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An investigation about the agricultural system in Torbeck plain, Haiti: a statistically driven SWOT analysis

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Abstract: Haitian agricultural potential is largely unexploited. The country needs a new approach to its agricultural development and development cooperation needs new practices to drive more appropriate interventions. Our research integrates advanced statistical methodologies and SWOT analysis at a pilot scale to identify the most relevant features for farm economic sustainability in the Torbeck Plain. Multidimensional data were collected in 49 farms and Principal Component Analysis (PCA) was used to discover the main components affecting the system's variability. The most meaningful variables are then used for Hierarchical Cluster Analysis (HCA) to provide farms' classification. Results were used to inform a statistically driven SWOT analysis. PCA reveals the presence of three main components. First, it seems that crop choice makes the difference because of the sale price's great importance. The irrigation system's availability affects neither yield nor income, whilst mechanization is mostly important for farms whose farmer's first crop choice is maize. Moreover, mechanization is a generally worthwhile investment for farms whose fields' area is at least about 1.2-1.5 ha. Overall, the statistical analysis provides reasonable farms' classification and interesting insights about the Torbeck agricultural system. These were valuable for informing a SWOT analysis suggesting data-driven strategies for improving the agricultural system in Torbeck, which match the existing international guidelines and provide local priorities for intervention. In the short term they include i) informing crop choice ii) providing opportunities and infrastructure for local marketing. Long-term goals include developing extension services based on subsistence farmers' needs, advocating for data-driven national and international strategies for intervention, deepening the knowledge about relevant threats such as the diffused use of dangerous pesticides, or the unadvised water management.

Keywords: Haiti; SWOT analysis; agricultural development.

Introduction

Although agricultural land in Haiti has been over-exploited, the land does give sustenance to its people. In the 1970s, domestic production met 90 per cent of Haiti's food needs. In 2000, Haiti was forced to import over 42 per cent of its food. In 2010, over 80 per cent of Haitian exports were directed to the US, and about 50 per cent of its imports came from the US. Over 85 per cent of its exports are textiles and leather products, chemicals make up 3 per cent, and agricultural products 3.5 per cent (Lorenzo *et al.*, 2010).

Today, about 2.5 million Haitians live in extreme poverty (below $1.25 per day), predominantly in rural areas (Relief Web, 2016). Fifty per cent of the labour force relies on agriculture as a primary source of income, yet agriculture contributes less than 25 per cent of GDP. The economy is largely informal and heavily dependent on subsistence agriculture, which has languished in the face of growing rural population pressures, recurrent natural calamities, adverse climate change, and a lack of access to modern technology in the absence of a functional agricultural extension service (USAID - FEWS NET, 2018). FAO considers Haiti the only severely food insecure country in Latin America and the Caribbean (FAO, 2020). The current situation is the result of several social, geopolitical, economic (Cohen, 2013), and environmental factors among which the devastating impacts of hurricanes Matthew and Irma, respectively in 2016 and 2017, constitute only the last in the temporal order. As a consequence, FAO estimates that 1.32 million people require food assistance in Haiti (FAO, 2020), and other international organizations witness the weakness of the agricultural sector (Public Integrity, 2020).

The main food crops in Haiti are rice, maize, bananas, yams, cassava, green beans, and millet, while important export crops include coffee and mangoes. Most of these food products are imported into Haiti and, in general, the population remains highly dependent on the market by sourcing 85% of their food needs from the import market (USAID - FEWS NET, 2018). In fact, internal agricultural production is mainly family-led and is highly dependent on unreliable rainfall, as fewer than 1 per cent of farmers use irrigation (Jadotte, 2007). Two main production models exist in Haiti, the plantation system and the smallholder's systems, with the second being the evolution of the historical Lakou system. The Lakou system was indeed developed in opposition to the colonial plantation system which was based on racial and class division (Merilus, 2015). Technical tools, machinery, and purchased inputs including improved seeds and agrochemicals (fertilizers, phytosanitary compounds) are scarcely accessible by small farmers also due to the very low rentability of agricultural activities because of transportation constraints and poor infrastructure which impact heavily on internal value chains (World Bank, 2005). The picture is completed by increasing demographic pressure on the natural resource base so that, for example, farm sizes are shrinking over time and soils lose fertility (World Bank, 2005). In fact, Haiti's exposure to frequent hurricanes and tropical storms, combine with diffused and un-optimal use of agrochemicals determining high rates of soil erosion and affecting crop output measured by productivity losses in agriculture ranging from 0.5 to 1.2 per cent (World Bank, 2005). Extensive deforestation in many parts of the country has worsened the erosion problem and led to the loss of enormous quantities of fertile topsoil (Coello *et al.*, 2014; Verner, 2008).

In terms of national agricultural policy, the Ministry of Agricultural Resources and Rural Development (MARNDR) has implemented important agriculture policy reforms (Coello *et al.*, 2014). Since 2010, the main strategy and investment plan for the period 2013-16 insisted on four main objectives for the agricultural sector: (i) modernize the ministry of agriculture to enable better governance; (ii) increase agricultural productivity to improve food security and increase revenue; (iii) develop agricultural value chains, with particular emphasis on increasing exports; and (vi) adopt and promote ecological agriculture to preserve natural resources. Consequently, a new scheme for subsidizing farmers was implemented and it is now based on vouchers, which are less distorting than traditional subsidies applied across the board to input prices (Coello *et al.*, 2014). As it appears clear Haiti is faced with a common decision in the least Developed Countries (LDCs) which is whether to push export-oriented agriculture or focus on subsistence and locally oriented agriculture (FAO, 2002, 2017; Fuglie *et al.*, 2019).

Concerning Development Cooperation (DC) role in such a context, Herbst (2013) analyses the action of international cooperation implemented in Haiti during the 1990-2004 period, and gives insights about how this action contributes to the setting-up of what the author calls ‘the actual (im)possibilities of sustainable development in Haiti’. In this regard, both North-South and South-South cooperation has not been able to tackle Haitian sustainable development so far. This stands true both for emergency programs and for development programs (Buss & Gardner, 2008; EURACTIV, 2017).

The existing literature about the approach used by DC in Haiti reports that ‘a new sense of cooperation is needed, without which Haiti, or Africa or any poor and underdeveloped country cannot face their ancestral poverty and get into a position to offer their societies a redistribution of wealth. Today, as never before, creative cooperation is needed, a new type that allows the enhancement and development of the strengths of each country. It is not therefore only a task to produce humanitarian emergency assistance, but to help create and restore productive capacities and generate endogenous strengths that provide sustainability to their model of growth and economic and social development’ (Lorenzo *et al.*, 2010).

Moreover, 'International support is essential for Haiti to promote a new pattern of real development, but the government and the Haitian people must be the biggest part of the reconstruction of their country and its destiny’ (Patterson 2010).

The specific situation in Haiti can also be seen in a more general framework concerning the ongoing rethinking of DC programming and impact evaluation worldwide, as in the 2030 Agenda for sustainable development, agriculture plays a central role (Food and Agriculture Organization (FAO 2017). The transition towards a more sustainable agricultural sector is a transversal challenge worldwide and implies the shift towards renewed approaches to the planning and evaluation of policies and specific interventions (International Panel of Experts on Sustainable Food Systems (IPES-Food, 2016, 2017). The diffusion of a new culture of programming and evaluation in development agendas is believed to be a part of the leveraging tool for this much-needed shift (Barbier & Hawkins, 2012). Consequently, the problem of choosing the best path towards sustainable development in the agricultural sector is currently central to development cooperation (De Marinis & Sali, 2020) and specifically in Haiti.

Working in this perspective, the present research focuses on the identification of triggering domains of intervention for sustainable agricultural development in Torbeck plains, South Department, Haiti. The proposed methodology integrates advanced statistical analysis methods to a Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis (FAO, 2019) to build evidence-based information. Section 2 describes in detail the integration of the methodologies implemented, section 3 reports the results and discuss them in front of existing literature and guidelines concerning agricultural development in Haiti. Section 4 presents possible conclusions and hints at further research perspectives. Acting from within a development intervention, we aim at identifying the most important activities to answer local needs and to achieve a balanced and sustainable development of the agricultural system.

Materials and Methods

Area of study

Torbeck (Haitian Creole: Tòbèk) is a Commune in the Les Cayes Arrondissement, in the South Department of Haiti, located about 40 m a.s.l. (see Figure 1). The Commune gives the name to the back standing plain. Torbeck Plain covers approximately 200 square kilometres, it is crossed from north to south by the Ravin du Sud river. From this and other minor rivers (Ilet, Torbeck and Acul rivers), a complex network of irrigation canals flows through the plain and plays an important role in the agricultural sector. Given its geographical position (UTM WGS84 18°10′00″N; 73°48′43″W), the plain is characterized by a tropical rainforest climate denoted as "Af" according to Köppen and Geiger classification (Peel *et al.* 2007). The recorded yearly average temperature is about 26 °C, August is the hottest month (average 28.1 °C) and January is the coldest month of the year (average 25 °C). The average temperature is during this period. Overall precipitation approaches 2000 mm per year. The rainy period extends from April to November, the driest month is December, with 86 mm of rainfall. The most precipitation falls in October, with an average of 321 mm. The daylight duration slightly changes along the season between 11 h and 13 h (Climate Data, 2020).

The population of Torbeck is about 76,083 individuals, 93.1% of them living in the rural section. Noteworthy, the share of under 18-year-old people is about 38% and it appears to be equally distributed throughout all the Torbeck administrative sections.

Torbeck plain is a suitable place for agriculture, and agricultural activities play a fundamental role in the population's subsistence. Despite this, there are several issues affecting farmers' income.

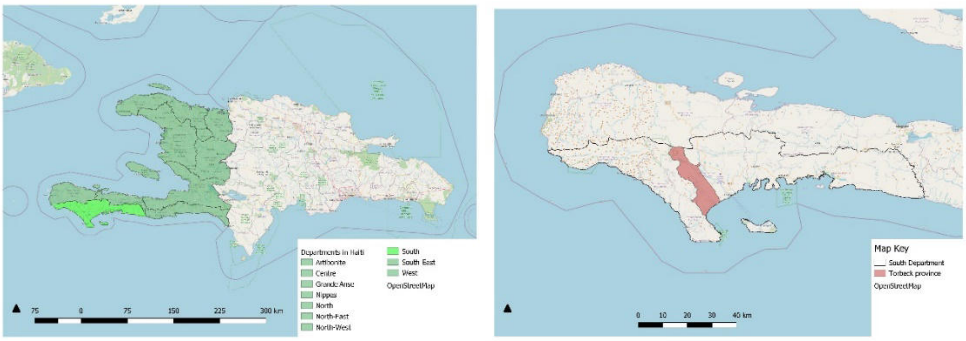

Figure 1 – Study area localisation

Workflow analytical methodologies

Figure 2 reports the overall workflow and the different methodological steps. The survey provided updated information about the specificities of agriculture in Torbeck. These were used to describe the existing agricultural system. Data were then submitted to Principal Component Analysis (PCA) (Mardia *et al.*, 1979; Venables & Ripley, 2002) to extract the main set of variables describing the sample. The most important variables identified by PCA were used for Hierarchical Cluster Analysis (HCA) (Kaufman & Rousseeuw, 2009) and to create groups of farms in the sample. Furthermore, the relationship between income and yield within each main crop was studied by a Linear Mixed Model (LMM) (Pinheiro & Bates, 2006) defined as follows:

$$y_{ij} = \beta_0 + \beta_1 x_{ij} + \varepsilon_{ij}$$

where yij is the income observed for the i-th farm adopting the j-th main crop, with j={bean, black-bean, maize, other crops}; β0=b0+u0j is the intercept, where b0 is the intercept's fixed effect and uj is the intercept's random effect estimated for the j-th crop; β1=b1+u1j is the yield's slope, where b1 is the yield's fixed effect and u1j is the random slope estimated for the j-th crop; xij is the harvested yield recorded for the i-th farm adopting the j-th main crop, with j={bean, black-bean, maize, other crops} and εij~ N(μ,σ2) are the residuals, which are assumed to be normally distributed. The comparison of these groups provided useful ground for informing a SWOT framework of the agricultural system in Torbeck.

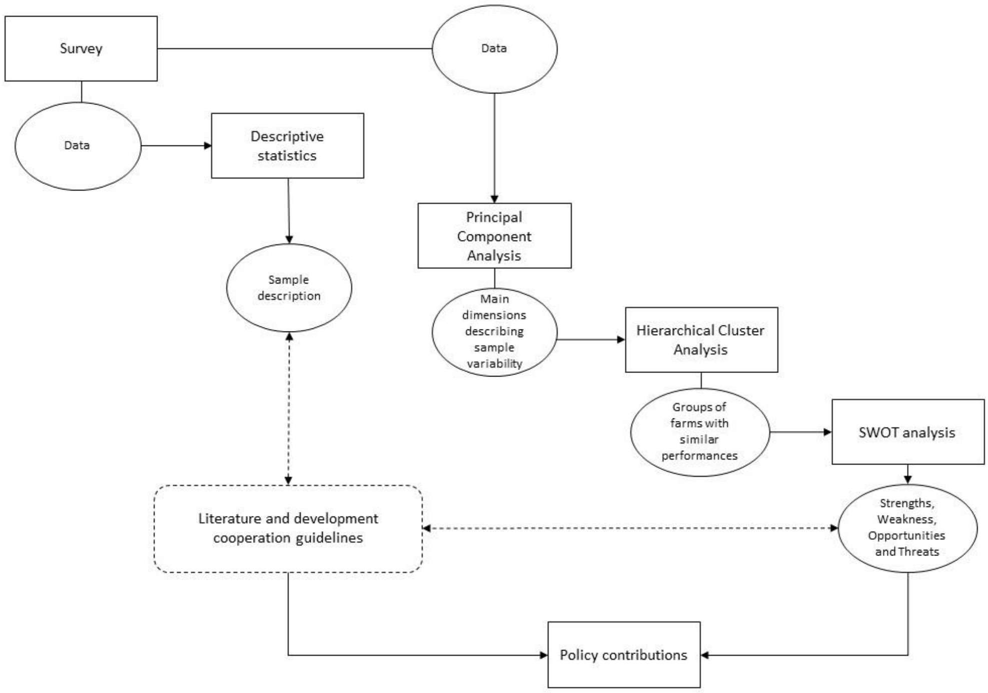

Figure 2 – Workflow. The scheme shows how we designed and implemented the research, from the survey to the SWOT analysis.

PCA was performed by prcomp() function implemented in R 3.4.3 stats package (R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.Rproject.org/), whereas Variables' plots, biplots and individuals' plot were obtained by specific functions implemented in R 3.4.3 factoextra package (https://CRAN.R-project.org/package=factoextra). HCA was then aimed at classifying observed farms and it was performed in two steps: in the first step, the dissimilarity matrix was computed according to the Gower's distance (Gower, 1971) by daisy() function implemented in R 3.4.3 Cluster package (https://CRAN.R-project.org/package=cluster). Choice of Gower's distance allowed to include categorical variables into the analysis (i.e.: the main crop, irrigation or no irrigation, etc.); in a second step, such dissimilarity matrix was processed to get the farms' classification via agnes() function implemented in R 4.3.4 Cluster package, then the results were summarized as a dendrogram. The LMM aimed at describing the relationship between income and yield was fitted by the lme() function implemented in R 4.3.4 nlme package (https://CRAN.R-project.org/package=nlme). All of the insights obtained by data analysis were used to draw a table reporting Strengths, Weaknesses, Opportunities and

Threats (SWOT) regarding the system under investigation (Fine, 2010). A SWOT is a planning tool widely used to evaluate the Strengths, Weaknesses, Opportunities and Threats that one may face in undertaking planning processes or in implementing a proposed set of interventions (FAO, 2019) in a given context.

The survey

The present research was commissioned in the framework of the project IFAH (Imparare e Fare Ad Haiti – Learn and Do in Haiti), led by Dévelo LCI association in collaboration with the University Notre Dame d'Haiti (UNDH) and the University of Milan. The IFAH project gave the possibility to collect data, through the work of one local surveyor, to identify the triggering interventions for sustainable development in the Torbeck plain among the project beneficiaries. During 2017, the agricultural and economic situation was investigated through the submission of a questionnaire to 49 farmers in Torbeck plain, which were randomly selected among the 80 farmers participating in the IFAH project. The questionnaire consisted of five sections regrouping 37 open and closed questions. In order to obtain an overall picture of the local system, the questionnaire focused on agricultural, economic, environmental and social information (see Table 1).

Table 1 - Questionnaire description

SURVEY FORM SECTIONS	DESCRIPTION	N° OF QUESTIONS
General	General information about the farm location and the owner's family.	7
Mechanization	Type of mechanical tolls in use and type of tenure/access.	2
Production and marketing	Information about farm inputs and outputs: crops, cropping season, surfaces, main cultural activities, fertilization, main pest/disease occurrence and treatment, animal production, market price and location.	21
Environmental issues	Information about water resources and other existing resources for income generation, existing knowledge about the agroecological approach to rural development.	3
Social issues	The openness of the farms to collaboration and onsite training.	3

Results and discussion

Looking at descriptive statistics, one can easily notice that farmers' age in Torbeck plain is between 28 and 76 years old with a mean value of 52.8 and a median value of 54. Only 25% of farmers are less than 48 years old. Such farmers live in families consisting of 6.5 members on average. All of the surveyed farms are family-run businesses. The 50% of families consist of more than 6 members and there is a 25% of families with more than 8 members.

The mean farm's area is about 1.55 ha; the largest mean fields' areas were recorded for farms whose first crop choice are maize, millet and beans.

The mean sale price is overall about 0.20 \$/kg of product. Anyway, the highest sale prices were recorded for rice (0.60 \$/kg), beans (0.32 \$/kg), black-beans (0.31 \$/kg) and tomatoes (0.30 \$/kg), whereas millet, peanuts, maize and okra barely overcome 0.08 \$/kg. Despite maize appears to be one of the less profitable crops, 47% of farmers say this crop is their first choice. By contrast, only 4% of interviewees grow either rice (2%) or tomatoes (2%) as the first crop, although the sale price of the products obtained by such crops is higher than the average product's sale price, especially for rice. On the other hand, 41% of farmers choose either beans (27%) or black beans (14%), whereas the remaining 4% of farmers choose peanuts as the first crop. Hence, 88% of farmers choose either beans, black beans or maize as the first crop. Kalalou or okra (*Abelmoschus esculentus* L. (Moench)) is known in many English-speaking countries as "lady's finger" and is valued for its green seeds and pods. Cultivated and perennials in tropical, subtropical and warm temperate regions around the world, in Haiti and South United States is the mainstay of a very popular and appreciated common dish. Further information is provided by crop choice priority, which arises from the combination of the first and the second farmer's crop choice. Although there is great variability among farms included in the survey, one can individuate some patterns. The 20% of interviewees choose beans as the first crop and maize as a second crop (i.e.: bean-maize), whereas 12% of farmers choose black-beans as the first crop and maize as a second crop and 10% of interviewees choose maize as the first crop and bean as a second crop. Noteworthy, 2% of farmers grow maize as unique crop. Hence, 44% of farmers choose to grow either bean, black-bean or maize.

In Torbeck plain farmers are organized in a fair number of farmers associations whose subscription share does not overcome 27%, recorded for the Mouvement Planteurs Periens de Torbeck (MPPT). Anyway, 8% of farmers say they did not subscribe to any farmers' economic association, whilst 14% of farmers did not communicate anything about their farmer's economic association subscriptions.

As outlined above, there is noticeable water availability in Torbeck plain, indeed a fair share of farmers say they get water supply from multiple sources. Regarding water supply, 67% of farmers say they obtain it mostly from rivers and lagoons, although only 24 farms out of 49 (50% circa) can rely on an irrigation system.

The propagation material essentially consists of seeds. The large majority of farmers buy seeds, more precisely, 67% of interviewees say they exclusively rely on purchased seeds, whereas the 12% of farmers can also rely on alternative sources as gifts (6%), NGOs (4%) and own seed reuse (2%). The 4% of farmers only rely on reusing seeds obtained by their production, thus the total share of farmers somehow resorting to their own seed reuse is 6%. A further 2% of farmers only rely on gifts, so the total share of farmers somehow resorting to gifts is about 8%. 6% of farmers only either rely on gifts or own seed reuse for seed supply, but including those who also purchase seeds, the total share of farmers somehow relying on gifts, own seed reuse or seed purchase is about 14%. A further 14% of interviewees say they obtained seeds from the Taiwan project (Taiwan ICDF, 2020). Such development projects seem to be welcome among farmers, indeed 73.5% of them say they agree on receiving an experimental trial performed by UNDH scholars.

Moreover, 75.5% of farmers are aware of the presence of other meaningful environmental resources for income generation, such as the presence of exploitable rivers, forests or other resources related to local culture and tradition. On the other hand, 79.6% of interviewees admit they don't know the agroecological approach to rural development. One aspect of such lack of knowledge reflects in the vagueness of the answers provided by farmers about the presence of pests and diseases on livestock and plants of their farms.

As a consequence of this unawareness, all of the interviewees admit they use very dangerous chemical compounds for pests' and diseases' management without specific knowledge and any personal protection equipment, i.e. active ingredients removed from Europe and North America markets. This part will be deepened in further analysis.

Principal Component Analysis (PCA)

The PCA performed on the data matrix drawn by the data obtained by the survey reveals that there are 3 main latent components (*i.e.*: Principal Components (PCs)) with an eigenvalue (*i.e.*: the expression of variability) higher than 1 (Table 2), whence these PCs can be considered as the most important among the PCs computed during the analysis. Overall, these PCs explain 74.6% of the total variability. PCs represent latent unobserved variable arising by the linear combination of single observed variables. The relative importance of single variables in a PC can be represented in terms of correlation: as the correlation between a single variable and a PC increases, the importance of that single variable increases too. All of these relationships are conveniently depicted in correlation variables' plots in Figures 3 and 4. Detailed correlations between PCs and simple variables are reported in Table 3.

Table 2 - Share and cumulative share of variance σ2 explained by PCs.

Principal components (PCs) and affected variability share			
PC	Eigenvalue (σ^2)	σ^2 %	Cumulative σ^2 %
PC1	2.250	32.148	32.148
PC2	1.799	25.702	57.850
PC3	1.030	14.719	72.569
PC4	0.809	11.556	84.126
PC5	0.510	7.290	91.416
PC6	0.433	6.192	97.608
PC7	0.167	2.392	100.000

Table 3 - Detailed correlation between Products' Sale Price in kg (PSP), farmers' age (Age), Number of Family Members (NFM), Farm's Field Area in ha (FFA), Harvested Yield in kg (HY), Crop Cycle Duration in days (CCD) and Farmer's Income in $ (IN) and the main Principal Components (PCs).

Variable	PC1		PC2		PC3	
	ρ	p(ρ≠0)	ρ	p(ρ≠0)	ρ	p(ρ≠0)
PSP	0.73	<0.001	0.49	<0.001	0	0.997
Age	-0.10	0.513	-0.53	<0.001	0.58	<0.001
NFM	0.13	0.381	-0.39	0.006	-0.74	<0.001
FFA	0.33	0.022	-0.69	<0.001	-0.27	0.059
HY	0.48	<0.001	-0.69	<0.001	0.19	0.192
CCD	-0.74	<0.001	-0.40	0.004	0.02	0.841
IN	0.90	<0.001	-0.11	0.412	0.19	0.194

PC1 explains the 33.435% of the total variance and shows a significant highly positive correlation with the product's sale price (ρ=0.90, p(ρ≠0)<0.001) both expressed per kg and per 13.2 kg. By contrast, crop cycle duration shows a significant highly negative correlation to PC1 (ρ=-0.75, p($\rho \neq 0$)<0.001). Hence, PC1 variance is primarily explained by the product's sale price and crop cycle duration, although the former variable gives the largest contribution to PC1 variability (see Figure 3).

PC2 explains the 28.783% of total variability and shows a significant highly negative correlation with yield (ρ=-0.89, p($\rho \neq 0$)<0.001), which also gives the largest contribution to PC2 variability. Harvest appears as a redundant variable with respect to yield, as well as the product's sale price per kg with respect to products' sale price per 13.2 kg.

Furthermore, there is a significant-good negative correlation between farms' area and PC2 (ρ=-0.6, p($\rho \neq 0$)<0.001) and a significant fair negative correlation between farmer's age and PC2 (ρ=-0.43, p($\rho \neq 0$)=0.002).

Nevertheless, there is a significant, although weak, correlation between the products' sale price and PC2 (ρ=0.31, p($\rho \neq 0$)=0.03). Not surprisingly, income shows a significant highly positive correlation to PC1 (ρ=0.83, p($\rho \neq 0$)<0.001) and fair negative correlation to PC2 (ρ=-0.43, p($\rho \neq 0$)<0.002). In other terms, data outline the obvious finding that income is positively correlated both to yield and product's sale price (see Figure 3).

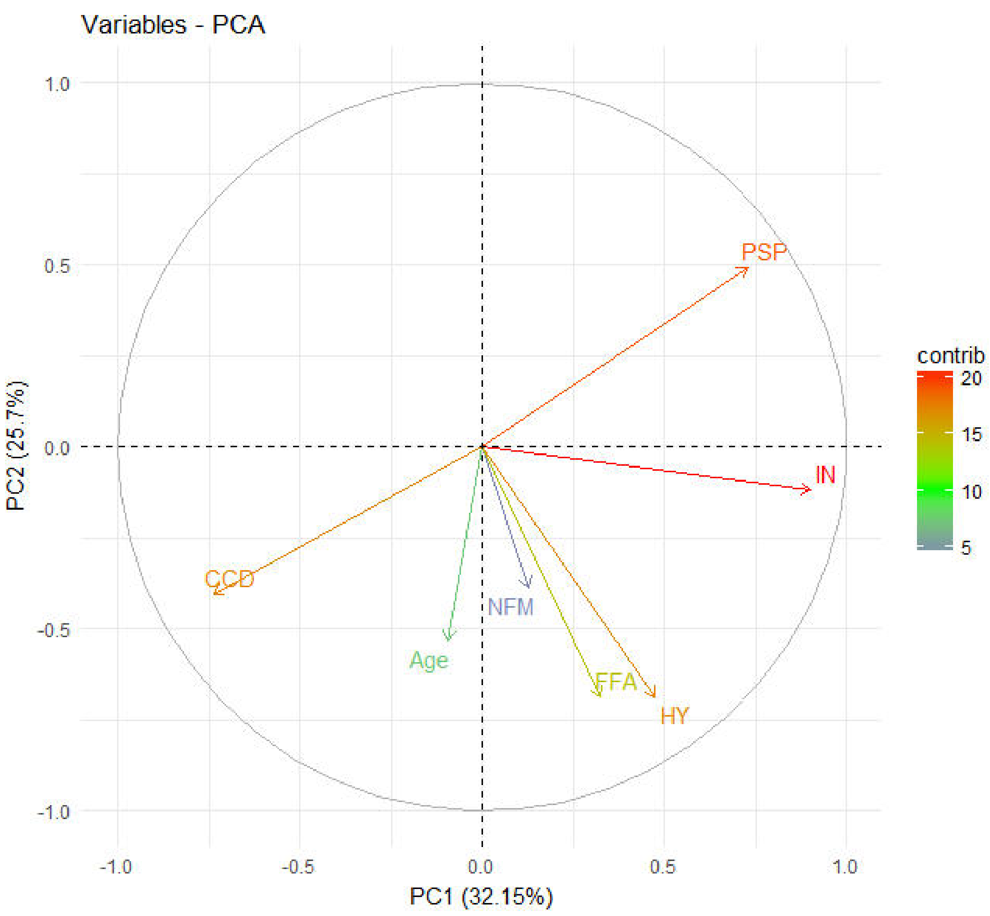

Figure 3 - Variables' correlation plot representing the relationship between Products' Sale Price in kg (PSP), farmers' age (Age), Number of Family Members (NFM), Farm's Field Area in ha (FFA), Harvested Yield in kg (HY), Crop Cycle Duration in days (CCD) and Farmer's Income in \$ (IN) and the main Principal Components (PCs), PC1 and PC2. The plot shows the % contribution of each variable to total variability (i.e.: contrib.).

PC3 explains the 12.379% of the total variability and shows a significant highly positive correlation to the number of family members ($\rho=0.85$, $p(\rho\neq 0)<0.001$) and fair positive correlation to the farm field's area ($\rho=0.48$, $p(\rho\neq 0)<0.001$). Variables' correlation plot for PC1 and PC3 is reported in Figure 4, whilst detailed information about correlations between variables and PC3 are reported in Table 3.

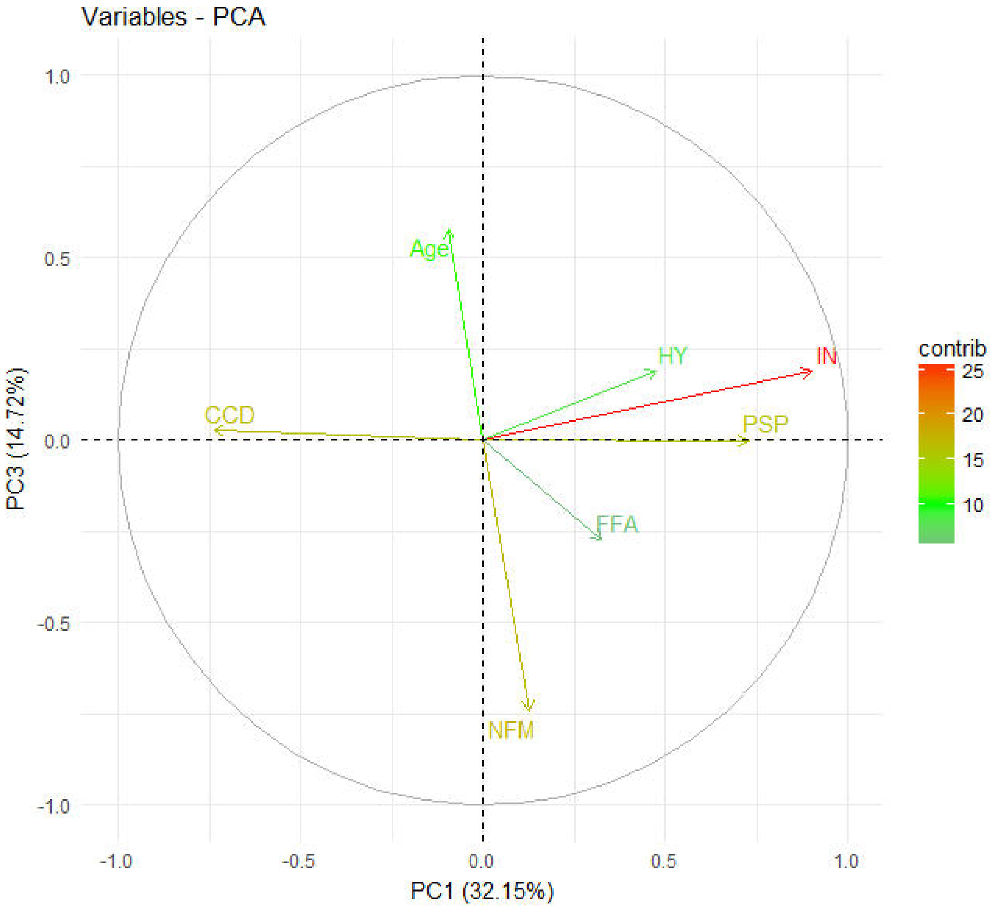

Figure 4 - Variables' correlation plot representing the relationship between Products' Sale Price in kg (PSP), farmers' age (Age), Number of Family Members (NFM), Farm's Field Area in ha (FFA), Harvested Yield in kg (HY), Crop Cycle Duration in days (CCD) and Farmer's Income in $ (IN) and the main Principal Components (PCs), PC1 and PC3. The plot shows the % contribution of each variable to total variability (i.e.: contrib.).

Table 11 in Appendix reports detailed information about the farms in the sample. Biplots for PCA performed (data not shown) reveal that farms f6, f10, f29, and f35 show the highest contribution to total variability (see Table 11 in the appendix for more details on farms). The plots show that there are some farms with a higher crop cycle duration and lower income, whereas, on the other hand, there are farms with a shorter crop cycle and greater income. Noteworthy, high contribution farms have either beans or maize as the main crop; furthermore, the mean crop cycle duration is about 75 days for bean and 112 days for maize (see Table 4). Thus, crop cycle duration is linked to the crop. Hence, it seems that the income rather depends on the crop choice which in turns is linked to yield and the product's sale price. The farms' association level is expressed in terms of correlation ellipses so that all of the farms falling into the relative ellipse are correlated with each other ($\rho \geq 0.6$). The first interesting categorical variable is the crop choice

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priority (data not shown). Indeed, farmers whose crop choice priority contemplates either bean or black-bean as the first crop are generally associated with high incomes. By contrast, farmers whose crop choice priority contemplates maize as the first crop are generally associated with low incomes, even in case of high yield. Anyway, farmers whose crop choice priority is maize-bean are still associated with high income, as well as some farms where at least one of the chosen crops are either tomato or rice.

Noteworthy, this finding is not true for the farm f35, where the crop choice priority is maize-tomato. Such inconsistencies can be better observed by looking at Figure 5. This plot shows a crop choice-dependent relationship between income and yield. Indeed, farmers whose main crop choice is maize obtain a pretty low income in all cases. Moreover, given sale price equality, the farm income is always low for the majority of farms whose first crop choice is maize, whilst it is not always high for farms whose first crop choice is beans. By the way, LMM's parameters (see Table 5) show that the income generally increases linearly with the yield, although such a trend appears to be linked to the first crop choice. Interestingly, farms whose first crop choice is beans show a marginal income increase of about 43% for one more kg yielded (β_{HY}=0.43958). Noteworthy**,** farms whose first crop choice is maize show a marginal income increase of just about 5% for one more kg yielded (β_{HY}=0.05334).

Table 4 - Average Crop Cycle Duration in days (CCD) by crop.

CCD (DAYS)							
BEAN	BLACK-BEAN	KALALOU	MAIZE	MILLET	PEANUT	RICE	TOMATO
75	81	60	112	120	90	120	90

Table 5 - LMM parameters β0= b0+uj and βHY= b1+uj with fixed parameter's p-values p(t) by farmers' first crop choice.

b_0	u_{0i}	β_0	b_{HY}	u_j	β_{HY}	FARMERS' FIRST CROP CHOICE
3.033, p(t)= 0.928	-38.218	-35.175	0.245, p(t)= 0.017	0.194	0.440	Bean
	-12.354	-9.320		0.063	0.308	Black-bean
	37.688	40.721		-0.192	0.053	Maize
	12.874	15.907		-0.066	0.180	Other crops

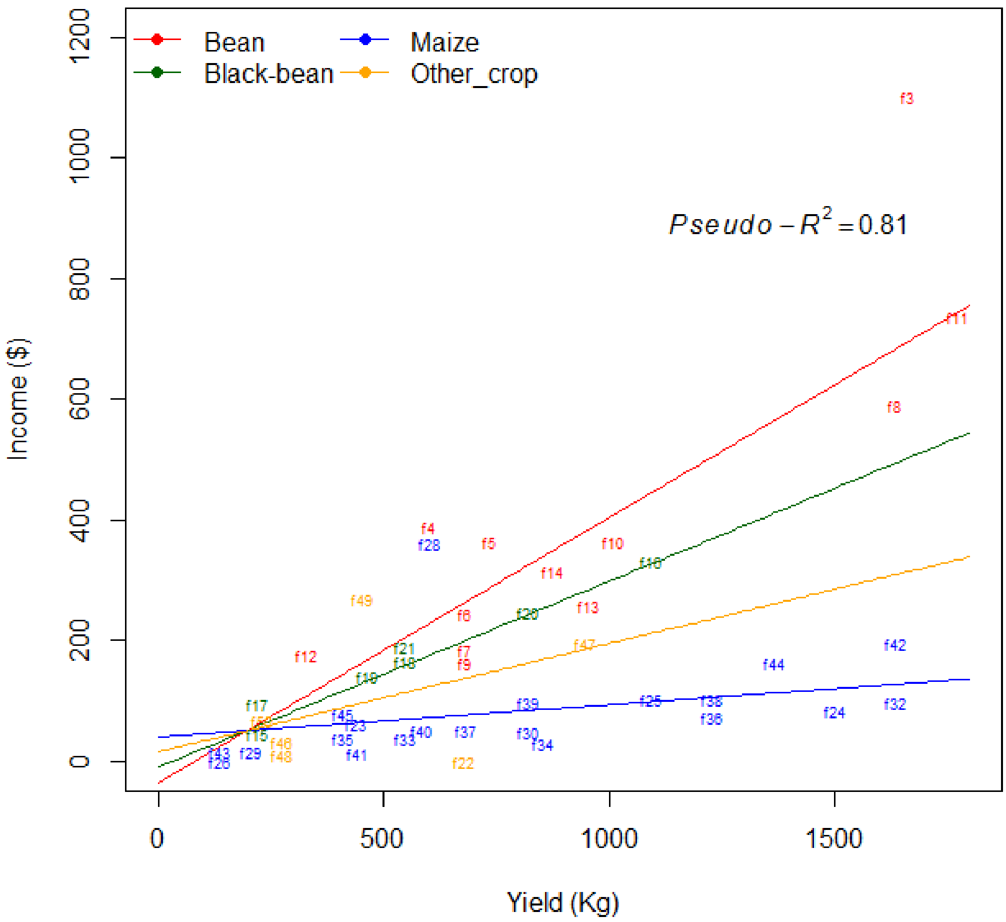

Figure 5 - Relationship between income (IN $) and Yield (HY kg) by farmers' first crop choice.

Mechanization (or tillage energy source)

Another key point in the agricultural Torbeck system is the tillage energy source. Interestingly, the majority of farms relying on mechanical energy are mostly associated with low incomes (data not shown), although farms f2, f6, f8, f10, f12, f28 and f49 appear to be associated with higher incomes (see Table 11 in appendix). Noteworthy, all of these farms are special cases among mechanic-driven farms. Anyway, the first crop chosen among these farms is the bean, except for farm f49, whose first crop choice is rice, and farm f28, which is the one, among mechanic-driven farms, adopting maize as the first crop. Farm f31 represents a singular case because, despite its high yield, it is not among the most profitable farms. Again, on this farm, the first crop choice is maize, whereas the second crop choice is peanuts. On the other hand, the majority of farms relying on animal energy are mostly associated with high incomes, although farms f24, f41 and f43 appear to be associated with lower incomes. Not surprisingly in these farms, the first crop choice is maize, but it is important to outline that these farms are among those with the largest field's area extension. Indeed, their area is about 3 ha for f24, 1.29 ha for f41 and 5 ha for f43. Particular cases are also farms f3, f11, f15, f17 and f19. These farms appear as particular cases among farms using animals and are associated with higher incomes. In these farms, the first crop choice is either bean (f3 and f11) or black-bean (f15, f17 and f19), whereas the second crop choice is maize. Anyway, the plot reveals a large ellipses' overlapping so that a meaningful part of farms relying on animal energy is also included in the mechanic-driven farms' ellipse (plot available on demand). Overall, the farm mechanization in itself does not significantly change the farmers' income (see ANOVA results on Table 6), even though observing Table 7 one can see that the income earned by a farm relying on animal energy is generally higher than the income earned by mechanized farms.

Table 6 - ANOVA table about overall energy sources effect on farmers' income in $ (IN).

TILLAGE ENERGY SOURCES EFFECT IN ($)					
Variability source	D.f.	SS(x)	MS(x)	F	P(F)
Tillage energy source	1	140164	140164	3.123	0.08369
Residual	47	2109407	44881		

Table 7 - Summarized information about farmers' income in $ (IN) by tillage energy source;

ANIMAL TILLAGE ENERGY IN ($)						MECHANIC TILLAGE ENERGY IN ($)					
min	1st q.	median	mean	3d q.	max	min	1st q.	median	mean	3d q.	max
0.65	66.12	196.62	264.31	330.58	1101.49	15.62	47.37	97.93	151.94	181.22	730.78

Water availability

The agricultural Torbeck system's puzzle can be complete after considering the artificial irrigation availability. The majority of farms relying on irrigation systems are mostly associated with high income (data not shown), although farms f24, f30 and f31 appear to be associated with lower incomes. Among irrigated farms associated with high incomes, f2, f3, f11, f17 and f49 are particular cases. By contrast, most farms without irrigation systems are mostly associated with low incomes, although farm f28 appears to be associated with higher incomes. Anyway, observing Table 8, one can notice that the irrigation system installation is linked to the most profitable crops. Indeed, most farmers whose first crop choice is beans and black-bean can rely on an irrigation system. Moreover, farmers whose first crop choice is rice and tomato have an irrigation system too. On the other hand, among farmers whose first crop choice is maize, only 3 out of 20 can rely on an irrigation system. Consequently, the presence of an irrigation system seems to lead to higher incomes. However, the irrigation system availability does not generally affect yield (see ANOVA results in Table 9).

Table 8 - Number of irrigated and not irrigated farms by crop.

NOT IRRIGATED FARMS							
BEAN	BLACK BEAN	KALALOU	MAIZE	MILLET	PEANUT	RICE	TOMATO
2	0	1	20	1	1	0	0

IRRIGATED FARMS							
BEAN	BLACK BEAN	KALALOU	MAIZE	MILLET	PEANUT	RICE	TOMATO
12	7	0	3	0	1	1	1

Table 9 - ANOVA tables about the overall irrigation system's availability effect on farms' crop Harvested Yield (HY kg) and farmers' income (IN $).

Irrigation system's effect HY (kg)						Irrigation systems' availability effect IN ($)				
Variability source	D.f.	SS(x)	MS(x)	F	P(F)	D.f.	SS(x)	MS(x)	F	P(F)
Irrigation	1	416691	416691	1.36	0.25	1	562051	562051	15.654	0.0003
Residual	47	14437525	307181			47	1687519	35905		

Hierarchical Cluster Analysis (HCA)

The HCA performed on the raw data matrix according to PCA results is reported in Figure 6.

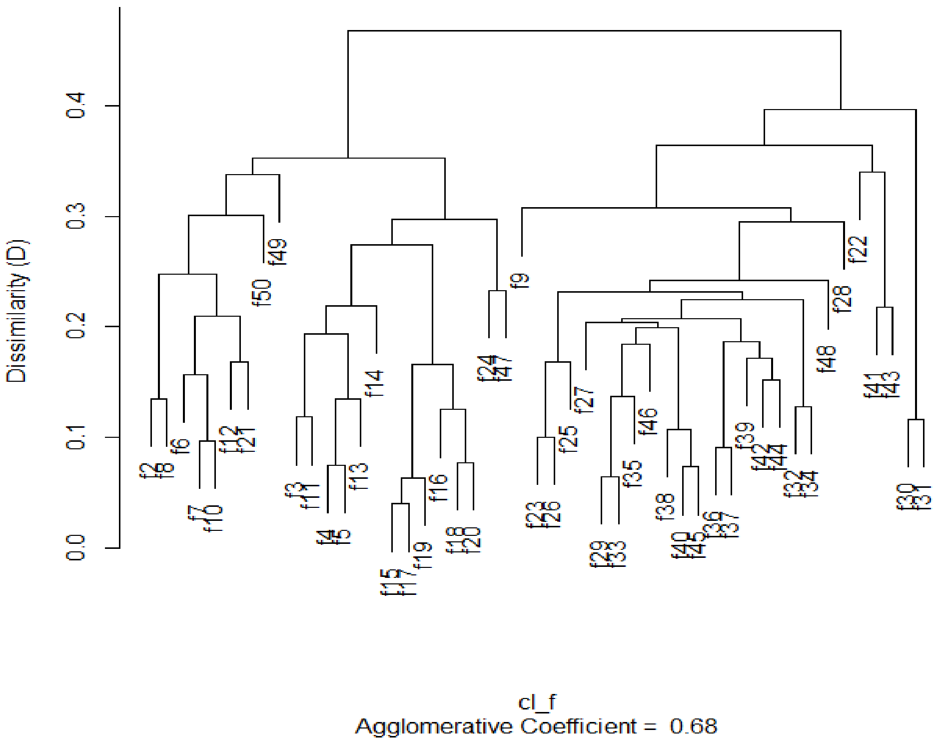

Figure 6 - Dendrogram representing the classification of farms included in the survey.

Overall, farms look heterogeneously clustered because of the noticeable variability affecting the data (Agglomerative coefficient=0.69). Nevertheless, the farms' classification appears reasonable and reveals further consistent insights concerning PCA. Considering a Dissimilarity (D) of about 0.3, one can individuate at least five groups including a different number of farms and some single farms representing particular cases. Reading the dendrogram from the left to the right side, one can find a first large cluster consisting of farms f2, to f50 (see Table 11 in appendix). All of these farms can rely on artificial irrigation, except for f6, which is not equipped with an irrigation system. By contrast, farms from f3 to f20 rely on animal-driven tillage, whilst farm f2 and the subgroup including farms from f6 to f50 are mechanized. Among the farms belonging to this cluster, the crop choice priority is bean-maize for farms from f2 to f14 and from f6 to f10, black-bean-maize for farms from f15 to f20, bean-peanut for f12, black-bean-rice for f21 and tomato-millet for f50. Furthermore, glancing at the dendrogram, one can easily notice that farms f2 and f50 look distant from the rest of the cluster. On the one hand, f2

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is the most profitable farm among those relying on mechanic tillage, its field's area is about 3 ha and the farmer's family consists of 12 people. On the other hand, f50 is the less profitable farm of this first cluster, its crop choice priority is unique in the survey, its field's area is about 0.65 ha and the farmer's family consists of just 2 people. Farms from f2 to f14 can be classified into 2 subgroups (D=0.2): the former one includes farms f2, f11 and f3, which are the most profitable among all farms included in the survey. The average income earned by these farms is about 856.52 $ with a maximum value of 1101.49 $ recorded for f3 and a minimum of 730.78 $ earned by f2. The latter one includes farms from f4 to f14, whose average income is about 326.63 $ with a minimum value of 258.23 $ recorded for f13 and a maximum of 368.18 $ earned by f4, which is the fifth most profitable farm. Noteworthy, farm f13 farmer's family has just 4 members, whereas the field's area is about 2.65 ha. Farms from f15 to f20 can also be classified into 2 subgroups (D=1.5), whose the former includes farms from f15 to f19, whilst the latter one includes farms from f16 to f20. The most meaningful difference between such subgroups is the field's area extension. Indeed, farms from f15 to f19 earn an average income of about 90.91 $ with an average field's area of about 0.56 ha, whereas farms from f16 to f20 earn an average income of about 247.93 $ with an average field's area of about 1.31 ha. Interestingly, farms f15, f17 and f19 are held by the youngest farmers in the survey as their average age is about 30 years old. On the other hand, farms f16, f18 and f20 are held by farmers with an average age of about 63 years old. The last subgroup (D=0.2) includes farms from f6 to f50 which represents a heterogeneous set of mechanized farms earning an average income of about 258.66 $. Noteworthy, f8 is the most profitable farm in this subgroup and the 4th most profitable among all farms included in the survey, earning an income of about 590.08 $. Going further, one can find a couple of farms, which represent particular cases: f28 and f49. The former one is the first most profitable farm among those whose main crop is maize; its income is about 360.45 $ with a field's area of about 1.13 ha. Farm f28 relies on mechanic energy for tillage, but it's not equipped with an irrigation system. The latter one is the unique farm whose main crop is rice among all of the farms included in the survey. It is equipped with an irrigation system and it can rely on mechanic energy for tillage. Farm f49 is the 11th most profitable farm: its income is about 270.34, despite its small field's area, which is just about 0.48 ha. Another particular case is the farm f9. This farm can rely on mechanic energy for tillage, it is not equipped with an irrigation system and the farmer's crop choice priority is bean-peanut. Farm f9 is held by a 40-year-old farmer, whose family consists of 12 people, and its income is about 163.74 $. Interestingly, among farms f9, f12 and f14, which are the ones characterized by bean-peanut crop choice priority, f14 is the most profitable. A further glance at the dendrogram shows that the largest cluster includes farms from f23 to f44 (D=0.25). In all of these farms the main crop is maize, except for f48 and f46, whose crop choice priority is peanut-millet and millet-okra respectively. The farmers' second crop choice is various in this cluster. All of these farms use mechanical energy for tillage, but none of them is equipped with an irrigation system. In this large farms' cluster, several subgroups can be identified. Subgroups appear to be somehow linked to the farm field's area and farmers' second crop choice. The first one includes farms f23 to f48, whose second crop choice is millet. These farms earn an average income of about 25.94 $, their fields' area goes from a minimum of 0.16 ha (f26) to a maximum of 0.65 ha (f48), farmers' average age is 69 years old and their families averagely consist of 7 members. The second subgroup includes farms f29 to f46, whose second crop choice is beans for f29 and f33, whereas it is tomato and okra for f35 and f46 respectively. Despite these crops can benefit from a sale price higher than 1 $ (see above), they earn an average income of about just 27.29 $; their fields' area goes from a minimum of 0.65 ha (f29) to a maximum of 1.50 ha (f46), farmers' average age is 53 years old and their families consist, on average, of 5 members. The third subgroup includes farms f25 and f27, whose second crop choice is millet and beans respectively. These farms earn an average income of about 108.47 $; their fields' area is about 2.50 and 2 ha respectively, whilst farmers' mean age is 57 years old and their families consist, on average, of 7 members. The fourth subgroup includes farms f36 to f39, whose second crop choice is sorghum for f36 and f37 and manioc for f39. These farms earn an average income of about 74.66 $; their fields' area goes from a minimum of 0.48 ha (f37) to a maximum of 0.68 ha (f39), farmers' mean age is 55 years old and their families consist of 4 members on average. The fifth subgroup includes farms f38 to f45, whose second crop choice is okra. These farms earn an average income of about 68.29 $; their fields' area goes from a minimum of 1 ha (f45) to a maximum of 2 ha (f38). Noteworthy, in this subgroup the oldest farmer can rely on the largest field's area, earning an income of about 94.31 $. By contrast, despite the youngest farmer obtains more favourable sale prices, his farm (f45) earns the smallest income in the subgroup (58.88 $). In other terms, in this subgroup income appears to increase with farmers' age and fields' area regardless of the products' sale price. The sixth subgroup consists of farms f32 and f34, whose farmer's crop choice priority is maize-peanut. These farms earn an average income of about 69.27 $; each farm's field area is about 2 ha; farmers' average age is 54 years old and their families consist of 5 and 6 members respectively. In this case, the income increase appears to be linked to yield and the product's sale price. Finally, the large cluster explored so far is complete with farms f42 and f44, whose second crop choice is pea for f42, whilst f44's farmer grows just maize. These farms earn an average income of about 179.55 $; their fields' area is 1.29 and 0.97 ha respectively; farmers' average age is 67 years old and their families respectively consist of 4 and 5 members. Going forward, there is a little cluster including farms f22, f41 and f43. These farms rely on animal energy for tillage and they are not equipped with an irrigation system. Their farmers' crop choice priorities are okra-pea, maize-pea and maize-okra respectively; their average income is about 16.43 $. Interestingly, f22 is a particular case in the cluster. This farm is the less profitable among all farms included in the survey (0.65 $) and its field's area is just about 0.24 ha; f22 farmer's age is 39 years old and his family consists of 6 members. Farms f41 and f43 earn incomes about 32.32 and 16.32 $ respectively; farm's field area is about 1.29 ha for f41 and 5 ha for f43, farmers' age is 42 years old for f41 and 55 years old for f43, whereas both farmers' families consist of 9 members. The last cluster includes farms f24, f47, f30 and f31, which are all equipped with an irrigation system. These farms appear grouped in 2 couples: the first one includes farms f24 and f47, whereas the second one consists of farms f30 and f31. Farms f24 and f47 rely on animal energy for tillage, their farmer's crop choice priorities are maize-bean and peanut-bean respectively, whilst their incomes are about 85.14 $ for f24 and 196.62 $ for f47; farm's field area is about 3 ha for f24 and 1 ha for f47, farmers' age is 51 years old for f24 and 39 years old for f47, whereas both farmer's families consist of 6 members. Finally, farms f30 and f31 rely on mechanization for tillage, their farmer's crop choice priority is maize-peanut, whilst their incomes are about 48.97 $ and 146.90 $ respectively; farm's field area is about 5 ha for f30 and 4 ha for f31, farmers' age is 54 years old for f30 and 62 years old for f31, whereas both farmer's families consist of 8 members (see Table 11 in appendix).

From data analysis to SWOT table

Information obtained by data analysis leads to numerous observations on the agricultural system of Haiti. These were organized in a SWOT table to point out the main strengths, weaknesses of the actual agricultural setting and to identify possible opportunities and threats laying outside the local agricultural sector. Table 10 contains the

SWOT table, starting from the evidence provided by data analysis and following the criterion outlined above.

Table 10 - SWOT table

STRENGTHS	WEAKNESSES
• All of the surveyed farms are run-family businesses (sense of community); • The local market is a reference point for farmers (development on territory); • Philosophy of reuse, not just sale; • Farmers' families averagely consist of 6-7 members; • Different economic associations in a balanced system can avoid income and political power concentration; • Almost all of the farms lean on a flatland; • Overall fair water availability; • The great majority of people lives in Torbeck rural section; • The high share of under 18-year-old people on the entire Torbeck population.	• The system appears to be too sensitive to sale prices; • Unadvised farms' mechanization investments; • Irrigation systems installation is linked to crop profitability rather than accounting for real water needs; • The average farmers' age is about 53 years old; • Under 40-year-old farmers are just 7 out of 49; • The majority of under 40-year-old farmers hold farms with small field's area.
• OPPORTUNITIES	• THREATS
• Farmers are generally open to the research activity; • 75.5% of farmers know about near meaningful environmental resources; • Small farms' field areas may favour crop diversity; • Widespread propagation by seeds can provide a good genetic variability for local crop selection; • Development of widespread extension service; • Implementation of funding plans for farms' sustainable mechanization; • Implementation of funding plans for young farmers; • Implementation of specific research programs; • Investments in farmers' and technicians' instruction.	• 44% of farmers grow maize, bean or black-bean (loss of crop diversity); • Use of very dangerous pesticides, even in mixtures, without personal protection equipment; • Very Dangerous pesticides are still widespread throughout Torbeck farms; • 79.6% admits he doesn't know anything about agroecology; • Low yield leads to unsustainable soil use (even more important for large surfaces farms); • Plant's diseases and pests need more careful monitoring; • Livestock's diseases and pest need more attention.

Looking at the results of data analysis, one can easily notice that farms' income mainly depends on crop choice priority and, just in some cases, on the level of mechanization, on the irrigation system availability and the single farm's field area. An interesting previous study (Zelaya *et al.*, 2017) found that small-scale farmers in the North Department of Haiti use the following factors to determine crop selection: financial security, familial traditions, concern for family, and availability of financial resources. When determining practices for crop production, farmers relied on the following drivers: financial limitations and previous learning experiences. Conversely, and even if our study does not relate to choice drivers, our results show that, on the one hand, mechanization is surprisingly associated with low incomes, although some among the most profitable farms rely on mechanized tillage. On the other hand, the irrigation system availability does not significantly affect yield and it is mostly associated with high incomes just because the majority of farmers holding farms equipped with an irrigation system usually adopt high sale price crops (i.e. beans, which are not so irrigation-dependent). For instance, farms from f3 to f14, which are among the most profitable ones, rely on animal energy for tillage and are all equipped with an irrigation system: not surprisingly, their farmers' first crop choice is beans. One possible explanation could be the adoption of irrigation and mechanization as a "status symbol" more than as a consequence of appropriate agronomic planning (Rao, 1972; Kienzle *et al.*, 2013).

Income and yield do not always increase with larger farms' fields' area. According to previous studies, larger farms may operate under different economic constraints and can hedge differently against risk compared to smaller farms (Rosenzweig & Binswanger, 1993). Particular evidence of this finding can be noticed considering farm f13 (see Table 11 in appendix). The income earned by this farm is the second-lowest in its cluster; its field's area is about 2.65 ha and the farmers' family consists of 4 members. By contrast, farm f11, which is characterized by 3.5 ha field's extension, earn the second-highest income among all those included in the survey. Likely, such a result is achieved because this farm can rely on a family consisting of 6 members and, perhaps, on a better sale channel granting a higher sale price. Anyway, as outlined above, the most profitable farm is f3, whose field's area is about 1.5 ha. Therefore, one could conclude that farms characterized by a field's area larger than 1.5 ha need mechanization unless the farmer's family consists of at least 6 members, the sale channel grants a good sale price and the first crop choice is beans. This hypothesis is supported by the f2-f50 cluster's situation. More precisely, f2 and f6 to f10 farms' income (and yield) increases with larger fields' area and, noteworthy, these farms can rely on mechanic energy, they are all equipped with an irrigation system, except for f6, and their crop choice priority is bean-maize. Among these farms, the most profitable one is f2, whose field's area is about 3 ha and the farmer's family consists of 12 members. In particular, farm f2 is the 3rd most profitable one among all those included in the survey. The less profitable mechanized farms in the f2-f50 cluster are f12, f21 and f50. Interestingly, these farms' crop choice priorities are bean-peanut, black-bean-rice and tomato-millet respectively. Among these farms, the higher income is earned by f21, whose field's area is about 2 ha and the farmer's family consists of 6 members. Hence, the mechanization and, to a lesser extent, the number of the farmer's family members, are important for large fields' farms, especially for a bean-maize crop choice priority. In a previous study, (Noack & Larsen, 2019) reviews a large corpus of literature studying the relationship between farm size and productivity, in which different authors generally conclude that farm output declines with farm size in most developing countries (Coello *et al.*, 2014). Anyway, as already mentioned, our results show that the success of farms mostly depends on crop choice that in turns bring about higher yield (e.g. maize) or high products' sale price (e.g. beans). Our results also shed light on another aspect of interaction among the field's area, mechanization and crop choice priority that is evident for farms f15, f17, f19, f16, f18 and f20, whose crop choice priority is black bean-maize (see Table 11 in appendix). All of these farms are irrigated and farmers rely on animal energy for tillage; their fields' area never overcomes 2 ha. Interestingly these farms appear clustered by income, farmer age and fields' area. On the one hand, f15 to f19 are held by the youngest farmers met during the survey, their field's area goes from a minimum of 0.48 ha (f17) to a maximum of 0.65 ha (f19) and their average income is about 90.9 \$. On the other hand, farms f16, f18 and f20 are held by definitely older farmers (61 to 67 years old), their field's area goes from a minimum of 0.65 ha (f18) to a maximum of 2 ha (f20) and their average income is about 247.93 \$. Interestingly, the most profitable farm in this group is f16, whose farmer's family consists of 5 members and the field area is about 1.29 ha. Moreover, f20 is the second most profitable farm in the same group and its vaster field's area (2 ha) is accompanied by a higher number of family members (9 people). Hence, one could conclude that farms with a field's area of about 1.2-1.5 ha whose crop choice priority is either bean-maize or black bean-maize are likely to achieve higher incomes. Same farms appear less profitable both when larger field's area is not accompanied by mechanization, and when the fields' area is too small. Nevertheless, it seems that a higher number of family members can partially mitigate the income decrease due to the absence of mechanization in large fields' area farms. Noteworthy, the combination of the field's area effect and tillage energy source generally leads to even lower incomes when the crop choice priority is different from bean-maize or black bean-maize. This is particularly evident considering the cluster including farms f22, f41 and f43. These farms' crop choice priorities are okra-pea, maize-pea and maize-okra respectively; moreover, they neither rely on mechanization nor any irrigation system. In the case of f22, the combination of crop choice priority and small field's area seems to lead the farmer to earn the lowest income recorded during the entire survey (0.65 $). On the other hand, the lack of mechanization combined with crop choice priority and large field's area leads to low incomes too, as found for f43. Indeed, this farm's field area is about 5 ha, the largest one in the survey (together with the f30 field's area) and its income is one of the lowest ones (16.32 $). Noteworthy, the farmer's large family (9 members) does not appear to be helpful in this case. Nevertheless, the same situation could be noticed considering farm f24, although it is equipped with an irrigation system. Furthermore, farm f41, whose field's area is 1.29 ha earns about double income (32.32 $) with respect to f43 (16.32 $), although f43 field's area is about 5 ha. Therefore, one can conclude that when a farmer chooses maize as the first crop, he/she should be willing to invest in mechanization regardless of the artificial irrigation availability, despite the number of farmers' family members overcomes 6 individuals and especially if the field area overcomes 1.5-2 ha. This is consistent with the well-known maize's tillage needs. Nevertheless, such investment might be unprofitable when the farm's field area is too small. This finding matches the possible explanation given by a previous report by the World Banck (Coello *et al.*, 2014) arguing that even if larger farms tend to decrease their yields, these are also able to invest in mechanization, to diversify their products and to increase the income of the owner by optimizing the use of labour and other inputs. In this perspective we consider farms f23, f26, f48 and f25, whose crop choice priority is maize-millet (see Table 11 in appendix). These are mechanized farms that are not equipped with an irrigation system. Despite crop choice priority, mechanization and irrigation availability are analogous among these farms, f25 is more profitable (102.69 $) and it belongs to another subgroup. Indeed, f26 is one of the less profitable farms investigated in this survey and, although mechanized, its income is just about 15.62 $. This might be due to the limited field's area (0.16 ha). This finding is also true for the farm f23, even though its income is higher because of its slightly larger field's area (0.40 ha) and thanks to the higher sale price probably granted by a better trade channel. Interestingly, farm f48 shows a lower income (19.63 $) despite its field's area is the highest in its subgroup (0.65 ha). This might be explained by the different crop choice priority (peanut-millet). One more time, the high number of family members do not appear to be helpful. Hence, the farm f25's success is likely to be due to the combination of mechanization and fairly large field's area (2.50 ha). This finding is also evident, although to a lesser extent, for subgroups including farms f38-f45 and f32-f34, whose crop choice priority is maize-kalalou and maize-peanut respectively. Interestingly, some farms can also be fairly profitable when their field's area is around 1 ha, as observed for f42, f44 and f47, whose crop choice priorities are maize-pea, maize and maize-bean; or even when farm field's area is smaller than 1 ha: this is the case of farms f36, f37 and f39, whose crop choice priority is maize-sorghum (f36 and f37) and maize-manioc (f39) respectively. In these cases, the relatively high incomes recorded might be linked to the high yield observed, or to specific cropping techniques (i.e. polyculture over yielding as reported by (Picasso *et al.*, 2011). By contrast, farms f30 and f31, although mechanized and characterized by a large field's area (5 and 4 ha respectively) surprisingly don't achieve the expected results in terms of income. Perhaps the efficiency of farms' mechanization and its technical aspects need to be further investigated. A particular case is represented by farms f49 and f28, whose crop choice priorities are rice-pea and maize-bean, respectively. Both farmers choose a cereal as a first option and a legume as a second option. The former farm earned the 12th highest income in the survey (270.34 $), although its field's area is just 0.48 ha: probably because of the rice's high sale price; whereas, not surprisingly, the latter one earned the 9th highest income (360.45 $): probably thanks to the mechanization combined with a sufficient field's area (1.13 ha). Anyway, the findings described so far should not be strictly interpreted from agronomical point of view, as data obtained by survey do not provide any information about rotation's effect: the variable named "crop choice priority" just expresses the farmers' crop options in ordinal terms. Nevertheless, the clues obtained by data analysis allow to identify some system's criticism that can be easily seen as weaknesses and threats according to the SWOT method. Overall, the majority of profitable farms are held by farmers who choose to grow high sale price crops and maize. As outlined in the results, the 44% of farmers grow beans, black-bean or maize and the 88% of them choose one of these crops as a first option. This can be explained by the fairly high profitability of beans and the virtually high production granted by maize, which also appears to be one of the main sources of carbohydrates. On the other hand, such loss of diversity appears to be somehow linked to a "western" development model, which does not completely account for territory needs and characteristics. Agricultural commercialization remains a widely pursued approach in development projects to improve food security in low-income countries, although there is no clear scientific evidence for it (Linderhof *et al.*, 2019). We should not overlook the negative side of agricultural commercialization that is impacting the overall environment, biodiversity, food and nutrition security, and animal health. For instance, the loss of crop diversity linked to crop profitability concentrates the enterprise risk on few main crops, whose profitability depends on their sale price, which, in turn, determines the farmer's income. Moreover, such a close relationship between a product's sale price and crop choice might be harmful to the landscape balance and might lead to long-term genetic erosion (Guzzon *et al.*, 2021). Furthermore, our findings suggest a relationship between farms' mechanization, farms' field area, irrigation, yield and income. It seems that mechanization is often implemented without considering its appropriateness. In some cases, there are mechanized farms with insufficient fields' area (ex.: farms f23 and f26) whilst in other ones, there are farms characterized by large fields' areas whose tillage is performed by animal energy (ex.: farm f43); in other seldom cases, mechanization does not seem to grant the expected incomes despite the large field's area (ex.: farm f30). These situations sometimes lead farms to be less profitable. On the other hand, irrigation does not seem to affect the farms' yield and profitability in a meaningful way. This may be because irrigation system installation is mostly linked to high sale price crops instead of real crop's water needs (Zelaya *et al.*, 2017). Noteworthy, 87% of farms whose first crop choice is maize are not equipped with an irrigation system. It's good to remember that maize's water consumption is usually high: water availability in maize is particularly important for flowering and dry matter uptake (Hall *et al.*, 1971). Thus, despite the usually fair water availability granted by Haiti's climate, maize might need water supply in particular phenological phases. Anyway, this topic should be investigated specifically. Moreover, all of the farms held by under 40-year-old farmers are characterized by small fields' areas (≤1 ha), except for farm f13. As outlined above, only the 25% of farmers is under 48 years old and the under 40-year-old farmers are just 7 out of 49. The average farmer's age is about 53 years. Despite the rural exodus risk seems to be unlikely in the short/midterm in Haiti, the noticeable prevalence of older people among farmers is a typical sign that the development trend is going that way. In many developed countries, at least in Europe, the high farmer’s age is a widespread problem, often addressed by specific funding plans. According to the Institut haïtien de statistique et d’informatique. (2009) the urbanization rate increased from 47.8% in 2010 to 51.9% in 2015.

Beyond the potential risk of genetic erosion, the survey allowed us to individuate further threats. Among farmers, there is a dangerous lack of knowledge about pesticides. As outlined above, all of the interviewees admit they use pesticides without any personal protection equipment. Moreover, most of them don’t know much about plants’ diseases and pests, usually referring to the different pests by broad agent families such as “moulds” or “insects”. On the other hand, most pesticides nowadays forbidden in most European countries are still allowed in Haiti (FAO & World Health Organization 2019).

Concerning alternative visions of agricultural development, unfortunately, 79.6% of interviewees, ignore the agroecological approach and any other related topic. This result is unexpected since the agroecology and food sovereignty movement date back to the ‘70s (Moore, 2017). This kind of approach to agriculture may help Haitian farmers in self-determining their path to a balanced and aware development, which should start from the features of their own territory. Indeed, the lack of knowledge also depends on the absence of a careful plant’s diseases and pests monitoring activity. Similarly, the knowledge about livestock’s health issues and needs should be enhanced. All of the strictly technical issues would require specific projects aimed at a gradual and wise transition to better conditions. The guidelines to achieve such a purpose can be directly drawn by the natural strengths of the system. The totality of farms included in the survey are run-family businesses, thus, it seems that the Torbeck population still conceives economics according to its etymological meaning, that is: “the science of managing home”. As a consequence, their mentality is mainly focused on the real and local economy, more than on exterior markets. Indeed, a little, although meaningful, the share of people still resort to the reuse of their own products and accept gifts. This approach is supported by generally numerous farmers’ families who are enrolled in various mosaic of agricultural associations addressing different needs. This fragmented situation might look like a weakness, but it is consistent with the productive system’s scale. Furthermore, it allows spreading the general enterprise risk on a good number of different economic subjects avoiding excessive political power and income concentration in few associations. Moreover, Torbeck province leans on a flatland characterized by fair water availability, most people (93.1%) live in the Torbeck rural section and 38% of them are under 18 years old. These positive aspects make agricultural development convenient in Torbeck plain, both because of the environmental vocation, and because of the possible involvement of young people in this process. In this perspective, the awareness about environmental sources, other than exploited by agriculture, together with the diffused willingness to participate in research projects, seems to be a good precondition.

Unexpectedly, some aspects that are normally seen as weaknesses can be considered as opportunities. For instance, the relatively small Torbeck farms field area scale (averagely 1.55 ha) determines an overall land fragmentation which is usually seen as a weakness. Although too small field’s areas may lead to low incomes, in the Torbeck context the agricultural land fragmentation might favour the overall crop diversity, especially if accompanied by appropriate investments. Similarly, the widespread open propagation by seeds can be considered a criticism for modern agriculture, which is mainly based on trade and product’s standards, but in the Torbeck context, such traditional practice may enhance genetic variability, especially for typical local crops. Obviously, such variability should be conveniently studied to lead wise local crop cultivars’ selection.

Conclusions

All of the insights deriving from our SWOT analysis on the agricultural Torbeck system seem to confirm that low productivity is the main problem encountered in this country, which in turn is bound to a low income and profitability of the subsistence agricultural system in the existing framework of international staple food import/export agreements (Weisbrot *et al.*, 2010). These are common issues in the least developed countries (FAO, 2002; InnovAfrica, 2018). It is now generally accepted that agricultural Extension and Advisory Services (EASs), when present, could implement specific research programs and rely on local technicians who may be able to successfully carry out a qualified advisory activity in compliance with the environment, the population's culture and the techno-economical characteristics of the productive system and the needs of small-holding farmers (Swanson, 2008).

In order to improve the agricultural system in Torbeck, we can suggest two different strategies based on statistical analysis, farms' classification and SWOT analysis as well.

The first strategy stems from identified strengths and weaknesses and focuses on the increase of farmers' incomes in the near future by improving crop choice and adapting appropriate cropping techniques, here comprised irrigation (Zelaya *et al.*, 2017). In particular, we suggest that specific programs focused on improving the existing agricultural EASs and on building synergy with research centres are needed. These new programs have to take into account peculiar Haitian agricultural strengths such as the farms being mostly run-family businesses and almost all of the farms leaning on flatland and showing water availability. These new programs have also to consider peculiar Haitian agricultural intrinsic weaknesses such as the market-price heavy instability; the existing inappropriate/unreasoned mechanization of farms, here comprised irrigation use. It is a matter of fact that the average field area is 1.5 ha, farmers' age mean-value is 52,8 and they live in families consisting of 6.5 members on average. While these features may represent a weakness for conventional and business-oriented agricultural development, they may be turned into strengths if appropriate agricultural outputs are sought, such as improved yields for locally relevant crops. Indeed, our analysis shows that the higher income is for farmers that choose rice or legumes as the first choice, sold locally and that irrigation is mostly used on these crops, even though other crops (maize for instance) are much more water-dependent.

The second strategy focuses more on long-term goals. Impacts beyond the short term can only be achieved if interventions also take into account available opportunities. These comprehend the widespread practice of propagating crops by seeds that can provide a good genetic variability for local varieties improvement programs and fight genetic erosion brought by the invasive promotion of improved hybrid varieties, which reduce their productivity if re-used after the first generation (which is indeed a traditional practice). Moreover, the existence of participatory EAS in northern Haiti could profitably be involved in coordinated efforts towards the diffusion of agroecological approach and techniques (Moore, 2017).

Finally, yet importantly, we identified some threats that have to be tackled as soon as possible to remove barriers to any agricultural development, i.e. the marketing of very dangerous pesticides, already forbidden in several "developed countries", but still sold on the Haitian internal market, and the increasing occurrence of new plant and animal diseases.

Policymakers should certainly give priority to the approval and the allocation of specific funds for farmers and technicians' training. Not least, younger farmers might benefit from specific funds allowing them to purchase fields and invest in agriculture.

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Appendix

Table 11 - Detailed farms' classification. Herein farms are sorted according to the clusters individuated by HCA (see figure 6). In particular, farms' identification code (id), farmers' age (Age), Number of farmer's Family Members (NFM), Farms' Fields Area (FFA), Yield (Y), Product's Sale price both per 13.2 Kg and per Kg (PSP), farmer's INcome (IN), Tillage Energy Source (TES), Crop Choice Priority (CCP), IRRigation (IRR), farm's Income Ranking and farm's Average INcome (A_IN) per each group are reported.

ID	AGE	NFM	FFA (HA)	HY (KG)	PSP (13.2 KG)	PSP (KG)	IN ($)	TES	CCP	IRR	IR	A_IN ($)
f2	54	12	3.00	2454.54	3.93	0.30	730.78	mechanic	Bean_maize	yes	3rd	
f3	60	7	1.50	3054.54	4.76	0.36	1101.49	animal	Bean_maize	yes	1st	856.52
f11	70	6	3.50	2045.45	4.76	0.36	737.60	animal	Bean_maize	yes	2nd	
f4	47	6	1.29	1227.27	3.96	0.30	368.18	animal	Bean_maize	yes	5th	
f5	67	5	1.29	1227.27	3.93	0.30	365.39	animal	Bean_maize	yes	6th	326.63
f13	34	4	2.65	954.54	3.57	0.27	258.23	animal	Bean_maize	yes	12th	
f14	52	7	2.50	872.72	4.76	0.36	314.71	animal	Bean_peanut	yes	10th	
f15	32	8	0.56	218.18	4.00	0.30	66.12	animal	Black-bean_maize	yes	34th	
f17	28	5	0.48	218.181	4.00	0.30	66.12	animal	Black-bean_maize	yes	33rd	90.91
f19	30	5	0.65	463.63	4.00	0.30	140.49	animal	Black-bean_maize	yes	24th	
f16	61	5	1.29	1090.909	4.00	0.30	330.58	animal	Black-bean_maize	yes	9th	
f18	62	11	0.65	545.45	4.00	0.30	165.29	animal	Black-bean_maize	yes	20th	247.93
f20	67	9	2.00	818.18	4.00	0.30	247.93	animal	Black-bean_maize	yes	13th	
f6	43	6	1.00	681.81	4.76	0.36	245.86	mechanic	Bean_maize	no	14th	
f7	54	6	1.00	681.81	3.57	0.27	184.40	mechanic	Bean_maize	yes	17th	
f8	43	5	3.00	1636.36	4.76	0.36	590.08	mechanic	Bean_maize	yes	4th	
f10	47	6	1.50	1009.09	4.76	0.36	363.88	mechanic	Bean_maize	yes	7th	258.66
f12	45	3	1.29	490.9	4.76	0.36	177.02	mechanic	Bean_peanut	yes	19th	
f21	41	6	2.00	545.45	4.36	0.33	180.16	mechanic	Black-bean_rice	yes	18th	
f50	62	2	0.65	230.67	3.96	0.30	69.20	mechanic	Tomato_millet	yes	32nd	
f28	55	5	1.13	600	7.93	0.60	360.45	mechanic	Maize_bean	no	8th	315.40
f49	47	8	0.48	450	7.93	0.60	270.34	mechanic	Rice_pea	yes	11th	
f9	40	12	1.29	681.81	3.17	0.24	163.74	mechanic	Bean_peanut	no	21st	163.74
f23	72	8	0.40	545.45	1.03	0.08	42.56	mechanic	Maize_millet	no	39th	
f26	60	8	0.16	327.27	0.63	0.05	15.62	mechanic	Maize_millet	no	48th	25.94
f48	76	5	0.65	272.72	0.95	0.07	19.63	mechanic	Paenut_millet	no	45th	
f29	60	5	0.65	204.54	1.03	0.08	15.96	mechanic	Maize_bean	no	47th	
f33	46	6	1.00	545.45	0.95	0.07	39.26	mechanic	Maize_bean	no	41st	27.29
f35	45	6	1.00	409.09	0.71	0.05	22.00	mechanic	Maize_tomato	no	44th	
f46	60	4	1.50	409.09	1.03	0.08	31.92	mechanic	Millet_kalalou	no	43rd	
f25	50	10	2.50	1909.09	0.71	0.05	102.69	mechanic	Maize_millet	no	26th	108.47
f27	63	7	2.00	1909.09	0.79	0.06	114.26	mechanic	Maize_bean	no	25th	
f36	39	4	0.56	1227.27	0.79	0.06	73.45	mechanic	Maize_sorghum	no	31st	
f37	60	6	0.48	878.78	0.79	0.06	52.59	mechanic	Maize_sorghum	no	36th	74.66
f39	67	3	0.68	1636.36	0.79	0.06	97.93	mechanic	Maize_manioc	no	28th	

f38	68	8	2.00	1575.867	0.79	0.06	94.31	mechanic	Maize_kalalou	no	29th	
f40	56	9	1.29	863.62	0.79	0.06	51.69	mechanic	Maize_kalalou	no	37th	68.29
f45	43	6	1.00	818.18	0.95	0.07	58.88	mechanic	Maize_kalalou	no	35th	
f32	41	5	2.00	1636.36	0.79	0.06	97.93	mechanic	Maize_peanut	no	27th	69.27
f34	66	6	2.00	850.9	0.63	0.05	40.61	mechanic	Maize_peanut	no	40th	
f42	62	4	1.29	3272.72	0.79	0.06	195.87	mechanic	Maize_pea	no	16th	179.55
f44	72	5	0.97	2727.36	0.79	0.06	163.23	mechanic	Maize	no	22nd	
f22	39	6	0.24	545	1.58	0.12	0.65	animal	Kalalou_pea	no	49th	
f41	42	9	1.29	540	0.79	0.06	32.32	animal	Maize_pea	no	42nd	16.43
f43	55	9	5.00	272.72	0.79	0.06	16.32	animal	Maize_kalalou	no	46th	
f24	51	6	3.00	1772.72	0.63	0.05	85.14	animal	Maize_bean	yes	30th	140.88
f47	39	6	1.00	2181	1.19	0.09	196.62	animal	Peanut_bean	yes	15th	
f30	54	8	5.00	818.18	0.79	0.06	48.97	mechanic	Maize_peanut	yes	38th	97.93
f31	62	8	4.00	2454.54	0.79	0.06	146.90	mechanic	Maize_peanut	yes	23rd	