots on farm	7.0 (1.9) [a]	7.2 (2.4) [a]	5.3 (2.2) [b]	6.7 (2.2)
	Wheat production (kg)	47.6 (144.9) [a]	8.3 (40.8)	212.0 (511.8) [a]	71.3 (256.2)
	Teff production (kg)	639.2 (532.6)[b]	925.0 (454.4) [a]	634.0 (594.4) [b]	689.4 (539.3)
	Sorghum production (kg)	1754.7 (3721.0) [b]	1924.2 (781.3) [a]	756.6 (585.9)[c]	1598.8 (3013.4)
	Wheat area proportion (%)	2.3 (5.4) [a]	3.2 (6.7) [a]	2.5 (8.5) [a]	2.5 (6.3)
	Teff area proportion (%)	24.8 (12.8) [a]	28.6 (11.5) [a]	30.9 (23.1)[a]	26.6 (15.1)
	Sorghum area proportion (%)	23.2 (12.5) [a]	24.0 (12.9) [a]	19.3 (15.9)[a]	22.6 (13.3)
	Other crops area proportion (%)	49.6 (17.8) [a]	44.2 (12.6) [a]	47.3 (23.5)[a]	48.2 (18.2)
Livestock	TLU	5.3 (2.4) [a]	6.4 (3.2) [a]	3.8 (2.1) [b]	5.2 (2.6)
	Cattle ratio	0.7 (0.2)[b]	0.6 (0.2) [b]	0.8 (0.2) [a]	0.7 (0.2)
	Small ruminant ratio	0.3 (0.2) [a]	0.3 (0.2) [a]	0.2 (0.2) [b]	0.3 (0.2)
	poultry ratio	0.0 (0.0) [a]	0.0 (0.0) [a]	0.0 (0.0) [a]	0.0 (0.0)
Land features	Rented in land proportion	0.1 (0.1)[c]	0.4 (0.2) [a]	0.2 (0.3) [b]	0.2 (0.2)
	Plots with flat land (%)	68.8 (25.0) [a]	80.1 (21.9) [a]	65.8 (31.5)[a]	70.3 (26.0)
	Plots with slope land (%)	27.3 (22.3) [a]	19.2 (20.9) [a]	23.4 (25.6)[a]	25.1 (22.7)
	Plots with steep slope land (%)	3.2 (9.2) [a]	0.5 (2.6) [a]	3.7 (7.2)[a]	2.8 (8.4)
Production use	Sorghum consumed (%)	65	69	68	67
	Sorghum sold (%)	13	16	15	15
	Teff consumed (%)	60	66	63	63
Categorical variables	Teff sold (%)	16	12	27	19
	Manure use (%)	79	25	48	51
	Compost use (%)	32	46	20	33
	Hybrid seeds use (%)	60	71	48	60
	Fertiliser use on sorghum (%)	88	79	20	62
	Urea use (%)	85	92	64	80
	Offfarm income source (%)	28	17	32	26
	Homegarden (%)	39	8	56	34
	Membership (%)	93	42	56	64
	Agricultural training (%)	65	58	64	62
	Food shortage (%)	47	17	56	40

*Most representative district