Influence of farm management on soil fertility in marginal farming systems in Tigray, Ethiopia

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MSc-thesis

Supervisors:
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ABSTRACT

Food insecurity is a serious problem in Africa and is likely to worsen with expected climate change and population growth. Increasing soil fertility is seen as the main factor to improve crop yield in most African countries. Soil fertility is influenced by farm management in combination with geology and geomorphology. In order to understand crop yield and identify options for improvement, it is important to understand the influence of farm management on soil fertility. This study focuses on four different regions in the northern highlands of Ethiopia. Agricultural fields were investigated using interviews to identify the management strategies, soil descriptions and soil sampling. Management varies in terms of ploughing, weeding and fertilization (including chemical fertilizer and manure). Soils are low in nitrate and organic matter. But also other indicators like K-exch, N-total and P-olsen indicate that the soil fertility is low. The four different regions differ in management strategies resulting of the intervention history. However, t is questionable if these management differences result in in soil fertility differences. However, no clear influence of management strategies like ploughing, fertilizer use, crop rotation, distance homestead and amount of livestock show on soil fertility could be found. The reason for the absence of the relationships can be found in the large variability of the soils and soil fertility in the area. It is concluded that other inherent soil forming factors dominate soil fertility variability between fields.

Keywords: Farm management strategy, soil fertility, crop productivity, Ethiopia, marginal farming systems

PREFACE

This research has been done within my MSc study Earth and Environment with the track Soil geography and Landscape. The research is related to the PhD-research of Richard Kraaijvanger, which aims to studying farm strategies to improve crop productivity in the northern highlands of Ethiopia. In order to understand the relationship between soil and management this investigation has been carried out. The urgency of the food security problem together with studying the landscape and soil processes makes it for me a very interesting topic.

I would like to thank Richard and his family for the time we could live in your house in Ethiopia and for his help during my research. Further on I would like to thank Jetse for being my supervisor during the six months of this research. I also want to thank Susanne for the nice time we spend in Ethiopia. We really worked hard as a team during these three months and I think that for both of us it was a really nice experience. Finally, I want to mention Marthijn Sonneveld. It was his idea to do this research and he convinced me to do this interesting thesis. Unfortunately he was not able to help us during our research and to see the final result.

It has been a challenging and interesting thesis and I worked with a lot of pleasure on this topic. The research in Ethiopia has been a nice challenge. I learned to set up my own research and to deal with all the related problems. It was for sure an experience I will never forget.

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1. INTRODUCTION

Food insecurity is a serious problem in Africa. The problem is likely to worsen with expected climate change and high population growth rates (Baldos & Hertel, 2014; Khan et al., 2014). In general, crop productivity is low in Africa, so there is an increasing need for higher yields to improve food security (FAO, 2012). Crop production is strongly influenced by soils. Soils vary a great deal in terms of origin, appearance, characteristics, and production capacity. Soil fertility is one of the factors that influence crop yield (Roy, 2006). Soil fertility can be influenced by farm management (Schlecht, 2004; Suzuki, 2014). Soil management is an interactive and interdependent process of managing water, crops and labour. A lot of factors are involved in the process like: biophysical processes, seasonality, crop rotation, climate, weather, labour intensity, and the prices on the market.

As already stated soil fertility plays an important role in the crop productivity. Therefore, sustaining soil fertility is important for farmers in this area (Kraaijvanger et al., 2013). It is the component of overall soil productivity that deals with the available nutrient status, and the ability to provide nutrients out of its own reserves and through external applications for crop production. All of these properties affect directly or indirectly nutrient dynamics and availability. Soil fertility is manageable on both a short-term and a long-term (Roy et al., 2006).

Kristjanson (2012) shows that there is a strong negative relationship between the number of food deficit months and innovation (mainly management changes). There has been several projects by the government and NGO's to improve productivity by introducing new technologies and by giving education, but the results are still marginal. It is not always clear what the reason is, but it seems there is still a limited understanding of the problems that farmers facing (Kraaijvanger et al., 2013). Farmers experiences a variety of problems related to soil: high risk of soil erosion, low soil fertility, soil dryness, difficult soil workability and soil compaction (Hadgu et al., 2009). Farmers have also to deal with land scarcity. For example in the north of Ethiopia farm size is around 0,75 – 1,0 ha (Kraaijvanger et al., 2013). Therefore, traditional management strategies like fallowing and crop rotation are abandoned. Other sources of nutrients are needed to maintain soil fertility. Nutrient inputs influence crop productivity (Van der Velde, 2014). Farmers use marginal inputs and benefit more from low-input approaches and other livelihood activities as livestock management and nonfarm activities (Pender & Gebremedhin, 2008). Farmers distinguish different types of fields, which are managed in different ways according to the agricultural and social value of the fields (Beyene et al., 2001). Earlier research showed for example that there might be a relation between soil fertility and the distance to homestead (Zingore, 2007).

Increased knowledge of the influence of management strategies on the variability of soil fertility may help to increase the crop productivity. A better understanding of the influence of management strategy, gives the farmer the opportunity to improve the soil fertility status of the fields. The main research objective for the investigation is to investigate the influence of farm management on soil fertility variability.

The sub-research objectives are:

- To identify and describe the variability of management strategies
- To identify and describe the variability of soil fertility
- To analyse the differences in management strategies between different regions.
- To research the effect of different management strategies on soil fertility

Figure 1 gives an overview of the relationships between soil fertility, management and yield. The main goal of this research is to understand the effects on soil fertility. Soil fertility is influenced by different management strategies, but also by soil. The effects of general soil parameters on soil fertility includes in general soil type, but also soil texture, parent material and pH. Management is also affected by some factors which might for example influence the labour intensity, due to distance homestead, family size, livestock and farm size. Soil fertility has influence on yield, but there are also other factors which influence yield.

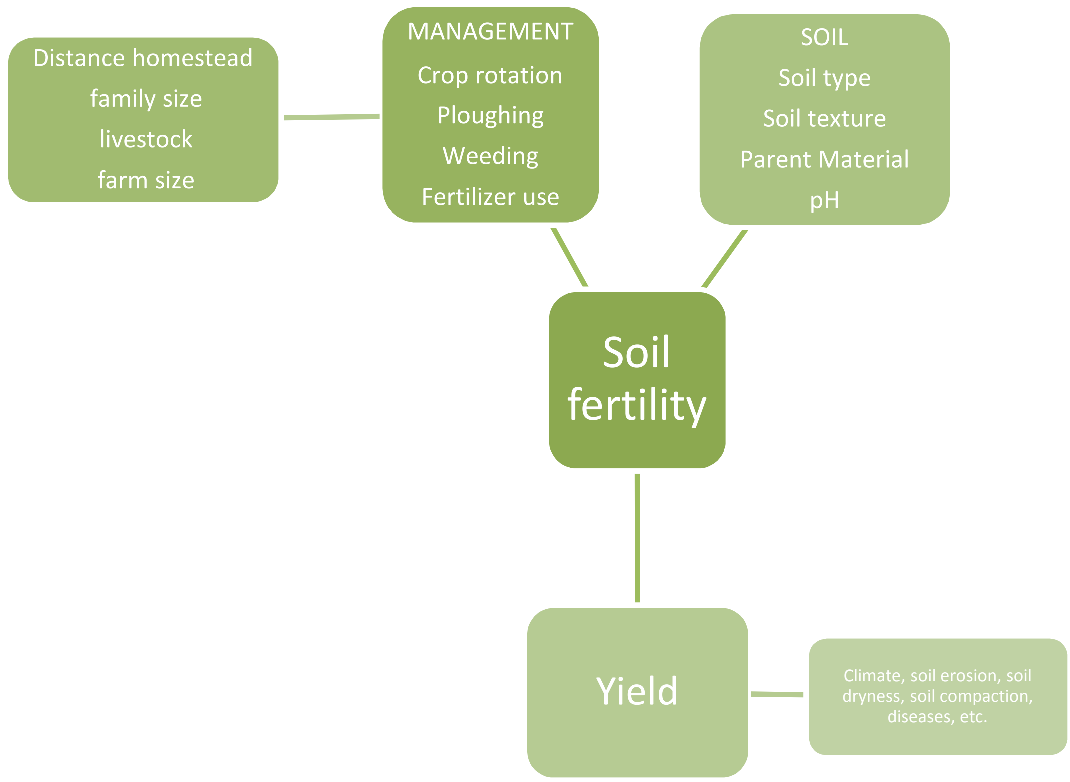

Figure 1 Overview of the relations around soil fertility

2. METHODOLOGY

2.1. STUDY AREA

The study area is the Tigray region in the north of Ethiopia. This is an area characterised by low crop productivity and low soil fertility. Together with small farms and soil erosion, makes this an interesting study area. The agricultural sector is important for the economy and social life of Ethiopia. Almost 80 – 85 % of the people work in agriculture and the agriculture sector contributes about 40 % of the GDP of the country (FAO, 2006). Agriculture is important for the food supply in the country. Food security is a serious concern in Ethiopia where in the past several famines occurred. Due to an increasing population there is a need for higher yields and a higher food security in the whole Sub-Saharan Africa (FAO, 2012).

Mixed farming is the most common way of agriculture in the northern of Ethiopia. This means livestock and crop production together. Main crops grown in Tigray are tef, barley, wheat; these crops grow in the long rainy season (Dorosh & Gemessa, 2013). Sometimes farmers grow hanfets. Hanfets is a mixed cropping of wheat and barley, which decreases the rick of a complete yield loss, reduces the chance of diseases, insect pests and weeds and is very useful as food and animal feed (Woldeamlak et al., 2008). If the rainy seasons overlap also maize, sorghum and finger millet can be grown (Kraaijvanger et al., 2013). Farm size is around 0,75 – 1,0 ha. The work on the field is very labour intensive. Ploughing is for example done by oxen. One of the traditional methods to improve soil productivity is fallowing. Farmers fallow their fields one period during a year or even leave a field fallow for a complete year to recover soil fertility. During the fallow period, farmers still grown legumes to have a small income. Due to increased scarcity of land, farmers has less opportunity to leave their field fallow for one year. Crop rotation is another method that is used to improve soil productivity. The rotation schemes depend on personal preferences and market price. Other methods to improve soil productivity are the incorporation of crop residues, manuring, weeding, stone bunds, and tillage (Corbeels et al., 2000).

Tigray is one of the nine regional states of Ethiopia covering a total area of 53,000 square kilometres. Geographically, it lies between 12^{o}15’ and 14^{o}57’ northern latitude, and between 36^{o}27’ and 39^{o}59’ eastern longitude. The altitude varies between 1900 up to 2600 m asl. (Kraaijvanger et al., 2013). Annual precipitation for the Tigray region is 709 mm (Gebrehiwot & van der Veen, 2013). There is a short rainy period from March till April and a long rainy period from May till August. The temperature in the highest in May and the lowest in December and the mean temperature ranges from 15˚C and 21.5˚C. Tigray can be considered as semi-arid dry lands.

Tigray is divided into 36 administrative zones, called ‘woredas’. The study area includes four woredas: Were Leke, Hawzen, Ahforom and Dogua Tembien (see Figure 2). These woredas differ with respect to intervention history. Within this research the names of the administrative centres have been used: Edaga Arbi (EA), Hawzen (HW), Inticho (IN) and Hagere Selam (HS). Due to delayed harvesting sampling in Hagere Selam was limited.

The mountainous landscape in the Tigray region consists mainly of strongly dissected sandstone, limestone and basalt plateaus. During the Mesozoic shales, sandstones and limestones have been formed. The Ethiopian flood basalts and associated pyroclastic rocks erupted around 30 Ma years ago (Hofmann, 1997; Nyssen et al., 2008). These flood basalts cover nowadays an area of about 600 km^2. After this period, a peak of activity resulted in large shield volcanoes. Over the past 25 Ma years these units uplifts of the order of 2500m took place. Differential resistance to erosion together with these uplifts resulted in the stepped, flat topped mountains. These flat topped mountains are dissected by canyon-like valleys (Meire, 2013).

The main soil types in this region include cambisols, luvisols, vertisols, regosols and leptosols (Wauw, 2008). Soil characteristics are very variable, due to differences in parent material, climate, topography and human activity. Most of the soils in the area are shallow, low in organic matter content, low in total nitrogen and available phosphorus. Potassium is in most of the soils not a problem. Soil nutrient balances are negative resulting in declining soil fertility and a low soil productivity (Beyene, 2006). Soil nutrient stocks in the northern of Ethiopia are decreasing with the exception of areas under intensively managemed permanent and vegetable crops. In the analysis, soil erosion was the major cause for nutrients depletion (Haileslassie et al., 2005).

Most of the land is used for agriculture, but also villages, exclosures and rarely pastures and rangelands can be found (Meire et al., 2013). Croplands can be found mainly on flat areas and sometimes also on steeper areas. To prevent erosion stone bunds or trenches are placed. Forests and rangelands usually cover mountain slopes. Irrigation is hardly used in this area except some farmers with small scale irrigation structures like ponds and shallow wells.

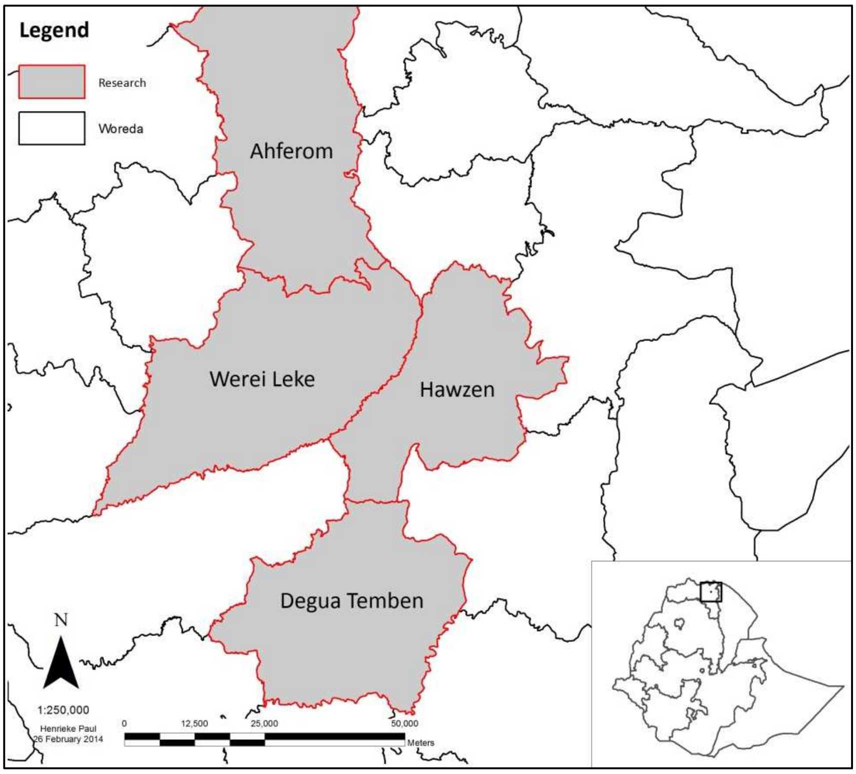

Figure 2 The study area including the four woredas used in this research

2.2. SAMPLING STRATEGY

This research is related to an ongoing PhD-project in the same area (Kraaijevanger et al., 2013)). This project includes experimental fields distributed over the four woredas. Some of the experimental fields have also been used during this research, since these fields have more available data about the soil. In total 14 experimental fields have been used for this research. If possible more fields within the same farm have been sampled, so in total 25 fields were sampled. Within Edaga Arbi 25 additioinal fields were sampled. The locations of sampling of the 25 other fields were based on the position in the landscape and the expected soil type. At least two samples at the same landscape position and the same parent material were taken.

Within each field a bulked sampling strategy was used to describe the soil fertility status of the whole field. For this bulk sample the top 20cm of the soil was sampled at four locations and mixed. One hole was dug to describe the soil profile, the soil type and the soil structure. Farmers were interviewed about the management strategies of each field. Fields and sampling units were identified by coordinates and unique numbers per field and sampling region.

There is not one comprehensive indicator to measure soil fertility. Soil fertility deals with chemical, biological and physical aspects of the soil. Many of the soil forming factors cannot be measured directly. Soil properties can be influenced by genesis or by management. The choice of these variables is based on the expected relation with soil fertility and the possibility to measure these variables easy in the field. The influence of management strategy will be described by statistical analysis.

Table 1 lists all the soil variables that were collected during the research. The choice of these variables is based on the expected relationship with soil fertility and farm management, and the availability of measurements. In addition, information about the location and management strategy is required. Organic matter content, nitrate and the thickness of the organic layer are direct measurements which are related to soil fertility and the management strategy. The soil structure gives an indication about the management strategy and a good soil structure is very important for a good soil quality. Soil texture cannot be influenced by management. Although it can affect other soil characteristics such as soil structure, organic matter content and the infiltration capacity of the soil. Soil type, soil depth and soil pH are indicators of the soil quality and during this research these variables will be used as non-manageable soil properties.

Location information:

- Coordinates
- Landscape position
- Description environment
- Aspect
- Altitude
- Slope
- Curvature

The soil type and soil depth were determined in a soil pit using a profile description according the FAO soil classification. The soil structure, parent material and the thickness of the organic layer have been described using the profile description. Nitrate has been measured in the bulk sample using a NitraCheck with a 1:10 soil-water solution. The same solution was used to measure the pH using a field pH-multimeter. The organic matter content of the sample was estimated by using the value of the Munsell colour system. Unfortunately it was not possible to calibrate this estimation with some laboratory data of this year. For the PhD-project soil samples for every experimental field have been taken during four years. This includes the parameters: K-exch, N-total, P-olsen, Organic Carbon, pH-water and pH-KCl. These measurements have also been done using a bulk sample and have been measured in a laboratory in the Netherlands.

Table 1 Observation and measurement soil variables (*=only measured in the soil samples of the experimental fields)

Field observations	Bulk sample measurements	Laboratory measurements*
Soil type	Soil pH	Organic carbon content
Soil structure	Nitrate	K-exch
Soil texture	Munsell colour value (Organic matter content)	N-total
Soil depth	Soil texture	P-olsen
Thickness organic layer		pH-H_2O
Profile description		pH-KCl
Parent material		

In Table 2 the variables to describe the farm management are given. Data will be collected using interviews. Plot size and distance homestead will be measured ourselves.

Table 2 Management variables

Management strategy	Management influencers
Times ploughing	Livestock
Ploughing depth	Family size
Type of fertilizer	Farm size
Crop type	Distance homestead
Crop rotation scheme	Plot size
Times weeding	

Yield per field was asked to the farmers during interviews. On experimental fields the yield on the plot was weighted. This includes the weight of the seeds and the weight of the straw.

2.3. DATA ANALYSIS

The analysis focused on differences between soil fertility. First the variability of management and the variability of soil fertility was investigated. This is then followed by the five management strategies, whereby the relation and influence of management strategies on soil fertility will be researched.

2.3.1. FARM MANAGEMENT

A statistical summary is given to create an overview of management in the study area. The following parameters were used: ploughing frequency, ploughing depth, type of fertilizer, crop type, crop rotation scheme. Livestock, family size, distance homestead, plot size and farm size was used to understand the management strategies and to describe the situation on the farm.

2.3.2. SOIL FERTILITY

General soil characteristics were used to describe the variability in soil fertility. These variables are soil type, soil texture, parent material, soil depth and thickness organic layer. The direct variables which have been measured in the field are soil pH, nitrate, the Munsell colour value (to estimate the organic matter content) and calcium carbonate. For all the experimental fields where soil samples have been taken and which has been analysed in the laboratory, the organic carbon content, exchangeable K, N-total, P-olsen, pH-H_2O and pH-KCl will be used to explore the variability of these properties for the whole region and within each woreda. The differences between the woredas were described using an one-way ANOVA-analysis or a chi-square test and if possible with correlation and regression analysis.

2.3.3. VARIABILITY BETWEEN REGIONS

To better understand the differences in management and soil fertility, the differences between the four regions was analysed. First management strategies and soil fertility were described using summary statistics. For the soil fertility data an one-way ANOVA analysis was used to check if there is a significant difference in soil fertility between the regions.

2.3.4. MANAGEMENT AND SOIL FERTILITY

Soil fertility is described by nitrate concentration, soil pH and organic matter. For a few management practices enough data is available to include the lab data of exchangeable K, soil organic matter, N-total and P-olsen. In addition, soil texture and soil type are taken into account. After the analysis of the variability, five management strategies or influencers have been analysed:

- Fertilizer use
- Distance to homestead
- Ploughing
- Crop rotation
- Livestock

3. RESULTS & DISCUSSION

3.1. FARM MANAGEMENT

Table 3 gives the descriptive statistics of the management strategies. The data gives an overview of the strategies and other relevant parameters which are important for management. Remarkable is the shallow ploughing depth, but also the differences in labour intensity.

Table 3 Important management parameters during this research

	Mean	SD	Max	Min
	Management strategies			
Times ploughing	3.6	0.96	5	1
Times weeding	2.0	1.1	5	0
Ploughing depth (cm)	13.2	5.16	29	4
	Farm information			
Farm size (ha)	1.3	0.7	3.0	0.5
Livestock	14.2	8.99	43	2
Family size	7	1.9	11	3
Plot size (m^2)	1605	1594	10000	165

Most farmers grow wheat, tef or hanfets (see Figure 4).Figure 4 shows the use of fertilizer in the area. Most farmers use chemical fertilizer or manure. The chemical fertilizers used in this area are urea and dap. Urea is an inexpensive form of nitrogen fertilizer (IPNI, a). Dap is a fertilizer with Nitrogen and Phosphorus (IPNI, b). Most farmer use a combination of urea and dap. A lot of farmers add manure on their fields.

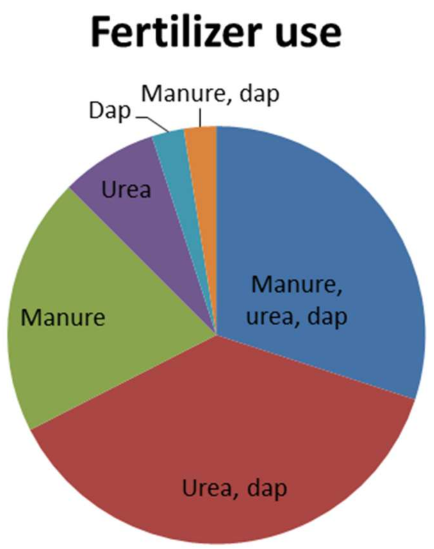

Figure 4 Use of fertilizer in the research area in 2013 (n=49). Total is amount of farmers that uses any fertilizer. Other groups show the amount of fields which uses this fertilizer.

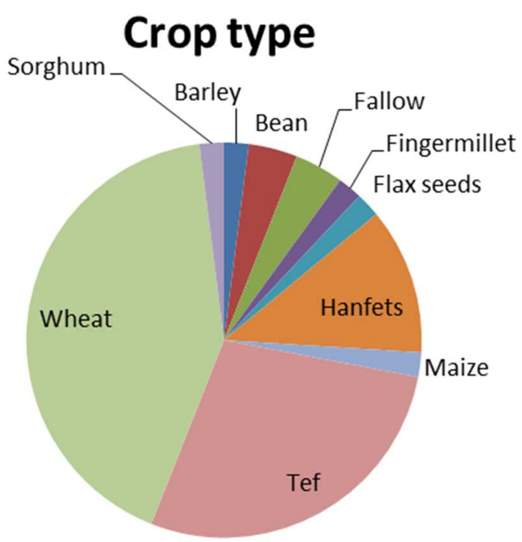

Figure 3 Different crop types in the area in 2013 (n=50)

The relationship between the management strategies and yield was studied using one-way ANOVA tests, but no significant relations between the management strategies and yield could be found (see Appendix, Table A2).

3.2. SOIL FERTILITY

Seven different soil types are found in the four different woredas (see Figure 5). Most of the locations are colluvial deposits, due to mass movements and erosion in the landscape. The main parent materials were basalt and sandstone, but also shale has been found. The soil texture is mainly clay in the area, but also loamy and sandy soil textures are found.

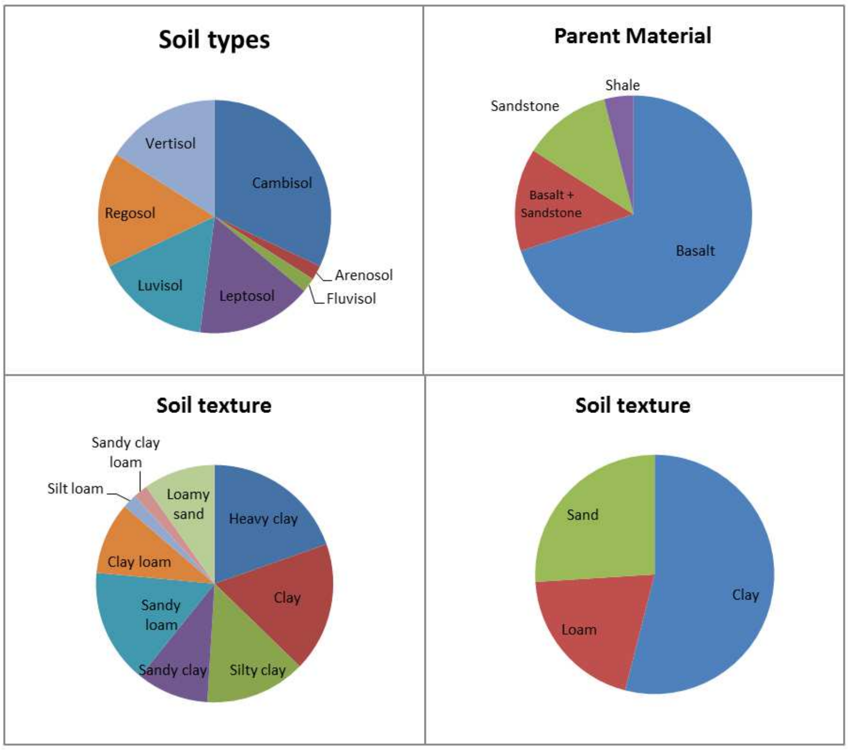

Figure 5 Overview of the different soil types, soil texture classes and parent materials found in the four woredas

During the fieldwork it became clear that the variability of soils in the area is high. Most soils have a plough layer in the upper 10-20cm of the profile. The stoniness of the field is in general high. Although the farmer fields are small, from the surface differences in colour, stoniness and soil texture were visible. Therefore in every field the soil type has been determined in the middle of the field.

In Table 4 the summary statistics of the measured soil fertility parameters are given. The nitrate and the organic matter content in most of the soils is low. Nitrate is also measured after the harvesting period and is therefore lower since the crops used the nutrients in the soil. The data show a clear significant relation (correlation=0.308, p=0.044) between organic matter and nitrate in the soil. N-total has significant correlations with K-exchange, OM and P-olsen, but remarkable not with nitrate.

Table 4 Summary statistics of soil fertility parameters

	Nitrate (mg/L)	OM (%)	pH	K-exch (mg/kg)	P-olsen (mg/kg)	N-total (mg/kg)
Mean	171	3,1	7,3	317	29	1151
St.dev	73,6	1,2	0,2	260,6	20,2	514,2
N	50	43	50	12	12	12

There is no significant correlation between soil fertility and yield. Only nitrate seems to have a significant negative correlation with the straw production ($p=0.037$). The number of observations for K-exch, P-olsen and N-total are limited ($n=5$), and therefore no reliable conclusion about the correlation can be given. The absence of a clear relationship between soil fertility and yield has probably to do with the fact that soil fertility is low in this area. Other influences like climate, parent material, diseases have probably more influence on the yield.

3.3. VARIABILITY BETWEEN REGIONS

3.3.1. FARM MANAGEMENT

Table 5 shows the differences in times weeding and ploughing between the woredas. It seems that the tillage is more intensive place in Inticho. In Edaga Arbi the tillage practices are less intensive. The one-way ANOVA does not show significant differences between the woredas (weeding p = 0.31, ploughing p = 0.27).

Table 5 Statistical data about the differences in management between the woredas (* Not enough observations points for statistics)

Weeding	EA	HS*	HW	IN
Mean	1.8	2.0	2.4	2.6
St. dev	0.8	-	1.8	1.5
Max	4	2	5	4
Min	1	2	0	1
N	33	2	8	5

Ploughing	EA	HS*	HW	IN
Mean	3.5	3.0	4.0	4.3
St. dev	1.0	-	1.0	0.6
Max	5.0	3.0	5.0	5.0
Min	1.0	3.0	3.0	4.0
N	30	2	8	5

To explore the differences between the different crop rotations, four main crop rotation groups have been made. The groups are:

- Tef-Hanfets
- Wheat-Hanfets
- Wheat-Tef
- Wheat-Hanfets-Tef

In Edaga Arbi mainly wheat, tef and some hanfets have been found in Hawzen it was mostly wheat and in Inticho there was a clear mix of wheat and tef. Table 6 shows the differences in crop rotation. The data of Inticho clearly show that mainly wheat and tef is grown within the crop rotation, but this includes only five experimental fields. In Edaga Arbi and Hawzen there is more variation in crops (e.g. finger millet, beans, maize). The wheat-tef crop rotation is the most intensive system.

Table 6 Differences in crop rotation. With the amount of different crops within five years and the use of the different crop types within a woreda. WH = wheat and hanfets, WT = wheat and tef, TH = tef and hanfets, WHT = wheat, hanfets and tef.

	WH	WT	TH	WHT	N
Edaga Arbi	19%	22%	25%	34%	34
Hagere Selam	50%	50%	0%	0%	3
Hawzen	14%	57%	0%	29%	8
Inticho	0%	100%	0%	0%	5

Data of properties which have influence or can explain the management strategies show also clear differences between the woredas. In Hawzen farmers have more livestock and larger families, but not necessarily a larger farm size. In Hagere Selam the number of livestock and family size are smallest. The differences are small, but there seems to be a relation between livestock and family size.

Table 7 Statistical summary of livestock, family size and farm size (Hagere Selam small amount of observations)

	EA	HS*	HW	IN
Livestock				
Mean	14.5	11.3	15.9	12.5
St. dev.	8.3	4.2	4.2	4.2
Max	19	17	43	17
Min	2	8	5	8
N	4	3	8	4
Family size				
Mean	6.5	6.3	7.6	6.8
St. dev.	0.6	2.3	1.8	2.9
Max	7	9	11	9
Min	6	5	5	3
N	4	3	8	4

	EA	HS*	HW	IN
Farm size				
Mean	5.9	5.3	5.1	5.1
St. dev.	2.9	3.1	3.3	2.3
Max	9	8	12	7
Min	2	2	2	3
N	4	3	8	4

Inticho uses most chemical fertilizer (see Figure 6), but not that much manure. In combination with the results of tillage practices which were also more intense in Inticho, it seems that farmers in Inticho manage their land more intensively. In Hawzen the number of livestock and family size was larger but less fertilizer was added to the fields. The ratio farm size and family size is an important factor to determine the management strategy.

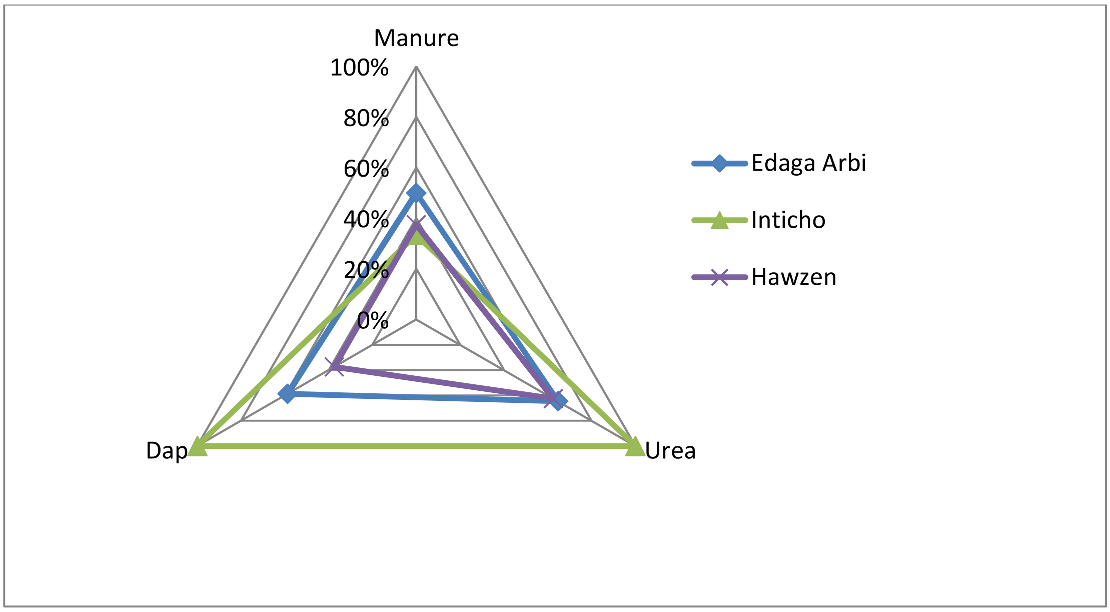

Figure 6 Percentages of amount of farms using type of fertilizer per woreda (Hagere Selam has been left out, since the amount of observations was low and the field were not representative)

3.3.2. SOIL FERTILITY

Differences between traditional management the differences in soils and soil fertility between the woredas are studied. Table 8 shows that there is no significant difference in yield between the woredas. Although the data of the produced seeds is not significant different (p=0.0733), the mean yields show differences.

Table 8 Yield data per woreda (*=not enough data available)

Woreda	Statistics	Yield interview (kg/ha)	produced seeds-dm kg/ha	produced straw-dm kg/ha
EA	Mean	2810.9	2202	2974
	St. dev.	2071.5	664	717
HS	Mean	NA*	2136	3102
	St. dev.		668	890
IN	Mean	NA*	1646	2497
	St. dev.		401	286
HW	Mean	NA*	1135	2855
	St. dev.		562	578
One-way ANOVA p-value		NA*	0.0733	0.3258

The landscape and genesis of the four woredas differ. Due to the differences in geology and geomorphology differences in soil types can be found (see Figure 7). In Inticho mainly luvisols developed in basalt have been found. In Edaga Arbi a wide variety of soil types is found (cambisols, luvisols, leptosols, regosols and vertisols). In Hagere Selam only three soil pits were made, it is therefore difficult to tell which soils are most common. In Hawzen mainly cambisols and a few regosols were found.

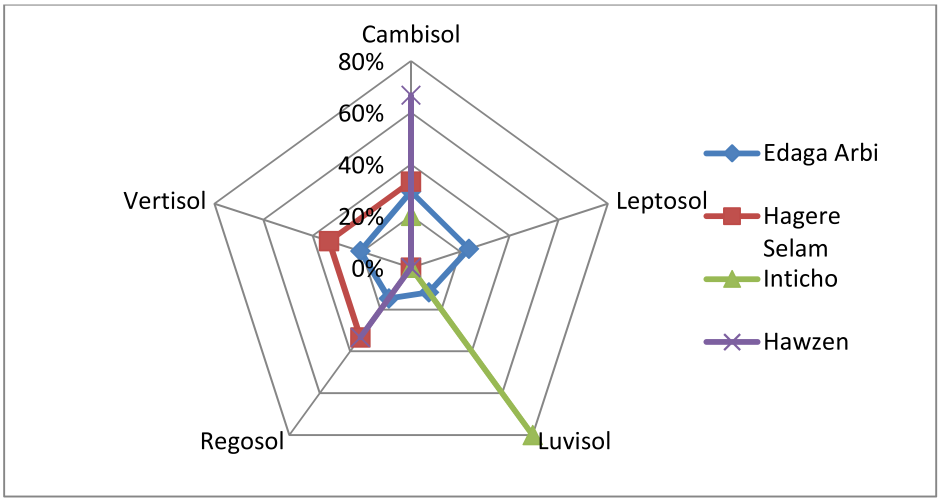

Figure 7 Percentage of soils found per woreda

Soil fertility within the four woredas seems to be differ, although the differences are not significant (see Table 9). In Hawzen en Hagere Selam the organic matter and the nitrate content are higher. In Inticho the soil fertility status is lower than the other three woredas. There is a significant difference in pH between the woredas. An explanation for this might be differences in parent material, climate and soil fertility status between the woredas. The combination of these influences might be an explanation to this difference.

Table 9 Soil fertility data per woreda (*= not enough data available, ** = field measurements)

Woreda		OM(%)**	Nitrate** (mg/kg)	pH**	K-exch (mg/kg)	P-olsen (mg/kg)	N-total (mg/kg)	OC lab (%)
EA	Mean	3.2	161	7.3	317.8	33.2	1190.0	3.2
	St. dev.	1.20	81.5	0.19	323.9	29.2	694.4	0.42
HS	Mean	4.0	196	6.9	234.9*	14.5*	1490.0*	4.3*
	St. dev.	0	9.4	0.05	-	-	-	-
IN	Mean	2.4	176	7.4	274.5	26.3	994.0	4.8*
	St. dev.	1.1	50.7	0.19	215.8	9.1	357.6	-
HW	Mean	4.0	212	7.1	463.6	37.3	1295.0	4.1*
	St. dev.	0	31.2	0.14	133.8	10.7	165	-
ANOVA test		0.176	0.476	0.000616	0.875	0.826	0.833	-

No conclusions about Hagere Selam can be given due to the small number of observations. Soil fertility seems to be higher in Hawzen and also here the intensity of management practices is higher. In Edaga Arbi the soil fertility seems to be lower and also the management practices are lower. The soil fertility status and the management practices in Inticho are intermediate, although soil fertility was higher than expected since there are a lot of clayey soils developed in basalt. In general it can be concluded that there is variability in management and soil fertility between the woredas, but a clear relationship cannot directly observed.

3.4. MANAGEMENT AND SOIL FERTILITY

Direct significant relations between yield and management strategies could not be found (see Appendix I). Ploughing and ploughing depth tend to have a trend towards significance with p = 0.079 with yield and p = 0.070 with produced straw. It is not strange that the relationship between management and yield is absent, since yield is influenced by many factors besides management.

A few relations between management strategies and soil fertility within the four woredas can be found although soil fertility and management do not differ significantly. Yields are highest in Hagere Selam and Edaga Arbi, but soil fertility is the highest in Hagere Selam. In Edaga Arbi the nutrient contents are low. The organic matter contents in Hagere Selam are higher due to a colder climate. In Hawzen the yield is lower than in the other woredas, but soil fertility is relatively high. In Hawzen the family size is relatively larger with more livestock. In Inticho the yield is relatively low. There are differences between management and soil fertility between the woredas, but clear relationships are absent. Management on a farm does not only depends on the soil, but also depends a lot of traditions and what available resources.

In order to analyse the differences five different management strategies and/or properties will be analysed on their effect on soil fertility.

3.4.1. FERTILIZER

Every soil type has his own unique chemical, physical and biological properties. Ethiopia has a blanket fertilizer recommendation to add around 100 kilograms of dap and urea per hectare (EATA, 2012). This amount is independent of the current situation of the soil. The most commonly used fertilizers are Urea and Dap and they are often combined with manure and/or compost. Soil samples were taken after the harvest. That means that most nitrate will have been used by the plant. Nitrate concentrations in the soil will therefore be relatively low.

Nutrient availability is an important factor for soil fertility. The optimal P:N ratio is different per soil type, but also soil types and past management determine when critical N : P thresholds are passed (van der Velde, 2014). The time and rate of application, weedings, the organic matter content, drainage, weather conditions, diseases and pest control plays all a role in the efficiency of fertilizer use. Together with the soil variability in soils in Ethiopia, a general recommendation for fertilizers is difficult Molla, 2013).

The fertilizer response of a soil will be described using nitrate and organic matter contents. Figure 8 shows the effect of different types of fertilization on yield, organic matter and nitrate. The boxplot does not show clear differences and also the groups are not significantly different (see Table 10). The dap/urea and manure applications counterintuitively show a reduction of yield. However, fertilizer use does also not affect nitrate concentrations, although manure seems to result in hight nitrate concentrations. Figure 8 shows the differences in organic matter. Also here no clear significant differences between adding the fertilizer or not and the effect on the organic matter content is found.

Type of fertilizer	Yield p-value	Nitrate p-value	OM p-value
Total	0.703	0.068	0.402
Manure	0.199	0.199	0.705
Dap	0.568	0.078	0.095
Urea	0.321	0.081	0.105

Table 10 P-values of the ANOVA-test for the use of fertilizer and the effect on yield, nitrate and organic matter. Difference between added to a field and not added is significant if p<0.05.

Figure 8 shows the differences between manure, dap and urea. There is clearly no significant difference in organic matter content between the different types of fertilizers (p=0.880). Also nitrate (p=487) and yield (p=0.538) show no significant differences.

Although the differences are not significant, some differences can be seen in the graph, like the higher nitrate contents when only manure is used. Interesting is that if fields with or without adding chemical fertilizer are compared, less nitrate is found in the soil. Probably this can be explained by the sampling after the harvest, so therefore it can be expected that the crop used the nutrients in the soil. The effect of manure is of course also a long-term effect and cannot directly been seen within one year.

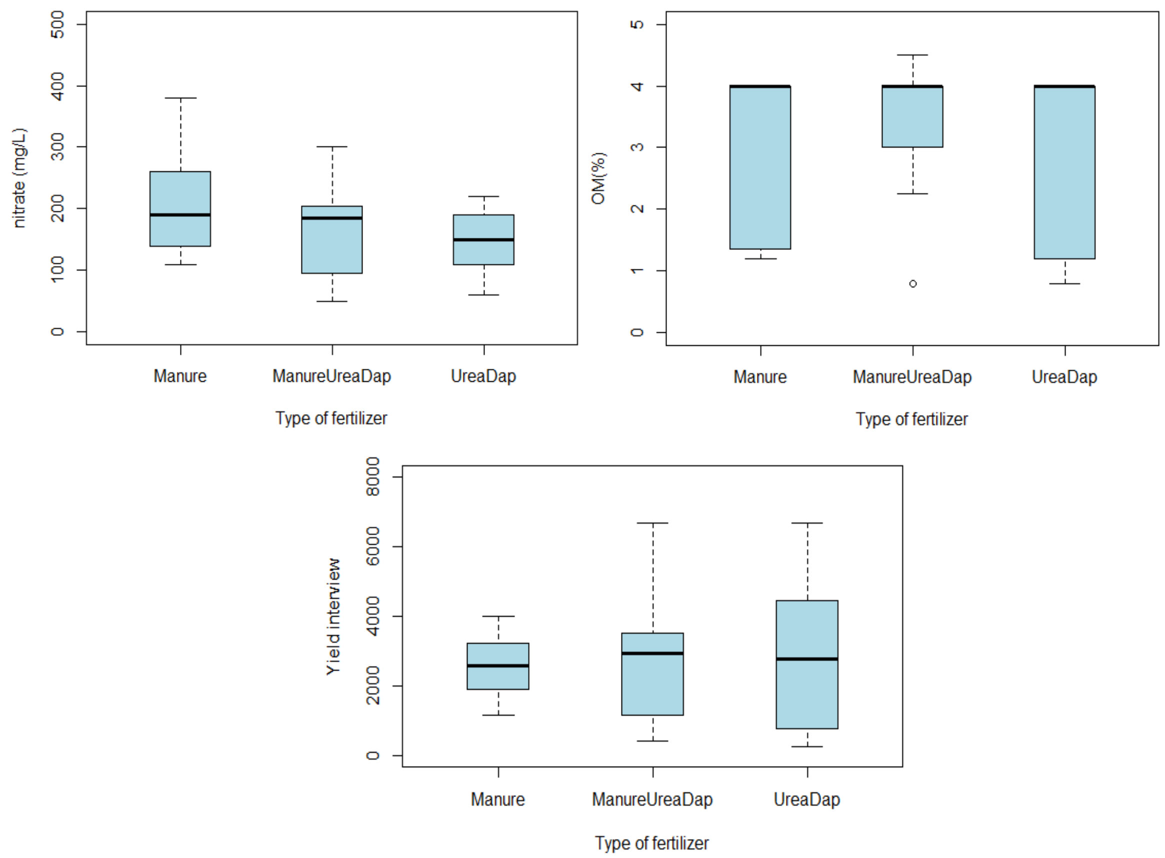

Figure 8 Type of fertilizer and the organic matter content (right above), nitrate content (left above) and yield (below)

Farmers do not use much fertilizer. The margins are small due to the small farm sizes. After a good year farmers will have the resources to purchase chemical fertilizers. However, after a bad year the farmers cannot buy fertilizers. So the choice to use a fertilizers is not only based on soil properties and crop requirements. Fertilizer management is mainly focussed on short-term thinking. Farmers have only been asked if they added the type of fertilizer not how much. Therefore, it is unclear how much fertilizer was been added on the fields by the farmer and it also not known when the fertilizer has been applied to the field. This could have given more information about the effects on soil fertility.

3.4.2. DISTANCE HOMESTEAD

Farm management strategies are selective and strategic. More manure is applied to fields closer to homestead, the fields with a deeper soil and fields that are owned by the farmer, rather than the fields which are leased (Beyene, 2001). Soil fertility is expected to be higher due to the higher nutrient inputs. An important role plays also the accessibility of the fields. The research of Tittonell et al. (2013) shows that soil fertility indicators decreased significantly with increasing distance from the homesteads within fields in Kenya and Uganda.

Figure 9 shows yield over distance to homestead. Most points have been taken closer to the farm. The relation between distance homestead and yield cannot be found. No significant correlation can be found and also the regression is weak. Although an interesting effect can be seen that closer to the homestead high and low values of nitrate can be found, but further away only low values were found.

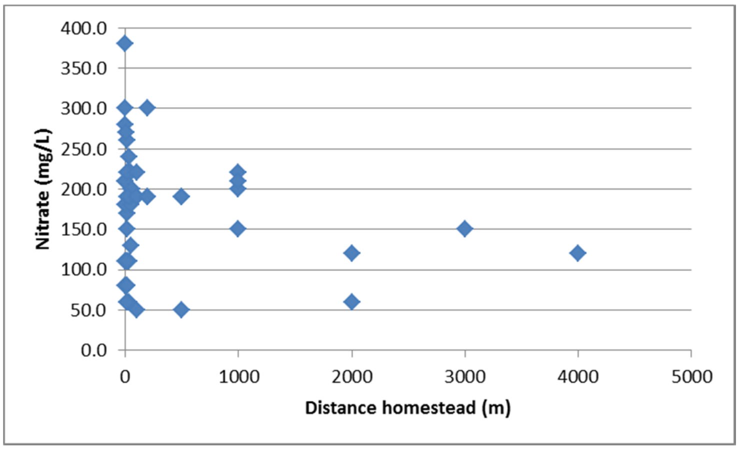

Figure 9 Nitrate content and the distance of the field to homestead.

The correlation between the distance to the homestead and soil fertility is presented in Table 11. In the case of nitrate concentrations an expected negative correlation is found, while for the OM and pH the correlation is positive. Also in the case of soil fertility no significant relation between the soil fertility parameters and distance homestead could be found. There seems to be a trend to significance with the organic carbon measured in the laboratory, but the amount of observations is really low.

Table 11 Correlation and regression coefficients between distance homestead and nitrate, pH, OM

		Nitrate (mg/L)	pH	OC lab (%)	OM (%)
Distance homestead	Correlation	-,187	,237	-,864	,054
	Sig. (2-t)	,199	,102	,059	,735
	R^2	0.035	0.056	0.747	0.003
	N	49	49	5	42

The distance to the homestead is arbitrarily subdivided into two classes . Fields within 1 km are considered to be close, whereas far is more than 1 km. Table 12 shows the results of the t-test analysis.

Table 12 Distance homestead in two classes and the effect on nitrate and organic matter. The differences are analysed with a t-test.

		Sig (2-tailed)	Mean	St. dev.
Nitrate (mg/L)	**Close**	0.534	159	20.1
	Far		187	19.8
OM	**Close**	0.280	3,00	0.464
	Far		2.89	0.497
pH	**Close**	0.859	7.2	0.22
	Far		7.3	0.25

The nitrate concentration or organic matter and the distance homestead are not significantly different. The mean shows even an higher nitrate value further away from homestead, although this difference is not significant (p=0.05). Probably this has to do with the fact that nitrate was measured after the harvest. Similarly no clear relationships between the distance to homestead and nitrate or organic matter contents (p=0.904).. In almost all cases fertilizer has been used, chemical and manure. It was expected that fields nearby the house would gain more attention from the farmer, but the relations does not show the differences.

A logical explanation might be that there are too many other effects than the distance to homestead including soil type, crop type, and differences in farming. Soil variability is particularly large, but even within the same soil type or crop, no effect has been found. How the fields are located to the farm depends also on the region and the landscape and also about the accessibility of the field from the homestead.

3.4.3. PLOUGHING

Farmers plough their field to incorporate plant residues and weeds in the soil. In the Tigray region farmers use oxen to plough their field. A well-endowed farmer is able to plough the fields more often. Ploughing improves the germination and rootability of the soil.. Nutrient availability also increases due to ploughing. Ploughing results in the mineralization of organic matter and therefore also in a decrease of the soil structure. Nyssen et al. (2010) describe ploughing practices in Ethiopia. Farmers use mainly the traditional, labour intensive ox-drawn ard plough. The farmers aim to increase water availability and yield and reduce soil loss. Farmers can plough 0.25 ha/day. The research of Habtegebrial (2007) shows that minimum tillage could benefit soil and moisture conservations and reduce costs for resource poor farmers in Ethiopia without significantly yield effect. Therefore it is interesting to know if also in Ethiopia ploughing result in a decrease of soil structure and that it will decrease soil fertility. Also the soil structure is affected by ploughing. Soil structure can be significantly modified through management practices and environmental changes. Practices that increase productivity and decrease soil disruption enhance aggregation and structural development (Bronick & Lal, 2005).

Table 13 and

Table 14 show the results of ANOVA test of times ploughing against different soil properties. No significant relation between the soil fertility parameters and times ploughing could be found. Therefore the absence of a relationship is therefore not strange. Also no significant relation between ploughing depth and the parameters have been found.

Table 13 ANOVA test of the effect of the number of times ploughing on soil fertility

	Sig. (2-tailed)
OM	0.187
Nitrate	0.873
pH	0.815
Structure grade	0.695

Structure size	0.594

Table 14 Effect of times ploughing on soil fertility

	Times ploughing	Sig (2-tailed)	Mean	St. dev.
pH	≤3	0.059	7.23	0.1955
	>3		7.35	0.2478
Nitrate	≤3	0.549	165.3	70.39
	>3		178.8	82.23
OM	≤3	0.123	3.3	1.19
	>3		2.7	1.26
Soil structure grade (1-3)	≤3	0.800	1.7	0.70
	>3		1.8	0.79
Soil structure size (1-5)	≤3	0.590	1.9	0.89
	>3		2.0	0.59

It was expected that more ploughing would lead to a decrease in soil structure and soil fertility. Most farmers plough their fields 2-5 times a year, but no significant difference has been found between farmers who plough less and farmers which plough more. Also differences in ploughing depth does not effect soil fertility and yield.

It can be conclude that also ploughing is not the main driving factor behindsoil fertility differences. Soil structure is probably more influenced by soil texture and other soil properties. The organic matter content and the nutrient level is already really low, so therefore the influence of ploughing is minimal. It is also questionable if more ploughing is better. The organic matter content and nitrate are lower with more ploughing. Although the difference is not significant, it implicates that too much ploughing leads to more decomposition of organic matter.

3.4.4. CROP ROTATION

During crop rotation different crops are cultivated in a recurring, defined sequence. Soil management controls the nutrients availability to to crops and subsequently to livestock and supressing weeds, pests and diseases. Accumulation of organic matter plays a major direct role in soil structure formation. A better crop rotation system results in higher organic matter content and higher nitrate. The pH of the soil will be lower. According to Palm (2013) crop rotations have less effect on soil C than tillage, but still can affect the organic matter content by increased biomass production. Different crops in the system can have an effect on pest cycles, diversifying rooting patterns and rooting depth (Palm, 2013). Since the soil fertility is low, these effects of crop rotations may have a large impact in the highlands of Ethiopia.

To explore the differences between the different crop rotations, four main crop rotations have been identified. Most crop rotations in the area include an additional crop (maize, bean, finger millet, etc.). Since this is very variable, this extra crop is not included in the description. The following four main groups are distinguished:

- Tef-Hanfets (TH)
- Wheat-Hanfets (WH)
- Wheat-Tef (WT)
- Wheat-Hanfets-Tef (WHT)

A crop rotation system with only wheat and tef is the most intensive system. Figure 10 provides the differences between the number of different crops for a five year period. The yield is higher with four different crops per five years, while the organic matter content seems to be lower. The nitrate levels are already low since it is after the harvest, so therefore the relationship is absent in the graph.

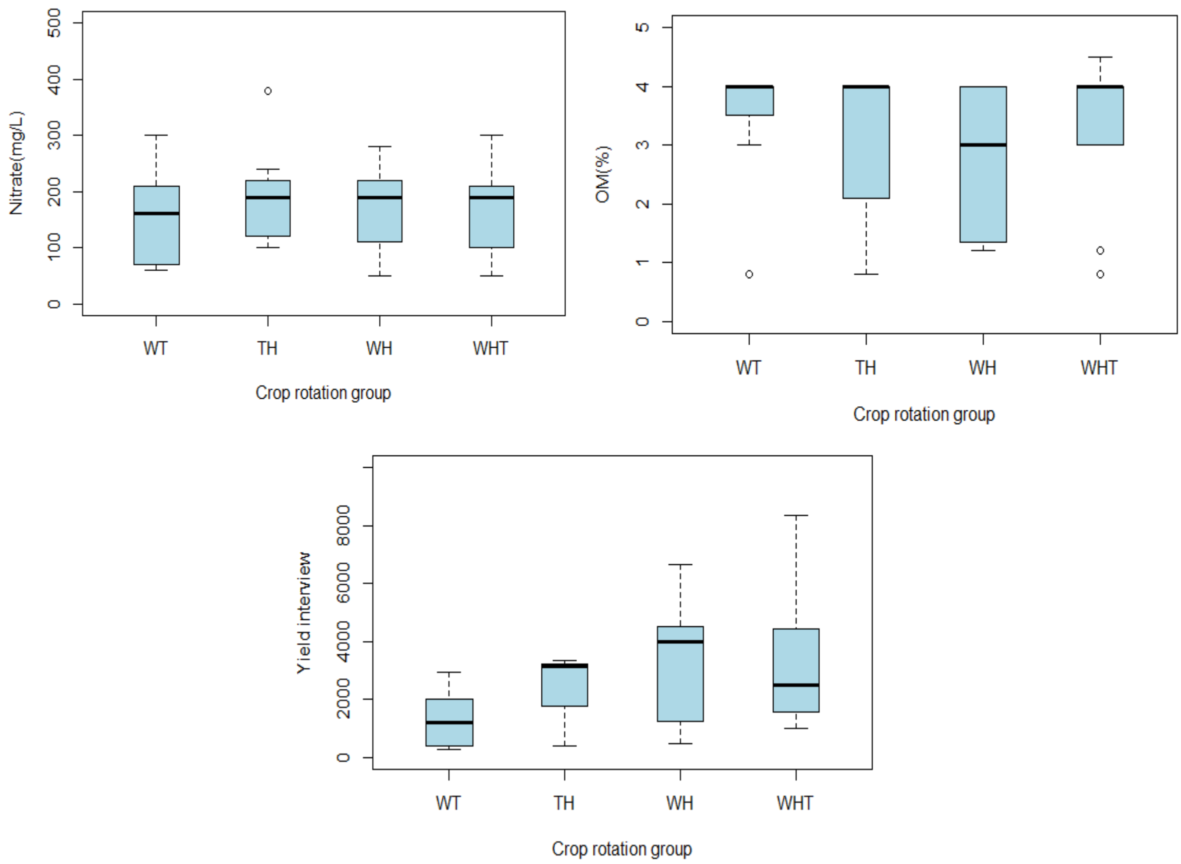

Figure 10 Different crop rotation groups per five years against nitrate (left above), organic matter (right above) and yield (below)

Table 15 shows the statistical analysis of the nitrate level for all the crop rotations.

Table 16 shows the differences in organic matter content for the crop rotation groups. The ANOVA test gives no significant differences between the groups. The group with only wheat and tef is low in organic matter and in nitrate. It is logical that that yield gives differences, since in general the yield is much lower for tef. Still it is interesting to see that there seems to be a difference between the wheat-tef group and the hanfets-tef.

Table 15 Different crop rotations and the nitrate level per crop rotation group including the ANOVA test

	Mean	St. dev.	Sig (2-tailed)
Tef-Hanfets	155	85.4	0.804
Wheat-Hanfets	193	90.0	
Wheat-Tef	166	72.6	
Wheat-Hanfets-Tef	170	72.9	

Table 16 Different crop rotations and the organic matter content per crop rotation group including the ANOVA test

	Mean	St. dev.	Sig (2-tailed)
Tef-Hanfets	3.40	1.21	0.5598
Wheat-Hanfets	3.00	1.42	
Wheat-Tef	2.77	1.24	
Wheat-Hanfets-Tef	3.42	1.152	

Crop rotations do not have a significant influence on soil fertility. Crop rotations are very different between farmers, but the influence on soil fertility and yield is unclear. The reason why a farmer chooses a crop depends not on the situation of the soil, but also on the availability of a certain seed, the market price of the crop and traditional management s play a role. Interesting to see is that only two farmers of the group of 50 farmers used once in the five years a fallow period. Fallow is important to restore the soil. Mainly in regions like this, where the soil fertility is already very low.

3.4.5. LIVESTOCK

Grazing land is scare in Ethiopia and the total area of land per family is small. In general sub-Saharan Africa shows a positve correlation between the number of livestock on a farm and farm size (Nabhan, H. (2001). Grazing areas even becoming more scare due to the increasing number of exclosures. The intensification of grazing often results in land degradation, mainly soil erosion. (Mwendera et al., 1997). Livestock can contribute up to 70% of the livelihood of an Ethiopian family (GebreMariam, 2010). Farmers collect manure and bring it back on the field, which could result in an increase of the organic matter in the field. Secondly the amount of livestock and wealth (here: area of land) are correlated resulting in easier access to chemical fertilizers. It is expected that more livestock increases organic matter in the soil and therefore increases soil fertility.

Table 17 and

Table 18 shows the correlations between livestock and the different soil fertility parameters and yield. However, the correlations are not significant.. Livestock and farm size are correlated. Earlier no relationship with manure was found, so it is not surpirising that no relationship between soil fertility and livestock is found.

Table 17 Correlation of livestock with yield (* = not enough data)

		Yield interview (kg/ha)	Produced seeds dry matter kg/ha	Produced straw dry matter kg/ha
Livestock	Correlation	NA*	-,166	,406
	Sig. (2-t)	NA*	,625	,215
	N		14	14

Table 18 Correlation of livestock with soil fertility parameters

		OM (%)	Nitrate (mg/L)	pH	K-exch (mg/kg)	P-olsen (mg/kg)	N-total (mg/kg)
Livestock	Correlation	,193	-,198	,303	-,230	-,021	-,640
	Sig. (2-t)	,491	,416	,207	,552	,957	,064
	N	15	19	19	9	9	9

The absence of a relationship might also have something to do with the fact that there are a lot more influencers which contributes to the amount of livestock and to soil fertility. Concluded can then be that livestock is not one of the most important influencers of soil fertility.

3.5. SYNTHESIS

The analysis of soil management showed a large variability in strategies. Ploughing intensity and weeding vary significantly. A direct relationship between the labour intensity and family size, livestock and/or farm size has not been found. What causes the differences management strategies? Management strategies are based on soil fertility and resource availability. According Corbeels et al. (2000) topography, soil depth and water holding capacity plays an important role in the management strategies of farmers in Ethiopia. But also tradition, family size, livestock and farm size play a role in farmers' choices.

The soil fertility parameters showed a large variability. Nitrate and organic matter concentrations have mainly been used as indicators of the influence of management on soil fertility. In general the organic matter content is low (±3%), the nitrate content is low (±171 mg/L) and the pH is in all four regions around 7. The differences are general caused by geology and geomorphology, but also the human influence is important. The role of management is complex, due to a lot of variability in soils and all different influences. During the fieldwork it became already clear that soil variability in the area is significant. Even within one field soil properties like texture and colour varied considerably. The problem was that there was and is very little known about the soils, geology and geomorphology of the area. The expected variability of the soils and the soil properties was therefore also unknown. Experimental fields with the same catena position and with the same parent material have been used in order to try to deal with the variability and that the variability of the area would influence the results too much. Due to the unclear and large variability in this area it is difficult to find significant relations between soil fertility and management. The area is almost completely terraced and the area has been used for hundreds or thousands of years for intensively agriculture. Due to a delayed harvested not all the 16 fields of this year could been sampled and also two fields per experimental fields could been sampled. From 14 of the in total 25 fields samples in the end there was no laboratory data available. More data would improve the significance and the reliability of the data, but it will not directly give more information about the relations between soils, management and soil fertility in the area.

There are differences between the woredas in types of management and there are differences in yield and soil fertility. An overall relationship is not found, although the data shows some differences mainly related to soil fertility. Between the woredas there are differences in adding chemical fertilizer or not. there are clear differences in geomorphology and soils between the woredas. Therefore also differences in soil fertility was expected and the research shows also that the differences are there. The differences in management and soil fertility gave no clear overview why there are differences and what the effect of management on soil fertility is.

None of the five hypotheses showed clear evidence that management has an effect on soil fertility. The reason for this might be that other inherent variables need to be included to understand the relationship between management and soil fertility. Also the lack of observations might be a reason for the absence of relationships. Human influence (e.g. tradition, wealth) plays a role in choices made by farmers. These choices are not directly related to soil fertility, so therefore this makes the relationship more complex. In other words it is important to understand how a farmer decides on the management strategy for a certain field? Why does the farmer grows a certain crop and why does he uses this fertilizer. You also have to take into account that farmers deal with problems for example small farms and small fields and land erosion. Farmers make chooses based on traditions and which seeds are available. Since farmers are poor, farmers do not always choose crop which is the best for long term soil quality, but only on which seeds are available. The same holds for fertilizer use. Farmers do not always decide how much fertilizer is needed, but more what they can effort.

How you can study the influence of soil management on soil fertility and how you can give the farmer management recommendations? This research focused on differences between woredas and tried to focus on sampling points at comparable soil typed. Sampling was insufficient to deal with soil and management variability in the region. The differences within soil types are mainly caused by human influence. Therefore, it is difficult to find the effect of management within the region, since comparing the different groups is impossible. Comparing the woredas gave better results, because it showed some understandable differences between management and soil fertility. But how to sample in an area where the variation in soils is not caused by the geology and the geomorphology and also not by pure management and you still want to know what to know what the influence of management is in the area? It might be useful to not only think about the position in the landscape in a landscape which is much influenced by humans and by erosion, the variability in the landscape cannot only be explained by soil forming factors, but you have to take into account the other influences of changes in soil and soil fertility. Most important is that location with expected extremes in management and/or soil fertility will be chosen. This makes it easier to find relationships and it would be easier to compare the management strategies and the effect of it on soil fertility.

4. CONCLUSIONS

The research does not show the relationship between management strategies and soil fertility. The reason for this might be a lack of observations, but also the complexity of the system. Since crop productivity and soil fertility is marginal, it is important for to improve the yield in order to improve their livelihood and their food security, but farmers does not have much possibility to improve their management practices. Farmers do not only decided to use a certain management strategy to improve their crop productivity or soil fertility, but mainly what is available and what they can afford. The regions in this research differ a lot in soils, due to differences in geology and geomorphology. Differences in traditional management and the influences of NGO's and government play also an important role. This research shows that the system is complex. There is a lot of variability in soils and soil fertility and management strategies are not only influenced by the soil. Therefore it is important to keep in mind that recommendations for management strategies (e.g. amount of fertilizer which have to be added to the field) is complicated and therefore general management recommendations are not advisable. In areas like this with a lot of variability in soils, but also with a lot of different management strategies, management recommendations should be given on a smaller scale, for example per farm, landscape position or soil type.

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APPENDIX I

Table A1 Results of the analysis between soil fertility parameters and yield.

		Yield_int	produced seeds-dm kg/ha	produced straw-dm kg/ha
OM_ top	Pearson Correlation	,298	,262	-,010
	R^2	0.051	-0.111	-0.035
	Sig. (2-tailed)	,139	,437	,977
	N	26	11	11
Nitrate (mg/L)	Pearson Correlation	-,079	,016	,562*
	R^2	0.006	0.258	-0.083
	Sig. (2-tailed)	,689	,956	,037
	N	28	14	14
pH	Pearson Correlation	,163	,213	-,339
	R^2	-0.011	0.041	-0.034
	Sig. (2-tailed)	,407	,465	,236
	N	28	14	14
K-exch (mg/kg)	Pearson Correlation	NA	-,595	-,089
	R^2		-0.139	-0.323
	Sig. (2-tailed)		,290	,887
	N		5	5
P-olsen (mg/kg)	Pearson Correlation	NA	-,475	-,024
	R^2		-0.333	-0.033
	Sig. (2-tailed)		,419	,970
	N		5	5
N-total (mg/kg)	Pearson Correlation	NA	-,457	-,739
	R^2		-0.054	0.395
	Sig. (2-tailed)		,439	,154
	N		5	5

Table A2 One-way ANOVA test results of the differences within management strategies on the yield (properties with * are tested using a correlation, **=Not enough data)

	Sig 2-t Yield_int	Sig 2-t Straw produced	Sig 2-t Seeds produced
Chemical fertilizer (y/n)	0.763	0.955	0.279
Dap (y/n)	0.101	0.797	0.680
Urea (y/n)	0.845	0.913	0.681
Manure (y/n)	0.305	0.955	0.279
Ploughing (≤3, >3)	0.309	0.791	0.070
Ploughing depth*	0.690	0.212	0.912
Distance homestead (m)(	0.721	0.244	0.705
Distance homestead (far/close)	0.284	0.617	0.094
Crop rotation (TH/WH/WT/WHT)	0.277	0.837	0.908
Livestock*	**	0.215	0.625

Table A3 Statistical analysis of the correlation between the different soil fertility parameters.

Correlations							
		Nitrate (mg/L)	OM	pH	P-olsen (mg/kg)	K-exch (mg/kg)	N-total (mg/kg)
Nitrate (mg/L)	Pearson cor	1	,308*	-,275	-,346	-,146	-,128
	Sig. (2-t)		,044	,054	,270	,652	,693
	N	50	43	50	12	12	12
OM (%)	Pearson cor	,308*	1	-,043	-,639*	-,690*	-,727*
	Sig. (2-t)	,044		,782	,047	,027	,017
	N	43	43	43	10	10	10
pH	Pearson cor	-,275	-,043	1	-,288	-,263	-,418
	Sig. (2-t)	,054	,782		,364	,408	,177
	N	50	43	50	12	12	12
P-olsen (mg/kg)	Pearson cor	-,346	-,639*	-,288	1	,875**	,701*
	Sig. (2-t)	,270	,047	,364		,000	,011
	N	12	10	12	12	12	12
K-exch (mg/kg)	Pearson cor	-,146	-,690*	-,263	,875**	1	,721**
	Sig. (2-t)	,652	,027	,408	,000		,008
	N	12	10	12	12	12	12
N-total (mg/kg)	Pearson cor	-,128	-,727*	-,418	,701*	,721**	1
	Sig. (2-t)	,693	,017	,177	,011	,008	
	N	12	10	12	12	12	12
*. Correlation is significant at the 0.05 level (2-tailed).							
**. Correlation is significant at the 0.01 level (2-tailed).							