Soil heterogeneity in smallholder African landscapes

A literature review of Sub Saharan Africa and a case study from Burkina Faso

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Period: March 2014 – June 2014

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Abstract

Around African smallholder landscapes various patterns in soil heterogeneity can be found. This is the result from the interaction between indigenous soil fertility and historical and current farm management. In various African farming systems a decrease in soil fertility is found with an increased distance from the homestead. Across African farm landscapes, four major patterns in soil heterogeneity have been described: (i) continuous gradients, (ii) discrete gradients, (iii) discontinuous gradients and (iv) inverse gradients. The spatial distribution ranges most commonly from home fields to remote fields of which the specific distribution is region (e.g. east Africa vs Sudan Savannah zone) and country specific. Soil fertility patterns are also found related to the soilscape, e.g. different positions along the toposequence. The patterns in soil heterogeneity influence crop performance and productivity. Also nutrient capture and nutrient use efficiency are influenced by soil variability. Resource allocation divers widely on soils within the soil fertility pattern, regarding manure input, labour and type of crop. High tech tools for precision agriculture are not available in African smallholder landscapes and farmers use local knowledge and soil quality indicators to define the higher fertile soils. A context specific form of precision agriculture is urgently needed to manage soil heterogeneity in SSA. In order to give recommendations on soil fertility problems, soil fertility patterns need to be defined. An understanding of farmers' perceptions, knowledge and management of soil fertility is essential.

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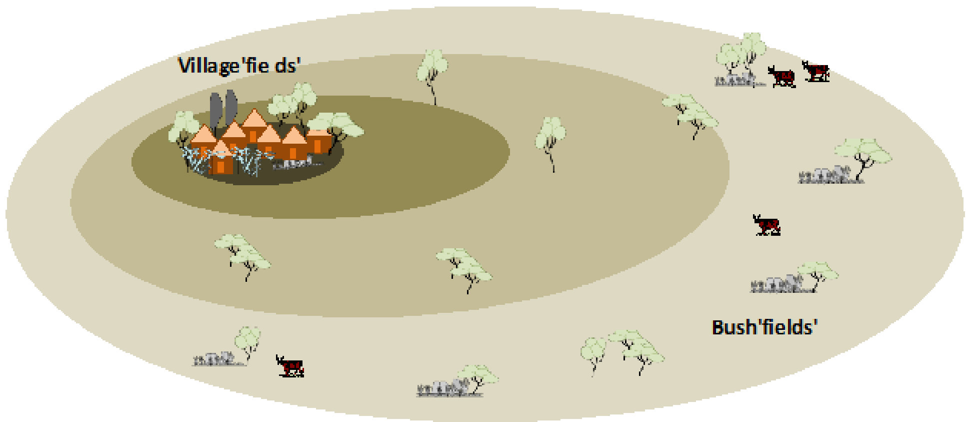
1. Introduction

Background

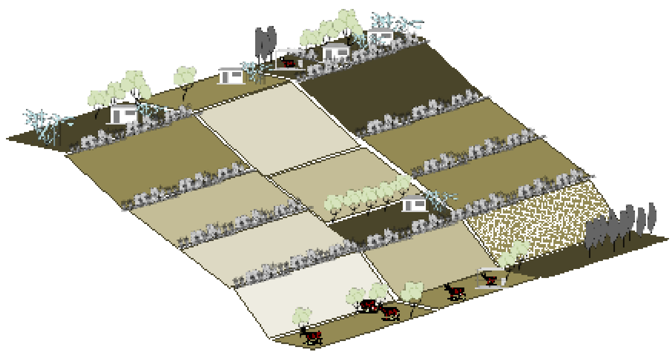
Within smallholder agro ecosystems in Sub Saharan Africa heterogeneity in soil fertility is found due to the interaction of indigenous soil fertility (geomorphology) and historical and current farm management (e.g. access and allocation of resources) of which the latter might vary between wealthy and poor farmers (Murage *et al.* 2000; Tittonell *et al.* 2005a; Tittonell *et al.* 2005b; Rowe *et al.* 2006; Wopereis *et al.* 2006; Zingore *et al.* 2006; Ebanyat 2009; Tittonell *et al.* 2010).

To give an introduction on soil fertility patterns, this section will explore soil heterogeneity based on three different spatial scales: between countries, between farms (within region) and within farm (between fields). The latter two scales are explored by the use of a case study from Western Kenya. In various African farming systems a decrease in soil fertility is found with an increased distance from the homestead. The spatial distribution ranges from home fields to remote fields of which the specific distribution is region (e.g. east Africa vs Sudan Savannah zone) and country specific. The fields closer to the homestead are in nearly any case more fertile and the remote fields show less fertile soils (Tittonell *et al.* 2005b). Figure 1 illustrates four spatial distributions of soil fertility gradients at farm scale ranging from homestead to remote fields.

A) Continuous gradient



B) Discrete gradient



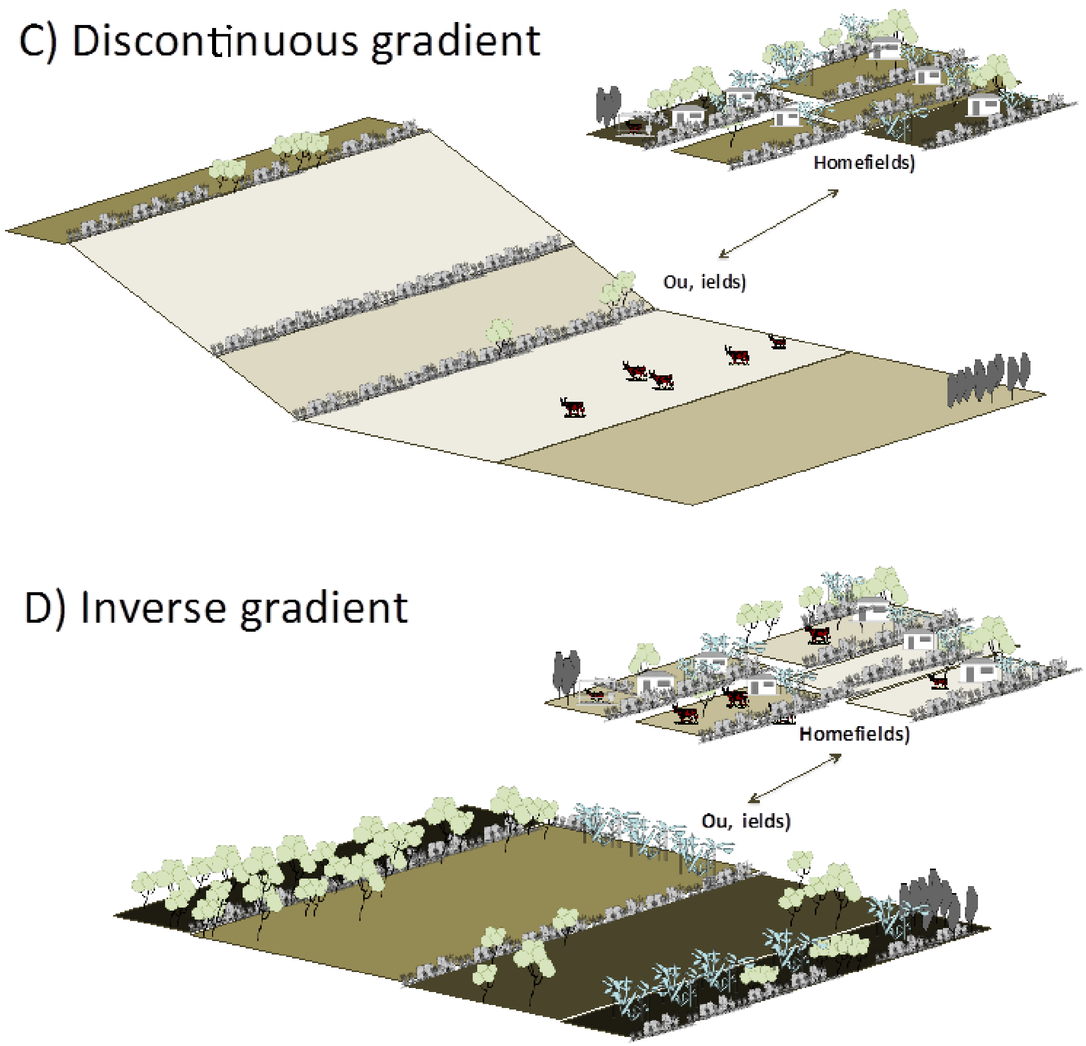


Figure 1. Examples of four different heterogeneous farming systems from SSA. ***Source: Pablo Titonell (2014)***

The four examples illustrate widely different on-farm soil heterogeneity patterns for different African case studies. Various case study examples can be found in literature. For instance, a homestead in Burkina Faso is situated in the middle of the farm encircled by the farm fields (Prudencio (1993)). The homestead in a Kenyian case study is positioned in the upper part of the farm (Tittonell et al. (2005b)). Next to the homegarden the bordering close fields, mid-distance fields and remote fields are located. A third example demonstrates a Zimbabwean farm showing two field compounds, homefields and outfields, located far apart (Masvaya et al. (2011)).

The second spatial scale focusses on different patterns of soil heterogeneity between farms within the same country/region. Figure 2 shows 5 different farm types, based on wealth class, within a region in Western Kenya (based on (Tittonell *et al.* 2005a)). The illustration provides an overview of average management strategies taking place within each of the farm types, causing soil heterogeneity within the region. This figure does not show exact data of soil heterogeneity between the different farm types, the diagrams rather give an idea about different farmer management strategies influencing between farm soil heterogeneity. These management strategies are about resource endowment as well as strategies towards market orientation, production of cash crops and labour division (off farm activities or on farm activities only). Each farm is assessed on its size, mineral and organic fertilizer use, livestock, % income from farming, labour availability and total food production. The farms are rated by including 1, 2 or 3 pictograms within the farm borders indicating the relative quantity of resources and capital available within the specific farm type. As some farmers lack financial capital and resources and might have low access to markets they cannot afford fertilizer and they might not be able to add fertilizer to each field of the farm. On the other hand a farm could be land (type 5) or labour limiting (type 1), affecting farm management strategies such as fertilizer use as well.

The farming system typology is based on wealth class and production orientation. Most farms of type 1 and type 2 belong to the wealthiest farm class. Yet farm type 1 gains a relative low percentage of income from farming and earns a fixed salary or income outside the farm. Resulting in low labour availability and low total production. Type 2 has high resource endowment and the focus is on production of cash crops. As this farm type represent a relative high wealthy class these farmers are able to hire additional labour. The farms of type 2 and type 3 have in general the largest areas under cultivation. Farm type 3 include smaller farms with lower resource endowment compared to type 2. The total food production is quite high as well is their % income from farming. As they lack financial capital, input-demanding activities are not widely applied in this farming system. The least wealthy farm types are type 4 and poorest type 5. Wherein type 4 livestock keeping is seen as a relative high labour demanding job. Some additional income is gained by extra services. Farm type 5 has high labour availability and hire labour to other farms, but is limited in land availability (Tittonell *et al.* 2005a).

An extra level of detail is added to take a deeper look at on farm soil heterogeneity, including farm management strategies resulting from and affecting soil fertility gradients. Based on the research of Tittonell *et al.* (2005b) from Western Kenya (farm type 3) exploring on-farm soil heterogeneity, Figure 3 has been developed. This diagram gives and overview of the fields located in relation to the homestead, the total N inputs, mineral and organic fertilizer use and total production. Four field types are distinguished: home garden, close fields, mid-distance fields and remote fields. Each field type is assessed on the above mentioned criteria and the relative outcome is shown by pictograms within each field. The smaller the pictogram, the lower the quantity of the input/output. Management strategies can be easily related to the soil fertility status of the different field types. A soil fertility gradient is seen from the home garden and close fields (high) towards the remote fields (low) (Tittonell *et al.* 2005a; Tittonell *et al.* 2005b; Zingore *et al.* 2006).

As Mowo *et al.* (2006) stated not all farmers, especially not the younger ones, are able to afford fertilizer transportation to remote fields. To apply manure or mineral fertilizer is easier as well on the close fields compare to remote fields. In addition, according to Zingore *et al.* (2006) the increase of on farm soil fertility gradients (from homestead to remote fields) only happened since 15 years as the fertilizer process increased and farmers were not able to afford fertilizer to apply on the whole farm. Another reason for a farmer to apply a higher quantity of fertilizer on close fields compare to remote fields has to do with risk management. The cultivation of cash crops provide farmers with some source of income. Hence, as a farm management strategy most of the available fertilizer and labour will be applied on the cash crops. In the fields around the homestead the level of theft is lower and therefore the main crops are grown in the fields around the homestead (Maroyi 2009).

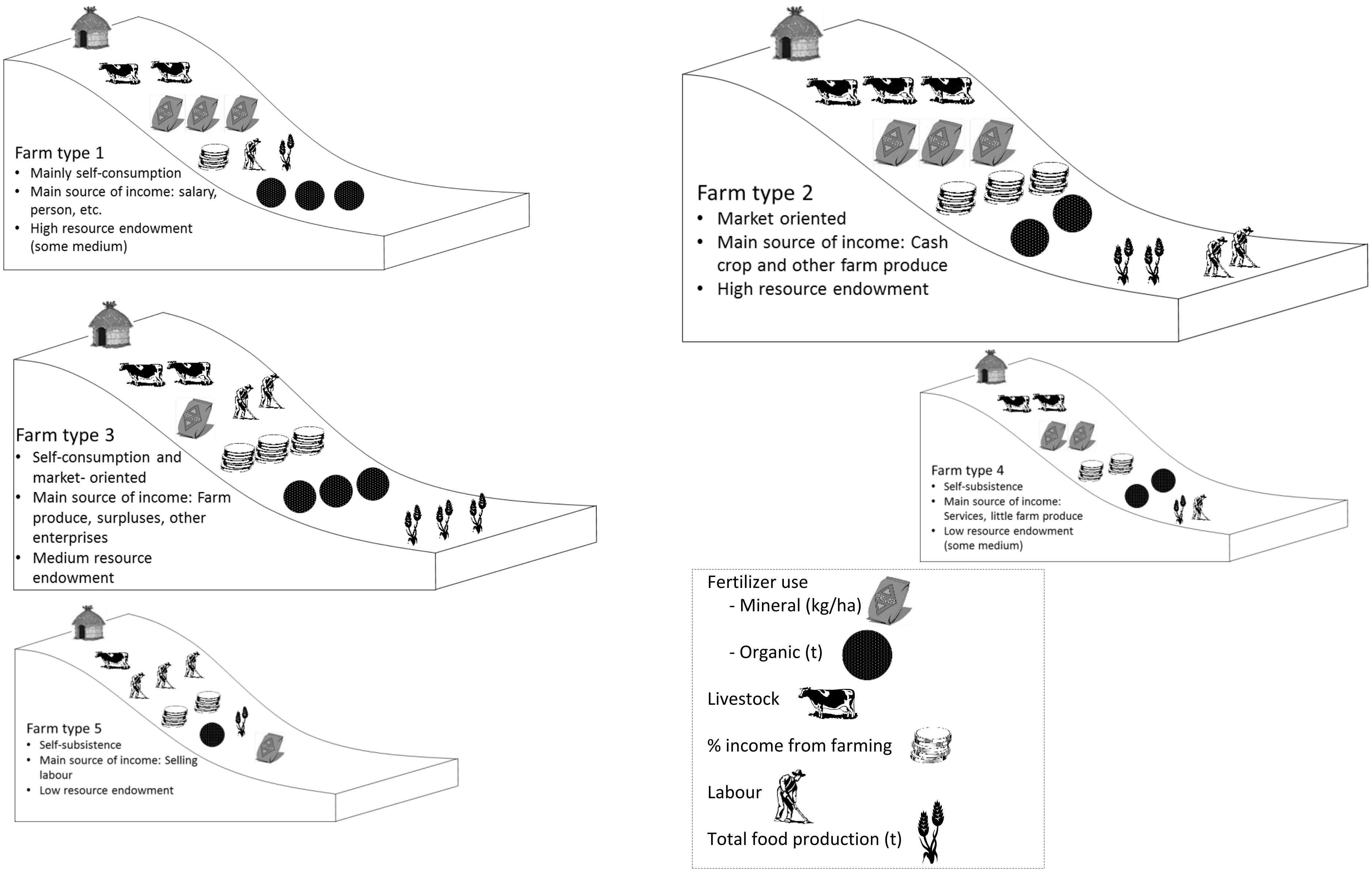


Figure 2. Farm management strategies causing soil heterogeneity between different farm types (wealth classes); example from Kenya (Tittonell *et al.* 2005a)

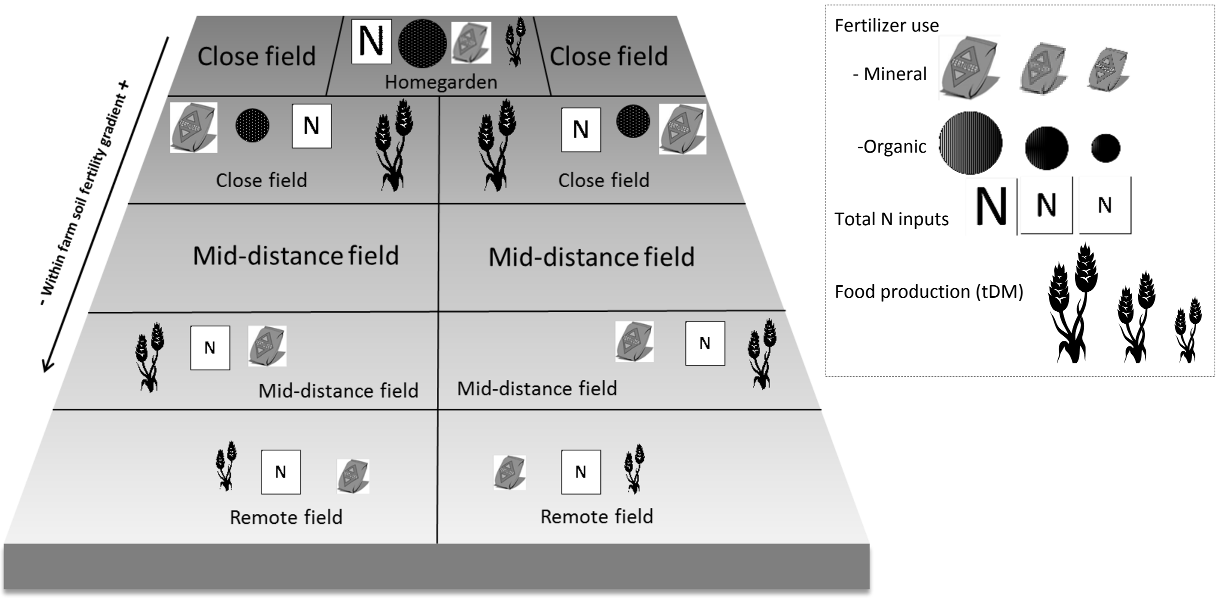


Figure 3. Farm management strategies causing within farm soil heterogeneity; example from middle farm class in Kenya (Tittonell *et al.* 2005b)

Purpose of the study

Limited resource availability leads to heterogeneity in agro ecosystems, because of concentration of nutrient inputs on certain spots in smallholder African landscapes (e.g. (Elias *et al.* 1998; Tittonell *et al.* 2005b; Zingore *et al.* 2006). Evidence from various agroecosystems around Sub Saharan Africa suggest that soil heterogeneity influences crop response to nutrients as well as nutrient use efficiencies (e.g. (Wopereis *et al.* 2006; Zingore *et al.* 2006; MacCarthy *et al.* 2010). These soils often range from poorly responsive fertile fields to responsive and poorly responsive infertile fields (Tittonell and Giller 2013a). There is a large number of literature available describing soil heterogeneity in SSA, though the availability of technogological recommendations to overcome these spatial patterns is limited. Management strategies are required to overcome these soil fertility niches and increase crop productivity within African smallholder agroecosystems. A context specific form of precision agriculture is urgently needed to manage soil heterogeneity. Soil responsiveness within SSA countries and spatial fertility patterns within smallholder landscapes need to be understood to introduce an adapted smallholder farming form of precision agriculture. A chemical soil assessment within African smallholder agro ecosystems is needed to get better insight in soil fertility patterns around SSA countries.

To provide targeting recommendations to manage soil fertility gradients within Sub Saharan African farms it is necessary to understand how to assess and diagnose soil fertility patterns. As these gradients are caused by inherent soil fertility (geomorphology) and farm management strategies (Tittonell *et al.* 2005b; Rowe *et al.* 2006) two specific soil fertility patterns could be distinguished related to 1) on farm field location (e.g. distance to homestead) and 2) soilscape field location (e.g. position along toposequence). This implies assumptions on relative soil fertility statuses could be made taking into account the position of a field within the farm which is, however, country and region specific. Moreover, an understanding of farmers' perceptions, knowledge and management of soil fertility is essential (Birmingham 2003).

The objective of this research is to identify and review the knowledge and research available on heterogeneity in soil fertility in smallholder African landscapes, through examining chemical soil fertility and farm participatory research. This report started with an introduction to give some initial background on soil heterogeneity in the African context. The following chapter will deepen fertility patterns by providing a literature review of chemical soil fertility assessments for various case studies around SSA countries and farmer perceptions in that regard. This in order to study the spatial levels and the scale in which soil heterogeneity occurs around SSA (location vs soilscape), to explore the influence of these fertility gradients on the responsiveness of plants and nutrient use efficiencies and to examine farmer perception towards soil fertility.

2. Literature review of Sub Saharan Africa

In this first part of the thesis report a literature review is given on patterns in soil heterogeneity among SSA case studies. The first section focusses on soil spatial heterogeneity in smallholder African agriculture through exploring gradients in chemical soil fertility related to farm management strategies and geomorphology. The second section elaborates on farmers' perceptions and knowledge towards soil fertility.

2.1 Soil spatial heterogeneity in smallholder agriculture

This first section is subdivided into three parts: 1) exploring chemical soil fertility patterns related to field location and land use, which is based on farm management strategies: e.g. resource allocation on farm, 2) exploring chemical soil fertility patterns related to soil scape: position of a farm within the landscape (mainly slope) and 3) assessing crop response and nutrient use efficiencies within heterogeneous agro ecosystems.

Field location

Table 1 provides an overview of case studies done across a large variety of Sub Saharan African agro ecosystems. On-farm spatial distribution of soil heterogeneity gradients are presented. For each case study soil fertility patterns are shown as a result of farm management strategies and indicate the soil fertility status of a specific location on farm. The majority of the studies include the distance to homestead (m) as soil fertility pattern related to current management strategies like farmers' risk attitudes, lack of transportation and limited access and availability of labour, fertilizer and manure (Mowo *et al.* 2006; Zingore *et al.* 2006; Tittonell 2008). Differences between countries' field components of soil fertility gradients are given in Table 1. As example the spatial distribution of fields in Western Kenya vary from home gardens to bordering close fields, mid-distance fields and remote fields with distances ranging from 7 to 100 meters from the homestead. The soil fertility gradient from homefields to remote fields seems limited, as most soil fertility indicators do not show extensively differences between fields (e.g. exchangeable K varied across different fields). In contrast, farms in Zimbabwe only distinguish homefields and outfields in which the outfields are found with quite a large distance from the homestead and the homefields. The soil fertility patterns in these case studies are more clear compared to the Western Kenya case study as the measured fertility indicators show a considerable decrease from the homefields to the outfields. Large distances from homefields to outfields are found in Rwanda as well, yet these farms include (bordering) close fields in between. The case of Rwanda shows a very clear decrease of soil fertility status with an increased distance from the homestead. In the Sudan-Savannah zone, like Burkina Faso, dissimilar on farm soil fertility patterns related to distance from homestead are found. The homestead is located in the middle of the farm area and the fields are positioned in rings around the homestead, resulting in soil fertility gradients from the homestead to the outer ring. As this figure shows ring 1 is called house field, ring 2 is called village field and ring 3 is called bush field. However, this distinction has not necessarily be the case. Taking a look at individual farm field compounds most cases are likely to correspond to this division, yet as example ring 1 could be a village field instead of a home field and ring 3 could be a village field instead of a bush field as well (Prudencio 1993). An increase in population density causes a disappearance of this ring distinction (into house fields, village fields and bush fields) as ring 1 of farmer 1 might be situated next to ring 2 or ring 3 of farmer 2 (Wopereis *et al.* 2006). According to Wopereis *et al.* (2006) on farm soil fertility gradients might in these cases occur due to, for example, abandoned kraals or sandy patches.

On farm soil fertility patterns are strongly related to historical management as well. Two case studies, associated to former kraals (in Central Kenya and Eastern Uganda), cause high soil fertility levels on recently abandoned kraals. A third on farm spatial soil fertility pattern is linked to land use as in Northwest Tanzania in which the division is made between fields growing perennial crops like bananas, fields with annual crops and grasslands. The results show a clear soil fertility gradient due to different management strategies associated to each of the land uses.

Soilscape

A dissimilar soil fertility pattern found within Sub Saharan African agro ecosystems are gradients related to the so called 'soilscape' of the area in which a farm is located (Table 2). The soilscape is linked to the geomorphology of an area and gives an indication about the position of a field within the landscape. In the majority of case studies found the soilscape fertility gradients are related to the position of a field along the toposequence. Table 2 presents an overview of soil fertility indicators related to the field location within the soilscape in diverse Sub Saharan African agro ecosystems. In general a decrease in soil fertility is found at the lower or valley parts of a toposequence. This does not apply for extractable P which shows an increase in quantity lower on the slope in several cases.

Soil fertility gradients along the toposequence are caused by a number of possible factors. Different positions along the toposequence could be associated with different soil types with, as a consequence, widely different inherent soil fertility rates. As sandy soils got by nature a low water holding capacity these soils would face larger difficulties dealing with crop water availability. In contrast, in the valleys (near the river/water stream) waterlogging could take place, especially during the rainy season. On the steeper slopes (in the middle field along the toposequence) sheet erosion occurs (Ebanyat 2009). These causes contribute to soil fertility gradients from the upper part of a slope down to the valley/bottom parts (Table 2).

Table 1. Soil fertility indicators at farm scale across heterogeneous Sub Saharan African agro-ecosystems.[a]

Case study area	Component soil fertility gradient	Soil fertility pattern	Soil fertility indicators								Sources
			Clay + silt (%)	pH (H_20)	SOC (g kg^{-1})	Total N (g kg^{-1})	Extracted P (mg kg^{-1})	Exchangeable bases (cmol$_{(+)}$ kg^{-1})			
								K^+	Mg^{2+}	Ca^{2+}	
	Historical field management										
Central Kenya	Abandonend bomas fields	1.5 years old	19.8	n.d.	n.d.	17.0	n.d	4.22	6.10	5.01	Augustine (2003)
		12-24 years ago	19.8	n.d.	n.d.	7.50 (2.5-10.5)	n.d.	0.48	2.47	3.12	
		30-39 years ago	19.8	n.d.	n.d.	2.30 (1.0-4.0)	n.d.	0.25	0.61	1.47	
	Land use										
Northwest Tanzania	Kibanja	Perennial crops	26.0	5.7 (4.8-6.8)	26.0 (16-48)	2.20 (2.2-4.2)	123.0 (10-515)	0.40 (0.1-0.6)	n.d.	4.90 (1.0-10.3)	Baijukya *et al.* (2005)
	Kikamba	Annual crops	34.0	5.5 (4.5-6.6)	22.0 (8-46)	1.70 (0.8-3.7)	21.0 (5-480)	0.20 (0.08-0.4)	n.d.	1.30 (0.8-4.4)	
	Rweya	Grasslands	31.0	5.2 (4.2-5.8)	26.0 (5-56)	1.30 (0.4-2.1)	13.0 (5-250	0.10 (0.04-0.2)	n.d.	0.90 (0.2-1.8)	
	Land use										
Madagascar	Tanety	Annual crops	58.6	5.2	32.7	2.28	72.5	n.d.	n.d.	n.d.	Alvarez (2012)
	Terraced foothill	Rice	56.1	5.9	18.0	1.24	74.3	n.d.	n.d.	n.d.	
	Flood lowland	Rice	57.7	5.7	18.0	1.34	64.0	n.d.	n.d.	n.d.	
	Field location										
Southern Ethiopia	Enset	Homegarden	n.d.	6.9	4.50	3.40	51.2	n.d.	n.d.	n.d.	Elias *et al.* (1998); Elias and Scoones (1999)
	Darkoa	Homestead field	n.d.	6.5	3.36	2.50	21.1	n.d.	n.d.	n.d.	
	Shoka	Outfield	n.d.	5.7	2.65	2.10	5.11	n.d.	n.d.	n.d.	
	Field location										
Sudan-Savannah Zone (e.g. Burkina Faso)	Champs de case	Ring 1	n.d.	7.5 (6.7-8.3)	16.5 (11-22)	1.35 (0.9-1.8)	110 (20-200)	1.60 (0.4-2.4)	n.d.	n.d.	Smaling and Braun (1996)
	Champs de village	Ring 2	n.d.	6.4 (5.7-7.0)	7.50 (5-10)	0.70 (0.5-0.9)	14.5 (13-16)	0.75 (0.4-1.1)	n.d.	n.d.	
	Champs de brousse	Ring 3	n.d.	6.0 (5.7-6.2)	3.50 (2-5)	0.35 (0.2-0.5)	10.50 (5-16)	0.08 (0.06-0.1)	n.d.	n.d.	

Table 1. Continued......

		Distance from homestead (m)									
Rwanda	Homefields	10-30	40.0	5.5	25.2	2.50	12.5	0.70	n.d.	n.d.	Bucagu (2013) chapter 2
	Close fields	50-100	40.8	5.2	19.3	1.80	7.90	0.30	n.d.	n.d.	
	Outfields	100-800	38.7	5.2	16.0	1.50	5.10	0.40	n.d.	n.d.	
		Distance from homestead (m)									
Mali	Fulawere	10 ± 20	± 30	5.7	13.2	0.70	10.0	0.12	n.d.	n.d.	Ramisch (1999); Ramisch (2005)
	Hamlet	80 ± 40	± 30	5.7	12.4	0.52	8.60	0.25	n.d.	n.d.	
	Village	1340 ± 820	± 30	6.1	11.5	0.46	11.6	0.22	n.d.	n.d.	
		Field location									
Northern Togo	Infield	Ring 1	n.d.	7.7	13.4	0.97	48.0	1.70	1.12	3.90	Wopereis *et al.* (2006)
	Outfield	Ring 3	n.d.	6.4	6.30	0.51	1.15	0.25	0.56	2.20	
		Historical field management (e.g. Kraal)									
Eastern Uganda	Former kraals	n.d.	34.0	7.30	16.0	1.60	18.0	1.10	1.30	5.20	Ebanyat (2009) Chapter 5
	Poor fields	n.d.	33.0	6.20	6.30	0.70	9.10	0.30	0.80	2.40	
	Degraded fields	n.d.	30.0	6.10	5.50	0.60	6.20	0.30	0.60	2.40	
		Distance from homestead (m)									
Ghana	Homestead fields	Close to settlement	n.d.	6.4	6.50	0.90	28.10	n.d.	n.d.	n.d.	MacCarthy *et al.* (2010)
	Bush fields	Outside settlement	n.d.	5.5	4.20	0.50	3.24	n.d	n.d.	n.d.	
		Distance from homestead (m)									
Malawi	Homefields	0-50	47.0	5.4	12.0	0.80	7.00	n.d.	n.d.	n.d.	Kamanga (2011) chapter 2
	Middle fields	51-100	39.0	5.5	9.00	0.50	4.90	n.d.	n.d.	n.d.	
	Remote fields	>100	35.0	5.7	7.00	0.40	3.10	n.d.	n.d.	n.d.	
		Field management									
Mali	Gradient 1 - Most intensively cultivated		n.d.	6.42	6.99	0.27	9.10	3.57	4.75	14.0	Benjaminsen *et al.* (2010)
	Gradient 2		n.d.	6.13	6.58	0.23	8.40	2.61	4.36	10.1	
	Gradient 3		n.d.	6.49	8.78	0.39	5.90	3.85	6.04	16.5	
	Gradient 4		n.d.	6.13	8.53	0.35	5.70	2.05	4.77	10.3	
	Gradient 5 - Least intensively cultivated		n.d.	6.57	12.6	0.67	19.7	2.98	6.15	21.7	

Table 1. Continued......

		Land use									
Northern Ethiopia	n.d.	Forest land	40.0	6.8	8.20	1.05	3.53	2.00	5.02	10.8	Tilahun (2007)
	n.d.	Grazing land	34.0	6.5	10.7	1.35	3.82	0.93	0.88	3.26	
	n.d.	Cultivated land	35.0	5.8	5.70	0.55	4.51	0.85	0.81	3.96	
		Distance from homestead (m)									
Western Kenya (Aludeka midland region)	Home gardens	10 ± 3.6	36.1	5.4	6.90	0.30	2.50	0.28	0.70	2.40	Tittonell *et al.* (2005b)
	Close fields	26 ± 8.6	42.9	5.8	7.50	0.60	5.60	0.44	0.80	3.90	
	Mid-distance fields	54 ± 17	44.3	5.4	8.80	0.60	2.90	0.25	0.90	2.90	
	Remote fields	82 ± 21	39.4	5.2	7.90	0.50	2.30	0.15	0.70	2.30	
		Distance from homestead (m)									
Zimbabwe	Homefields	29 ± 12.7	4.7 (clay)	5.4*	6.90	0.29	16.8	1.98	1.47	5.53	Masvaya *et al.* (2011)
	Outfields	159 ± 36.4	3.1 (clay)	5.1*	5.40	0.20	9.00	1.06	1.06	3.15	
		Distance from homestead (m)									
Highlands Ethiopia	Homestead	5	n.d.	6.7	n.d.	0.23	6.30 (2.5-10)	10.2 (8.6-11.8)	n.d.	6.75	Amede and Taboge (2007)
	Outfields	60	n.d.	6.0	n.d.	0.17	0.80	3.35 (2.7-4)	n.d.	4.25	
		Distance from homestead (m)									
Sahel of Mali	n.d.	10	n.d.	8.5	5.40	0.25	8.40	0.07	n.d.	n.d.	Samaké *et al.* (2005)
	n.d.	100	n.d.	7.2	3.60	0.19	4.50	0.06	n.d.	n.d.	
	n.d.	500	n.d.	6.0	1.20	0.11	2.50	0.02	n.d.	n.d.	
	n.d	2000	n.d.	5.2	1.00	0.12	2.50	0.01	n.d.	n.d.	
		Distance from homestead (m)									
Zimbabwe	Sandy homefield	<50	15.0	5.1	5.00	0.40	7.20	n.d.	n.d.	n.d.	Zingore *et al.* (2006)
	Sandy outfield	100-500	12.0	4.9	3.00	0.30	2.40	n.d.	n.d.	n.d.	
	Clayey homefield	<50	54.0	5.6	14.0	0.80	12.1	n.d.	n.d.	n.d.	
	Clayey outfield	100-500	58.0	5.4	7.00	0.50	3.90	n.d.	n.d.	n.d.	

[a] In case results from several farm wealth classes were available, only the middle wealth class is considered.

[*]As measured in $CaCl_2$

Table 2. Soil fertility indicators at farm scale across heterogeneous Sub Saharan African soilscapes.[a]

Case study area	Landscape characteristic/Position	Characteristics position and soil	Soil fertility indicators								Sources
			Clay + silt (%)	pH ($H_2$0)	SOC (g kg^{-1})	Total N (g kg^{-1})	Extracted P (mg kg^{-1})	Exchangeable bases ($cmol_{(+)}$ kg^{-1})			
								K^+	Mg^{2+}	Ca^{2+}	
Kenya (Meru South)	Different positions along toposequence	Upslope	46.0	5.8	20.3	n.d.	15.6	0.64	1.50	5.60	Tittonell (2008)chapter 2
		Midslope	48.0	5.6	19.7	n.d.	17.2	0.54	1.40	4.90	
		Footslope	47.0	5.5	19.1	n.d.	21.2	0.53	1.30	4.80	
		Valley bottom	51.0	5.3	20.3	n.d.	24.6	0.56	1.40	4.40	
Rwanda	Different positions along toposequence in a watershed area	Upper hill: Mountainous	n.d.	5.5	17.3	0.18	2.70	0.28	0.82	5.02	Rushemuka *et al.* (2014)
		Upper hill: Interfluves	n.d.	5.6	11.3	0.85	26.0	0.51	1.41	4.19	
		Upper hill: Shoulder	n.d.	6.5	22.8	0.17	7.00	0.85	3.55	7.39	
		Hill side	n.d.	4.8	2.40	0.14	1.50	0.09	0.06	0.28	
		Valley bottom (Ibumba)	n.d.	4.3	2.63	0.20	2.50	0.10	0.09	0.49	
Southern Rwanda	Different positions along toposequence	Upper slope	39.0	5.7	16.0	2.40	n.d.	n.d	n.d.	4.30	Steiner (1998)
		Middle slope	39.0	5.1	15.0	1.60	n.d.	n.d	n.d.	2.80	
		Lower slope	39.0	4.9	14.0	1.60	n.d.	n.d	n.d.	2.30	
Burkina Faso	Different positions along toposequence	Mid-slope	28.5	6.5	7.10	n.d.	0.80	0.10	0.70	2.10	Stoop (1987)
		Lower slope	39.0	6.0	6.10	n.d.	0.50	0.14	0.50	1.20	
		Lowland	59.0	5.8	9.50	n.d.	0.70	0.14	0.60	2.20	
Uganda	Different positions along toposequence (2-8%)	Upper (Erony)	12.0 (Clay)	5.8	4.60	0.50	7.90	0.30	0.60	1.20	Ebanyat (2009) Chapter 3
		Middle (Eitela)	37.0 (Clay)	4.5	6.20	0.70	6.00	0.20	0.50	1.00	
		Middle (Apuuton)	14.0 (Clay)	5.7	5.20	0.60	11.0	0.30	0.60	1.20	
		Bottom (Akao)	10.0 (Clay)	5.5	3.70	0.40	23.1	0.40	0.40	1.00	
South-west Nigeria	Different positions along toposequence	Upper slope	44.7	6.1	5.73	0.47	3.81	0.31	0.78	3.09	Salako *et al.* (2006)
		Middle slope	32.1	6.1	3.78	0.24	3.67	0.13	0.81	2.81	
		Lower slope	26.8	6.2	4.50	0.55	3.55	0.13	0.65	2.67	

Table 2. Continued......

Western Niger	Different positions along toposequence	Plateau	11.6	5.5	1.70	0.08	2.79	n.d	n.d.	n.d.	Gandah (1999)
		Upper slope	8.0	5.7	1.40	0.05	2.15	n.d	n.d.	n.d.	
		Undulating terraces	7.8	5.7	1.10	0.06	1.70	n.d	n.d.	n.d.	
		Valley	8.4	5.2	1.20	0.06	2.31	n.d	n.d.	n.d.	
South-west Uganda	Different positions across bench terrace, from upper (1) to lower position (5)	Strip 1	28.4 (Clay)	n.d.	20.1	0.22	5.34	0.35	n.d.	5.89	Siriri *et al.* (2005)
		Strip 2	26.8 (Clay)	n.d.	20.3	0.21	4.71	0.33	n.d.	6.88	
		Strip 3	22.4 (Clay)	n.d.	20.5	0.27	4.15	0.31	n.d.	6.90	
		Strip 4	20.5 (Clay)	n.d.	20.7	0.29	4.47	0.29	n.d.	7.34	
		Strip 5	18.6 (Clay)	n.d.	20.8	0.30	4.84	0.25	n.d.	7.36	

[a] **In case results from several soil depths were available, only the upper soil depth is considered.**

As discussed, on farm soil heterogeneity gradients are caused by different factors, including farm management strategies, like fertilizer input, early planting date and plant density (Zingore *et al.* 2006; Tittonell and Giller 2013a). The rate of fertilizer application is associated with soil heterogeneity patterns in SSA countries (Figure 4). The best plots and (in most cases the same) plots closest to the homestead receive the highest amount of N fertilizer (kg N ha^{-1}). Additionally on these fields the organic fertilizer N application rate exceeds the mineral fertilizer N input, while, in general, the mineral N input is higher on the more remote or worse fields. The decrease of fertilizer input associated with worse or remote plots is for the greatest part due to the decrease of organic N input. This has, besides strategies to grow cash crops near the homestead and risk aversion, likely to do with cattle grazing around the homestead in combination with the limited ability to transport (e.g. labour availability) manure to remote fields (Zingore *et al.* 2006).

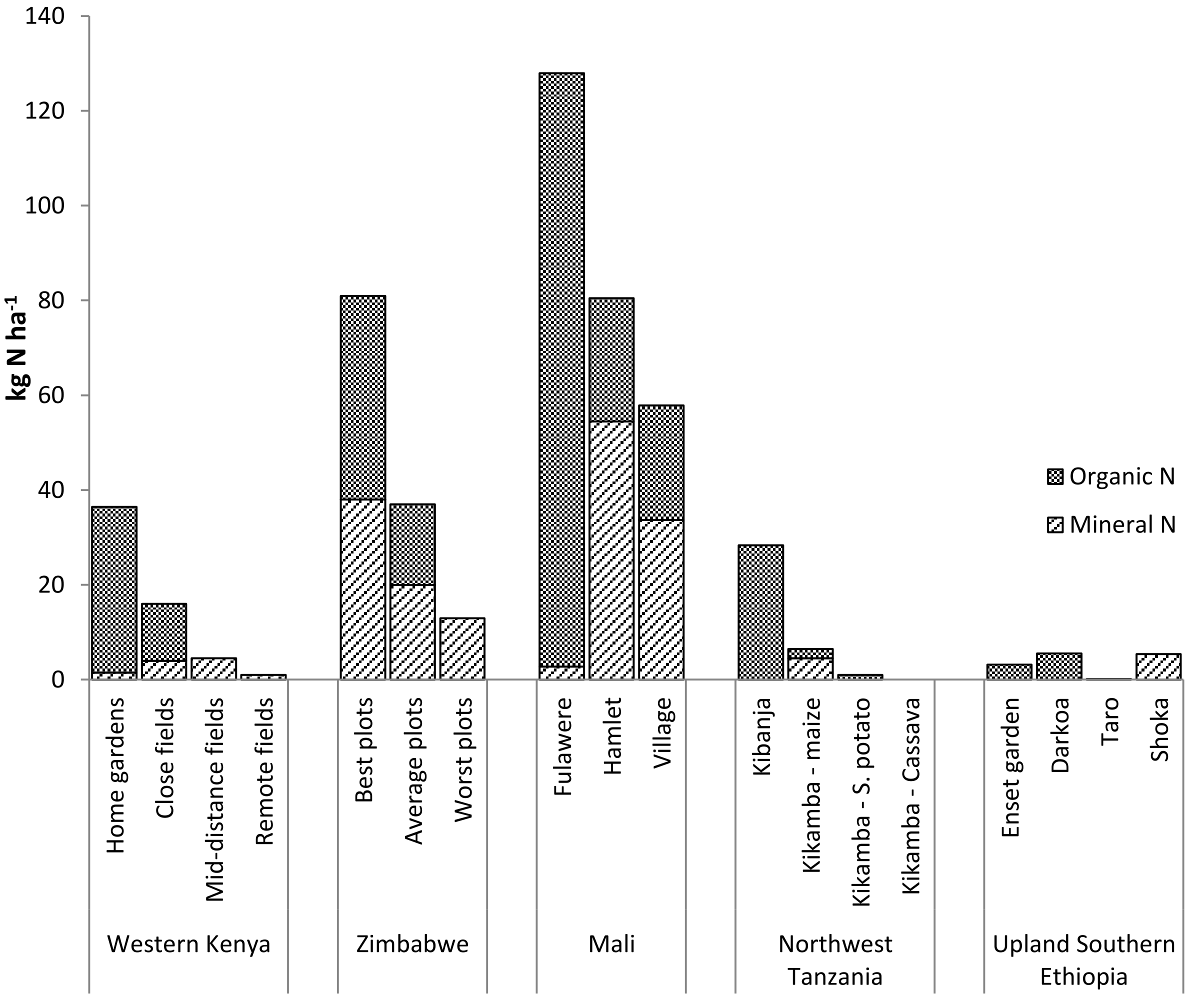


Figure 4. Mineral and organic N fertilizer input (kg ha^{-1}) along on-farm soil fertility gradients for case studies in Kenya (Tittonell *et al.* 2005b), Zimbabwe (Zingore *et al.* 2006), Mali (Ramisch 2005), Tanzania (Baijukya 2004) and Ethiopia (Elias *et al.* 1998).[a]

[a] In case data from different wealth classes was available, only the middle class data is considered.

The total N fertilizer application might be higher on close and fertile fields compared to remote and worse fields. Yet, it does not give an indication about the effect on yield on heterogeneous farms: crop response to fertilizer application. Crops on different positions on heterogeneous farms respond widely different to (organic and mineral) fertilizer applied (Figure 6). A pattern can be distinguished from relative high crop responses to N and P fertilizer on fields close to the homestead, to lower crop responses to N and P fertilizer on remote fields. This may indicate multiple nutrient deficiencies on the remote fields (especially on sandy soils) like shortages in K and Zn (Zingore *et al.* 2006). Wopereis *et al.* (2006) explain this difference by an increased infiltration capacity and reduced evaporation in infields compared to outfields due to household waste and crop residues scattered over infield soil surface. Even though the percentage crop yield increase after a fertilizer treatment in Western Kenya is higher on the remote fields, the absolute yield on the close fields is still quite much higher, due to the greater inherent soil fertility level. A research done on crop response on heterogeneous farms in Ghana shows a demand of 80 kg N ha^{-1} on bush fields to gain the same grain yield (t ha^{-1}) when applying 40 kg N ha^{-1} on homesteads (MacCarthy *et al.* 2010).

Crops grown on limited or non-fertilized fields will deplete the soil. Many case studies on nutrient balance estimations conducted at field scale in SSA show negative results (Baijukya *et al.* 2005; Nkonya *et al.* 2005; Tittonell and Giller 2013a). Additionally, in various cases the crop yield response to fertilizer is rather low (Figure 6). The soil fertility gradients at farm scale show the increase in soil degradation across the farm (Table 1). In order to tackle soil degradation effectively and replenish soils it seems important to get an understanding of farm specific soil fertility gradients. Soil degradation is a widespread concern all around SSA countries. GLASOD, an UNEP funded project to describe and map soil degradation, describes soil degradation as a human-induced occurrence limiting soil capacity to preserve human life, like soil erosion (Vlek *et al.* 2008). According to a research published by ISRIC (World Soil Information) in the early 90's 494 M ha of African soils (over 6% of the total African land area) got degraded due to human-induced causative factors of which GLASOD recognizes the following five: deforestation, overexploitation, overgrazing, agricultural activities and (Bio)industrial activities. Major causes of soil degradation found in Africa are related to overgrazing and misconduct of agriculture (Oldeman 1994; Kiage 2013). Statistics on worldwide soil degradation (per country) are summarized by Bai *et al.* (2008) and mentions even a degradation level of 13% of the global degrading area in Africa south of the equator between 1981- 2003.

The phenomena of soil degradation will decrease the productivity in SSA agro ecosystems and, in addition, it reduces the capture and use efficiency of applied fertilizer on crops (Tittonell and Giller 2013a). The crop use efficiencies differ widely across heterogeneous smallholder farm as can be seen from Figure 5 and Figure 6, resulting in higher fertilizer demand on less fertile soils (Tesfahunegn *et al.* 2011). Tittonell and Giller (2013a) distinguish three categories of soil responsiveness within SSA countries which need to be understood to introduce an adapted smallholder farming form of precision agriculture. The three soil categories range from poorly responsive fertile fields to responsive or poorly responsive infertile fields, wherein, as elaborated, the fertile fields are generally located closest to the homestead and the infertile fields are usually the remote or outfields. The limited responsive soils seems to appear predominantly in resource scarce areas which are dense populated (Vanlauwe N.D.). Especially sandy soils are under stress due to their limited chemical and physical properties. As 13% of the SSA soils are sandy soils the challenge for soil replenishment is considerable (Hartemink and Huting 2005).

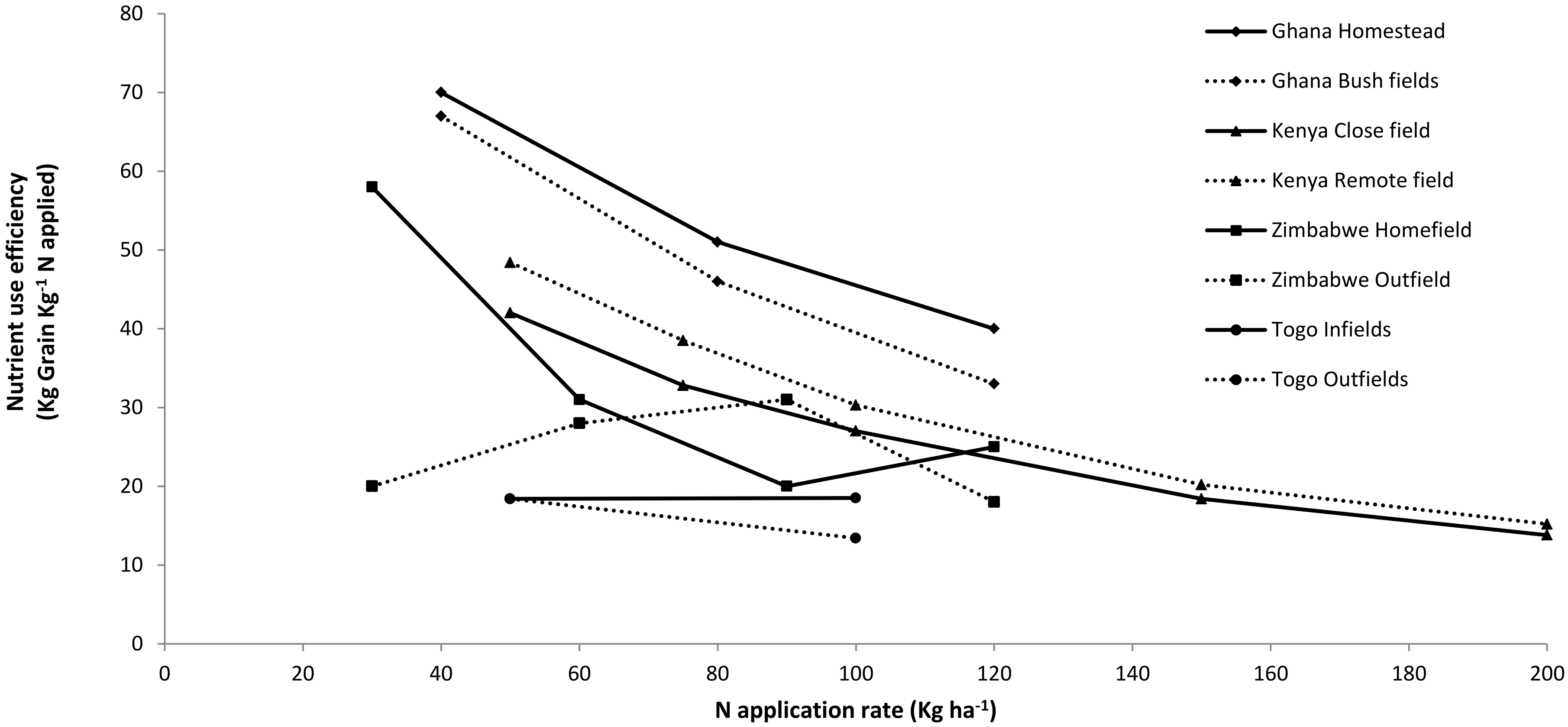


Figure 5. Nutrient use efficiencies for different N application rates on heterogeneous farms for (i) Sorghum cropping in Ghana (MacCarthy *et al.* 2010) and (ii) Maize cropping in Kenya (Tittonell *et al.* 2006; Zingore *et al.* 2006), Zimbabwe (Tittonell *et al.* 2007a) and Togo (Wopereis *et al.* 2006; Zingore *et al.* 2006; Ebanyat 2009).

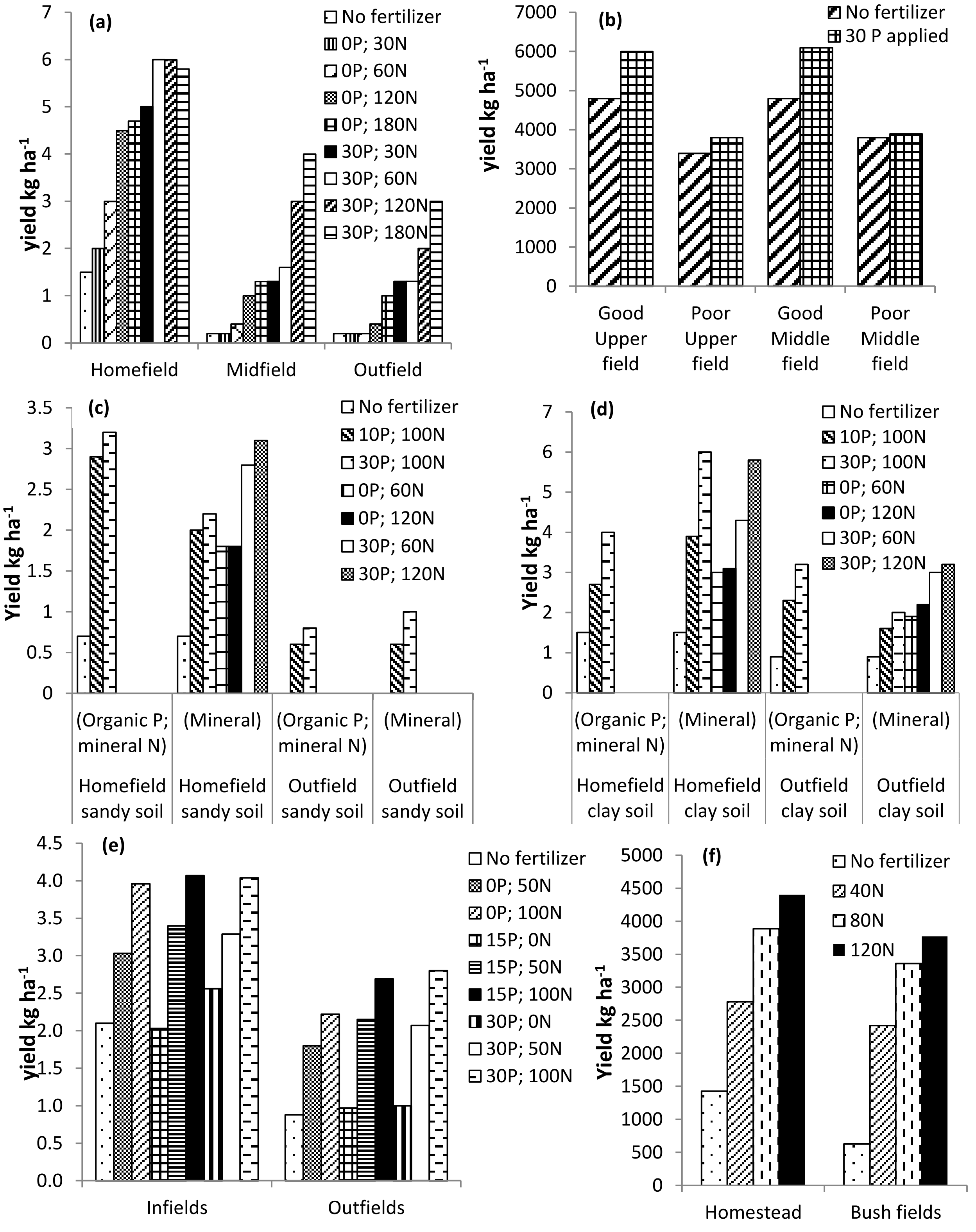


Figure 6. Crop response to N and P fertilizer input (kg ha^{-1}) along on-farm soil fertility gradients for several case studies: (a) maize yield response on mineral N and P input in Western Kenya (Tittonell *et al.* 2008a); (b) cowpea yield response on mineral P input in Uganda (Ebanyat 2009); (c) and (d) maize response on mineral N and organic and mineral P input on sandy (c) and clay (d) soil in Zimbabwe (Wopereis *et al.* 2006; Zingore *et al.* 2006); (e) maize yield response on mineral N and P input in Togo (Wopereis *et al.* 2006); (f) sorghum yield response on mineral N input in Ghana (Wopereis *et al.* 2006; MacCarthy *et al.* 2010).

2.2 Farmers' perceptions and management of soil fertility

As outlined in the previous section, soil fertility gradients are found all over Sub Saharan African countries. These gradients exist due to inherent soil fertility levels, to field location within the landscape and farmers might reinforce heterogeneity by their historical and current farm management strategies. Applied strategies are for instance varying organic and mineral fertilizer input, early planting date and adjustable plant densities (Zingore *et al.* 2006; Tittonell and Giller 2013a). Various factors, like lack of resources, risk aversion, purposed diversification and lack of transportation and labour, constrain farmers to apply certain management strategies causing soil fertility gradients without necessarily initially purposed (Vanlauwe and Giller 2006; Zingore *et al.* 2006; Tittonell *et al.* 2007b).

To replenish soil fertility and decrease the level of soil degradation, suitable soil fertility management strategies and extension approaches should be applied. An understanding of farmers' perceptions, knowledge and management of soil fertility is essential (Birmingham 2003). Moreover, an understanding of local soil fertility characterisation will facilitate cooperation between researchers and local farmers (Tabor 1990; Gray and Morant 2003). In addition farm knowledge of soil fertility will contribute to the development of technologies and recommendations (Benjaminsen *et al.* 2010). Diverse case studies conducted around SSA countries indicate farmers' perceptions and knowledge towards indigenous soil classification. Farmers are asked to characterise their soils according to their perceived fertility level (Table 3). This classification is mainly related to characteristics they can see, feel or notice while they are in the field, without assessing the soil chemically (Mairura *et al.* 2007). According to Gray and Morant (2003) "whether a soil type was productive or not was intrinsically linked to how the soil was used as well as to specific environmental conditions". The local soil characterisation is used by farmers to make decisions on specific farm management strategies, like crops grown and soil fertility management (Saïdou *et al.* 2004). This indicates that fields perceived as most fertile are not necessarily seen as most suitable for certain crop cultivation (Gray and Morant 2003). Moreover Gray and Morant (2003) observed in their research in Burkina Faso that smallholder farmers noted a change in soil colour which they linked to erosion and a decline in soil fertility.

In some cases a translation from local terminology about soil fertility into scientific explanation is needed. Dawoe *et al.* (2012) designed a list of local soil fertility terms used by farmers in Ghana. If farmers talk about a fat soil, a nutrient rich, fertile soil is meant and if a soil has reduced fertility farmers will talk about a tired soil. The research paper of Mowo *et al.* (2006) gives an overview of the technical equivalent of farmers perceived soil characterisations in Tanzania, like the black colour of a good soil is due to high organic matter content.

Various researches around SSA countries compared farmers' perceived field soil fertility status (fertile vs infertile) with soil chemical analyses (Table 4). In each of these seven explored case studies chemical soil fertility was found to be lower on the fields perceived as less fertile compared to the fertile fields, indicating the ability of local farmers to perceive the fertility status of their fields. If farmers will use the soil fertility characterisation (Table 3) to identify whether a field is fertile or infertile they will be able to adapt their management strategies to the specific soil fertility status of a field, as well as to the local soil circumstances (e.g. influenced by environment or soilscape). The ability of farmers to identify soil fertility patterns within their farm or village, using their soil fertility characterisation, might reduce soil heterogeneity and soil degradation by applying targeting farm management strategies. It will improve the efficiency of local use of natural resources and soils (Benjaminsen *et al.* 2010).

Local farmers seem not only aware of the fertility status of their fields, yet they appear conscious on the causes of low soil fertility as well. According to Murage *et al.* (2000) Kenyan farmers are aware of the causes of the decline in soil fertility. All of the questioned farmers indicated inadequate fertilizer application and removal of crop residual as causing factors for low soil fertility. Moreover continuous cropping, lack of crop rotation and soil erosion are brought forward as reducing soil fertility factors. Dawoe *et al.* (2012) observed the same outcome from his questionnaire among farmers in Ghana who mentioned continuous cropping without fertilizer application as main cause of low soil fertility. A case study conducted in Nigeria indicates the scarcity of fertilizer (both organic and inorganic) and soil erosion as main factors influencing soil fertility status as well (Hoffmann *et al.* 2001).

If one is aware of soil fertility gradients within a single farm or village, targeting fertility management strategies can be applied. Various soil management practices are introduced in SSA to replenish soil fertility. However, farmers' adoption (using) rates of these techniques differ widely (Figure 7). In addition, an using rate of a certain management practice does not necessarily mean farmers apply the technique to each field of the farm. If farmers become better aware of the effectiveness of these fertility management practices on soil fertility status (Figure 8) and combine this with their field fertility knowledge, fertility of their soils could be improved. Figure 8 shows an increase in soil nutrient levels using different soil fertility practices in Tanzania and Niger. Ajayi *et al.* (2007) observed percentage yield increase in Malawi, Tanzania, Zambia and Zimbabwe when applying soil fertility management practices. Yields after fertilizer application could increase up to 850 % in Zambia and yield increases of 93% are observed in Zimbabwe after a natural fallow period. A proper selection of farming practices is needed to meet farmers' preferences and their ability to carry out (including labour and resource availability) as the practices should fit within the social and cultural circumstances. Becx *et al.* (2012) outlined the main constraints for farmers to implement certain soil fertility practices in Ghana, giving diverse reasons like labour, resources availability, expenses, transportation and many more. Thapa and Yila (2012) observed the perceived advantages and disadvantages of farmers towards the use of farm management practices as well, who came up with labour constraints and high production costs as well as deficit food for livestock and so on.

Table 3. Local soil characteristics as perceived by farmers in various SSA countries.

Case study	Soil fertility level	Soil characteristics									Source
Ghana	Fertile fields	Dark soil colour	High WHC	Few stones and pebbles present	Located in valley bottom or lower middle slope	Consistently high yields	Fast/ high growth rate	Soil is easy to work	Numerous wet worm casts present	Indicator weed: Chromolaena odorata with large green leaves	Dawoe *et al.* (2012)
	Infertile fields	White/ pale/ light soil	Low WHC	Numerous stones and pebbles present	Located upper slopes/ summits	Low yields	Stunted and slow plant growth	Soil is difficult to work	Few worm casts present	Indicator weed: Chromolaena odorata with small yellow leaves	
Ethiopia	Reguid (fertile)	Red and brown soil	Heavy texture	Slight stoniness	Location: level (valley bottom)	Maximum and most reliable yield	Deep soil depth	Soil is difficult to work	Intensively cultivated arable land		Corbeels *et al.* (2000)
	Mehakelay (moderately fertile)	Brown soil	Medium texture	Moderate stoniness	Location: gentle slope (between valley bottom and hills)	Medium yield with slight risk of crop failure	Medium soil depth	Soil is average to work	Some cultivation, also used for pasture		
	Rekik (least fertile)	White and black soil	Light texture	High stoniness	Location: very steep (hilly)	Low yields with high risk of crop failure	Shallow soil depth	Soil is easy to work	Not cultivated		
Ethiopia	High soil quality (Reguid)	Dark soil colour	Texture is clay loam, loamy, loam clay	Deep topsoil depth	Hold moisture well and give and take water easily	High yield	Even growth, matures on time	Easy to work or soil flows and falls apart	Soil stays loose, does not pack	Soil has numerous worm holes and castings, bird behind tillage	Tesfahunegn *et al.* (2011)
	Medium soil quality (Maekelay)	Brown, gray or reddish soil colour	Too heavy or too light, but no or little problem	Shallow topsoil depth	Soil is drought prone in dry weather	Medium yield	Uneven growth and late to mature	Difficult to work or needs extra passes	Soil has thin hardpan or plow layer	Few worm holes and castings present	
	Low soil quality (Rekik)	Light coloured soil	Texture is extremely sandy, clayey, rocky, is a problem	Subsoil exposed or near surface	Soil dries out too fast	Low yield	Stunted growth, never seems to mature	Plow hard or soil never works down	Soil is tight and compacted, can't get into it, thick hardpan	No casts or holes of worm activity	
Tanzania	Good soil	Black soil colour	Cracks during dry season due to high clay content	High WHC	Presence/vigorous growth of certain plants	Abundance of earthworms	Good crop performance				Mowo *et al.* (2006)
	Poor soil	Yellow and red colours in soil	Compacted soil	Shallow soil depth	Stunted growth	Presence of rocks and stones	Presence of bracken ferns	Salt visible on soil surface			
Zimbabwe	Rich field	Red or grey coloured soil	Relative high clay content	Soils do not dry easily and do not readily wilt crops	Consistently contributing the highest amount of yield	High crop growth and yield responses to external inputs	Exhibit clods on tilling	Presence of islands of termite mounds			Mtambanengwe and Mapfumo (2005)
	Poor field	Light coloured soil	Very sandy soil	Often poor seed emergence due to surface crusting	Crop yields are poor year after year	Low, poor seed emergence, low input response					

Table 4. Chemical soil fertility indicators on good and poor fields as perceived by farmers around different SSA countries

Case study area	Soil fertility level	Soil fertility indicators								Sources
		Clay + silt (%)	pH (H_20)	SOC (g kg^{-1})	Total N (g kg^{-1})	Extracted P (mg kg^{-1})	Exchangeable bases (cmol$_{(+)}$ kg^{-1})			
							K^+	Mg^{2+}	Ca^{2+}	
Ethiopia	High soil quality	73.0	6.9	25.6	5.30	17.95	1.33	12.4	22.4	Tesfahunegn *et al.* (2011)
	Medium soil quality	64.0	6.4	15.7	2.10	8.68	0.62	7.10	15.0	
	Low soil quality	45.0	6.3	9.80	1.20	5.57	0.67	7.80	9.30	
Western Kenya	Good field	n.d.	5.9	20.0	2.18	18.2	0.66	n.d.	n.d.	Tittonell *et al.* (2013)
	Medium field	n.d.	5.6	19.6	2.19	14.7	0.55	n.d.	n.d.	
	Poor field	n.d.	5.5	19.7	2.22	16.9	0.53	n.d.	n.d.	
Central Kenya	High fertile sites	67.0	5.6	0.034	1.60	20.5	n.d.	3.10	8.20	Mairura *et al.* (2007)
	Low fertile sites	65.5	5.1	0.024	1.60	16.0	n.d.	2.80	7.50	
Central Kenya	Productive soils	68.0	6.3	n.d.	n.d.	55.2	1.90	3.40	13.0	Murage *et al.* (2000)
	Non-productive soils	65.0	5.6	n.d.	n.d.	17.1	1.10	2.40	8.30	
Eastern Uganda	Good fields	25.0	6.6	9.3	0.97	19.0	0.47	0.66	2.10	Ebanyat (2009) Chapter 3
	Medium fields	23.0	6.3	6.6	0.69	14.0	0.37	0.58	1.44	
	Poor fields	20.0	6.1	5.5	0.59	12.0	0.30	0.53	1.25	
Ghana	Fertile soil	n.d.	6.3± 0.48	n.d.	2.70± 0.5	3.12± 0.86	0.35± 0.04	n.d.	n.d.	Dawoe *et al.* (2012)
	Infertile soil	n.d.	5.6± 0.61	n.d.	1.30± 0.53	2.10± 0.59	0.23± 0.04	n.d.	n.d.	
Zimbabwe	Rich field	15.0	4.4 (CaCl2)	7.10	0.70	7.80	0.03	0.60	1.20	Mtambanengwe and Mapfumo (2005)
	Poor field	13.0	3.7 (CaCl2)	4.60	0.50	4.30	0.02	0.30	0.40	

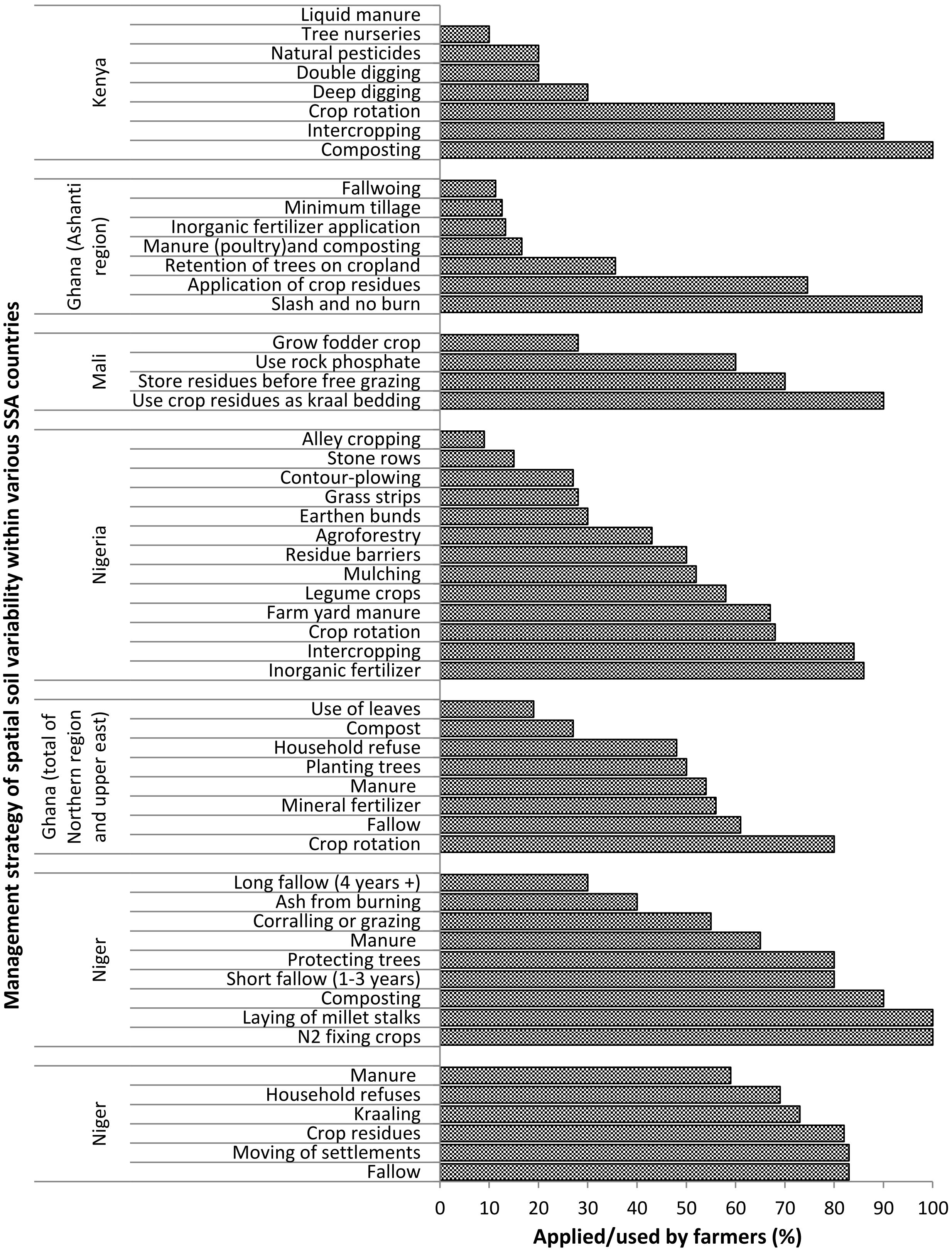


Figure 7. Farmers' adoption rate of soil fertility management strategies within various SSA countries: (a) soil fertility management applied by conventional farmers in Kenya year 2 after project implication (de Jager *et al.* 2004); (b) applied soil fertility management by farmers in Ghana (Vanlauwe and Giller 2006; Dawoe *et al.* 2012); (c) Farmers in Mali who were directly exposed to the management strategies in a test and continued applying the soil fertility management strategies (Elias *et al.* 1998; Defoer 2000; Tittonell *et al.* 2007b); (d) soil fertility management used by farmers in Nigeria (Thapa and Yila 2012); (e) used soil fertility management by farmers in Northern Ghana (Becx *et al.* 2012); (f) applied soil fertility management by farmers in Niger (Osbahr and Allan 2003; MacCarthy *et al.* 2010) and (g) applied soil fertility management by farmers in Niger (Lamers and Feil 1995).

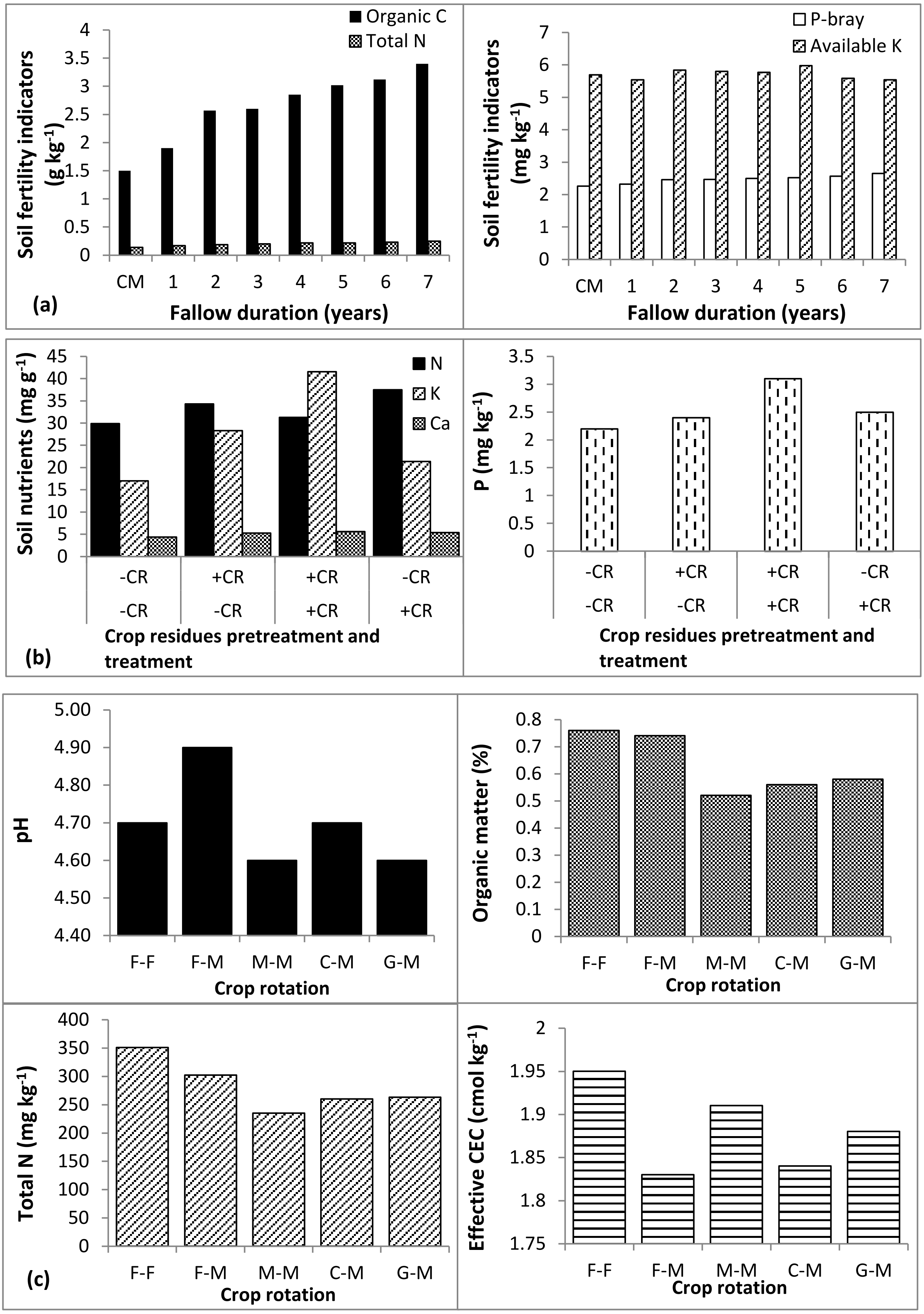


Figure 8. Effects of farm management practices on soil fertility in SSA Africa; (a) effect of fallow duration on soil fertility in Tanzania on unfertilized bush fields (500-2000m) (Samaké *et al.* 2005); (b) short and long term effects of crop residues (+CR) on soil fertility in Niger in which the upper line in the x-as indicates treatment (1990) and the lower line indicate pre-treatment (1986) (Rebafka *et al.* 1994); (c) effect of crop rotation on soil fertility in Niger F-F, continuous fallow, F-M, alternate fallow-millet, M-M, continuous Millet, C-M, Cowpea-Millet rotation, G-M, Groundnut-Millet rotation (Elias *et al.* 1998; Bationo and Ntare 2000; MacCarthy *et al.* 2010).

4. Concluding remarks

This literature review showed the variety of soil fertility patterns around Sub Saharan African countries. These patterns are the result from the interaction between indigenous soil fertility and historical and current farm management. Research results and local knowledge available on heterogeneity in soil fertility in smallholder African landscapes are given. Soil fertility gradients at farm scale show the increase in soil degradation across the farm (from homefields to outfields). Also soil fertility patterns on landscape scale are distinguished. In order to tackle soil degradation effectively and replenish soils it is important to get an understanding of farm specific soil fertility gradients. Soil degradation is a widespread issue around SSA agro ecosystems. Between 1981 and 2003 in SSA a degradation level of 13% of the global degrading area is mentioned by Bai *et al.* (2008). Major causes of soil degradation found in Africa are related to overgrazing and misconduct of agriculture (Oldeman 1994; Kiage 2013). Soil degradation decreases the productivity in SSA and it reduces the capture and use efficiency of applied fertilizer on crops (Tittonell and Giller 2013a). Tittonell and Giller (2013a) distinguish three categories of soil responsiveness within SSA countries ranging from poorly responsive fertile fields to responsive or poorly responsive infertile fields. A context specific form of precision agriculture is urgently needed to manage soil heterogeneity in SSA. Soil fertility patterns and soil responsiveness within African Smallholder landscapes need to be understood to introduce an adapted smallholder farming form of precision agriculture. Within the African context this need to interact high tech solutions with local farm knowledge and perceptions on soil fertility.

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6. Appendix Case study from Burkina Faso

To get field experience and discover farm perceptions and soil fertility patterns myself I went on a field trip to Burkina Faso, as an additional exercise. This chapter elaborates on what we have been doing in the field. The research is part of the PhD project of George Felix from the Farming Systems Ecology Chair group.

6.1 Background case study area

The fieldwork in Burkina Faso focussed on soil fertility gradients, the current soil fertility status and soil degradation in a small rural village called Yilou in Burkina Faso (13°0' N, 1°32' W). Burkina Faso is a landlocked country in semi-arid West Africa. In Yilou, the rainy season starts around the end of May and lasts till September/October (Some *et al.* 2013), with an annual rainfall rate of 400-600 mm (Diarisso *et al.* 2012). Around 40% of the Gross Domestic Product is accounted for agriculture (Some *et al.* 2013) and main crops grown in Yilou are Cereals, like Sorghum and Millet, intercropped with Cowpea and Groundnut (Tittonell *et al.* 2012). Over 3% of total area of Burkina Faso is degraded (Bai *et al.* 2008), resulting in a decrease in productivity and, in addition, it reduces the capture and use efficiency of applied fertilizer on crops (Tittonell and Giller 2013a). In order to tackle soil degradation effectively and replenish soils it seems important to get an understanding of farm/village and landscape specific soil fertility gradients.

In the Sudan-Savannah zone, like Burkina Faso, ring patterns are found in agro-ecosystems (Table 1). The homestead is located in the middle of the farm and the fields are positioned in rings around the homestead, resulting in soil fertility gradients from the homestead to the outer ring. Ring 1 is called home field, ring 2 is called village field and ring 3 is called bush field. However, currently this distinction has not necessarily to be the case. Taking a look at individual farm field compounds, most cases are likely to correspond to this division. Yet, as example, ring 1 could be a village field instead of a home field and ring 3 could be a village field instead of a bush field as well (Prudencio 1993). An increase in population density causes a disappearance of this ring distinction as ring 1 of farmer 1 might be situated next to ring 2 or ring 3 of farmer 2 (Wopereis *et al.* 2006). According to Wopereis *et al.* (2006) on farm soil fertility gradients might in these cases occur due to, for example, abandoned kraals, ancient termite mounds or sandy patches.

6.2 Research objective

In order to tackle soil degradation effectively and replenish soils it seems important to get an understanding of farm/village and landscape specific soil fertility gradients. Prudencio (1993) wrote about ring patterns on soil fertility in Burkina Faso. Does the ring pattern still exist? The aim of this research is to discover the soil fertility patterns in the smallholder farm landscape of Yilou. Chemical soil fertility of each taken sample will be linked 1) to GIS data on the position within the landscape and 2) to farmer perceptions on their best and poorest fertile field. Based on the farm perceptions, chemical soil fertility is also linked to farm management practices on either the good and poor field.

The research questions are:

- What soil fertility pattern can be discovered in the smallholder farm landscape of Yilou?
- Does chemical soil fertility match with perceived soil fertility of local farmers?
- What is the relation between farm management practices and chemical soil fertility?

6.3 Methodology

This experiment is based on farmers' perceived soil fertility status of their fields. Farmers were asked to indicate their good and poor field according to their own perceptions. This farmer discussion is done by a French speaking researcher before the soil sampling started. In addition, the farmers were asked about their management strategies on both their good an poor field. At the good and poor field of each farmer a composite soil sample was taken with a shovel and auger at 0-10 cm and at 10-20 cm. The composite soil sample consists of 10 subsamples taken from a cross transect along each field. 40 farmers are participating. Some farmers only own one field (perceived by us as a good field) and other farmers indicate a dissimilar distinction than 'good' vs 'bad' fields (e.g. clay depressions, downslope vs upslope). Also some samples are taken from termite mounds and bush fields. In total 172 soil samples were taken. From each field, soil type, soil colour, field elements, soil cover, landscape elements and slope are notated as well. Chemical analyses will show us if there is any significant difference in soil fertility status between the perceived poor and good fields. This analyses will makes us able to link the chemical differences to farm management as well as to the soil type, position within the landscape and to landscape elements (like present bush fields).