Trends and prospects for the productivity and sustainability of home garden systems in southern Ethiopia

Beyene Teklu Mellisse

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Invitation

You are cordially invited to attend
the public defence of my PhD
thesis

Trends and prospects for the productivity and sustainability of home garden systems in southern Ethiopia

On Wednesday 20th of
December 2017 at 4 pm in
the Aula of Wageningen University
General Foulkesweg 1a,
Wageningen.

After the defence, there will
be a reception in the Aula.
You are most welcome.
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Paranymphs

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Yodit Kebede
kebede.yodit@gmail.com

Propositions

1. Acknowledging diverse agroecosystems from only the ecological perspectives is the same as judging a smiling sick person as healthy.
   (this thesis)

2. The sustainability of home garden systems should be explained by the contribution of livestock rather than plant species diversity.
   (this thesis)

3. While scientists conduct research to propose proactive measures, policy makers always act re-actively.

4. At the beginning, the PhD life is the same as walking in the dark.

5. If increasing agricultural productivity is an engine to address food insecurity in Africa, efficient use of resources is an oil pump.

6. The ambition to feed the burgeoning African population from smallholder agriculture is achieved only if young people do not remain in farming.

7. Promoting indigenous knowledge has become a key factor for the development of Africa.

Propositions belonging to the thesis entitled
“Trends and prospects for the productivity and sustainability of home garden systems in southern Ethiopia”

Beyene Teklu Mellisse
Wageningen, 20 December 2017

Trends and prospects for the productivity and sustainability of home garden systems in southern Ethiopia

Beyene Teklu Mellisse

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This research was conducted under the auspice of the C.T.de Wit Graduate School Production Ecology and Resource Conservation (PE&RC).

Trends and prospects for the productivity and sustainability of home garden systems in southern Ethiopia

Beyene Teklu Mellisse

Thesis
submitted in fulfilment of the requirements for the degree of doctor
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Prof. Dr A.P.J.Mol,
in the presence of the
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ABSTRACT

Increasing population pressure and market developments are the major drivers of home garden system change from traditional, diverse systems towards mono-cropping systems. Home gardens are characterized by multipurpose trees and shrubs in intimate association with annual and perennial crops and livestock around the homestead which support the livelihoods of more than 15 million people in southern Ethiopia. The aim of this study is to gain a better understanding of how increasing population density and market developments influence home garden systems and impact on agricultural sustainability. First, we studied dynamics of farm components such as the cropping pattern and livestock population over the past two decades (1991-2013). To understand the diversity of home garden systems, farms were grouped into five types: Khat-based, Enset-cereal-vegetable, Enset-based, Enset-coffee and Enset-livestock based on the area share of crops and grazing land. Farm trajectories revealed a shift from the traditional Enset-based, Enset-coffee and Enset-livestock systems to 1) cash crop-oriented Khat-based systems in densely populated, market-proximate areas, and 2) combined food and cash crop-oriented Enset-cereal-vegetable systems in less populated and less accessible areas. Over the last two decades the area under khat (*Catha edulis* Forsk) expanded from 6% to 35% of the farm area, whereas the share of farm area devoted to both enset (*Enset ventricosum* (Welw.) Cheesman) and coffee (*Coffea arabica* L.) decreased from 45% to 25% in densely populated market-proximate areas. Meanwhile, in medium-populated, less accessible areas, enset and coffee together maintained a share of over 45% per farm, but cereals and vegetables gained in importance. Given the difficulty in the quantification of the productivity of the perennial crops enset and khat, we used allometric relations to estimate the edible and commercial yield of both enset and khat plants. As the home gardens produce several crops with distinct advantages (e.g. food, feed, cash generation), the farm level productivity was expressed in three ways, in terms of annual crop yield, human edible energy yield and revenue. The lowest farm level crop productivity was attained in the traditional Enset-coffee systems (1820 kg DM ha^{-1}) whereas the highest in the newly evolved Enset-cereal-vegetable systems (3020 DM kg ha^{-1}). Energy productivity from food crops was higher in Enset-based systems (43 GJ ha^{-1}) than in other systems whereas annual revenue was lowest in Enset-based systems (719 US$ ha^{-1}) and highest in newly evolved Khat-based systems (6817 US$ ha^{-1}). Introducing the high value cash crop khat and annual cereals in traditional home garden systems enabled smallholders to maintain food security and dietary diversity without jeopardizing plant species richness. Contrary to common claims, there was no positive effect of plant species richness on total crop and energy productivity except for the revenue in enset-oriented systems. The farm level gross margin attained in Khat-based systems was 4, 4, 2, and 2 times larger than in Enset-cereal-vegetable, Enset-based, Enset-coffee and Enset-livestock systems respectively. However, the shift away from enset and coffee, which received only organic fertilizer, to khat, which received solely inorganic fertilizer, led to a decline in N, P and K stocks by 20%, 70% and 30% respectively. With population density expected to continually increase in the region, improvement options tailored to the specific systems are required for sustainable development of home garden systems.

Key words: Allometric equations, crop productivity, dietary diversity, food security, ecological sustainability, home garden dynamics, market dependency, nutrient balances; nutrient stocks, population pressure, species richness, socio-economic sustainability

CHAPTER ONE

1. General introduction

1.1 Home garden systems in the highlands of East Africa

The East African highlands are among the most densely populated areas of Africa (Tittonell 2007). Many smallholders in this region own less than a hectare of land (Abebe 2005; Tittonell 2007). Low agricultural productivity and continuous farmland fragmentation limit smallholders in their ability to provide a sustainable supply of food and feed (Abebe 2005; Tittonell 2007). As a lack of capital stands in the way of increasing agricultural productivity through the use of more inputs, farmers try to maximize the output per unit of land by growing more crops in one field (Fernandes et al. 1984; Kippie 2002; Abebe 2005). By doing this, for example by intercropping cereals with legumes or annual crops with perennials, they can both increase land productivity and diversify their produce (Spiertz 2012). Home garden systems, in which crop production is combined with the rearing of livestock and the growing of trees on small plots of land (Kumar and Nair 2004; Landon-Lane 2011) are an example of integrated land use systems. The high population density – up to 500 and even 700 persons per km^2 in parts of the highlands of Tanzania and Ethiopia respectively (Fernandes et al. 1984; Abebe 2005) – underscores the need to increase productivity in the face of prevailing farmland constraints. Home gardens allow for increasing productivity by combining crop species with a diverse canopy structure, ensuring an optimal utilisation of light, water and nutrient resources (Soemarwoto 1987; Niñez 1987). Perennial crops such as banana, enset, papaya, yam, coffee and timber and fruit trees are useful in home gardens, not only because they provide cash, but also because they protect the soil from erosion by providing permanent cover, and enrich it by supplying continual organic matter in the form of litter fall (Fernandes and Nair 1986; Kippie 2002; Abebe 2005); (Torquebiau 1992). Trees have multiple functions as well, supplying fuelwood, wood for construction, livestock feed and cash, besides helping to maintain soil fertility (Kumar and Nair 2004; Abebe 2005).

One important reason for the popularity of home gardens in the densely populated East African highlands is they are more stable than monocropping systems (Torquebiau 1992 ; Banik et al. 2006). In Ethiopia, Uganda and Tanzania, home gardens are covering about 576,000, 130,000 and 120,000 hectares respectively (Fernandes et al. 1984; Oduol and Aluma 1990). Home gardens are claimed to be efficient, ecologically and socio-economically sustainable agro-ecosystems that can sustain basic needs without causing environmental deterioration (Fernandes and Nair 1986; Kumar and Nair 2004). The ecological sustainability of home gardens is related to their plant diversity and the role those plants play in soil fertility maintenance through continued organic matter supply, nitrogen fixation and soil protection (Kumar and Nair 2004; Wiersum 2004). The economic sustainability of home gardens is commonly attributed to the low cost of production, the possibility to harvest multiple products and to generate income from multiple sources (Kumar and Nair 2004). Their social sustainability is attributed to the fact that they give access to diverse food sources (Thaman 1995; Kumar and Nair 2004).

Increasing population pressure, with expanding food demands, exerts a huge pressure on home garden systems in the east African highlands (Fernandes and Nair 1986; Kippie 2002; Abebe 2005). In response to this, and the resulting farmland fragmentation, traditional home garden systems tend to change towards monocropping systems. In Ethiopia the rise of the high value cash crop khat (*Catha edulis* Forsk) has been attributed to such drivers (Abebe 2005). Increased market opportunities are also claimed to facilitate the turning towards cash crops in this region (Abebe and Bongers 2012). The change of home garden systems is claimed to have resulted in a simplification of the traditional land use systems (Abebe et al. 2010; Dessie and Kinlund 2008), which is believed to threaten food security and the ecological benefits that traditional home gardens provide. However, hardly any quantitative information is available on how these transitions have influenced ecological and socio-economic sustainability of home garden systems. On account of the diversity in farms in terms of resource endowment and the difference in their proximity to market places, the influences of these drivers is likely to vary both within and between localities. Understanding this variability is essential for designing new technologies to improve agricultural productivity (Giller et al. 2011; Descheemaeker et al. 2016). The aim of the present study is to gain a better understanding of how increasing population density and market developments influence home garden systems and impact on agricultural sustainability.

1.2 Home gardens in Ethiopia

In Ethiopia, particularly in the Southern Nations Nationalities and Peoples' Regional State (SNNPRS), home gardens are the most important land use system, covering about 576,000 hectares, which amounts to 31 % of the region's arable land (Abebe 2005), and supporting more than 15 million people (Abebe et al. 2010). In these land use systems typically the production of perennial staple food crops, especially enset (*Enset ventricosum (Welw.) Cheesman*) and cash crop coffee (*Coffea arabica L.*), is combined with annual crops, the rearing of livestock and the growing of multipurpose trees, usually on less than a hectare of land (Abebe 2005). Enset and coffee are cultivated over more than 65% of the farm area; therefore this land use type is often called ‘enset-coffee home gardens’ (Abebe 2005). Enset is a herbaceous multipurpose crop and a staple food for about 18% of Ethiopian population (Amede and Diro 2005; Abebe et al. 2010). Besides being a food source, enset is also a major source of livestock feed (Abebe 2005; Kippie 2002). These two perennial crops limit soil erosion and runoff, thus contributing to water and nutrient conservation in the system (Amede and Diro 2005). Hence, enset and coffee fulfil both productive and protective functions (Abebe 2005; Kippie 2002). The home gardens’ capacity of supporting a very dense population of up to 500 person per km^2 (Abebe 2005) is mainly explained by the fact that they produce a larger amount of biomass from enset than annual crops could yield (Fig. 1.1b) (Tsegaye and Struik 2001; Abebe 2005).

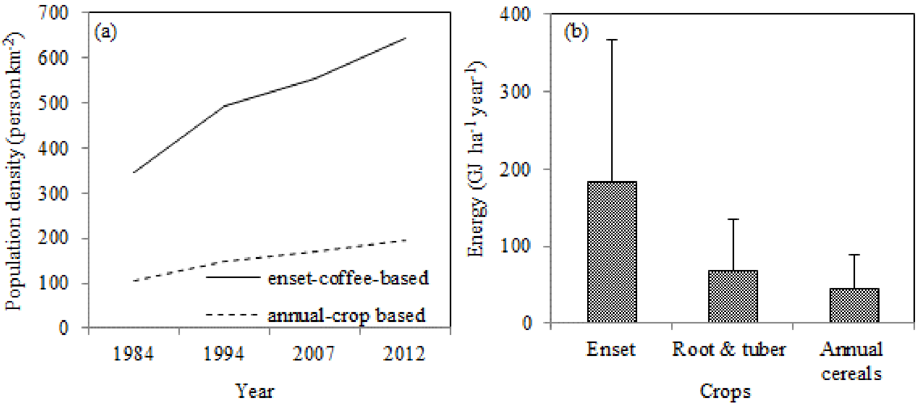

Fig. 1.1a Population density in Sidama and Gedeo zones for two farming systems from 1984 to 2012. Fig. 1.1b Annual productivity of enset (2000) in enset-coffee-based systems, and root & tuber crops (1998-1999) and cereals (1990-1997) in annual-crop-based systems (Source: population density based on CSA statistical bulletin (1984-2012) and crop yields based on Tsegaye and Struik (2001).

The livestock products in the home gardens complement the nutrition-poor enset in the diet (Brandt et al. 1997; Tsegaye and Struik 2001). Manure is used as fertilizer for enset and coffee and, in turn, enset leaves are used as livestock feed; thus organic matter is being recycled (Abebe 2005). The combination of these two native perennial crops can support a higher population density than an annual-crop-based systems in Ethiopia (Fig. 1.1a). However, to what extent these systems can continue to support the increasing rural population is uncertain, as population density in southern Ethiopia is exceeding the 500 person per km^2 the home garden system is claimed to be able to support (Fig. 1.1a).

1.3 Home gardens and the need to feed Ethiopia's growing population

Rapid population growth, from 42.6 million in 1984 to 83.7 million in 2012, has made ensuring sustainable access to food a major challenge for Ethiopia (CSA 2012). Limited land resources and low agricultural productivity are compounding the problem (Bezu and Holden 2014). In the country's densely populated SNNPRS region, where the problem of land scarcity is severe (Worku 2004), the enset-coffee land use is declining (Tsegaye and Struik 2001; Abebe 2005). Many households have become more dependent on the food market (Amede and Diro 2005). The growing market dependency for family food is partly caused by the declining enset productivity (Amede et al. 2001). Consequently, farmers are tempted to replace enset and coffee with monocropping cash crops, such as khat (*Catha edulis Forsk*) and annual cereals (barley and maize) (Fig.1.2).

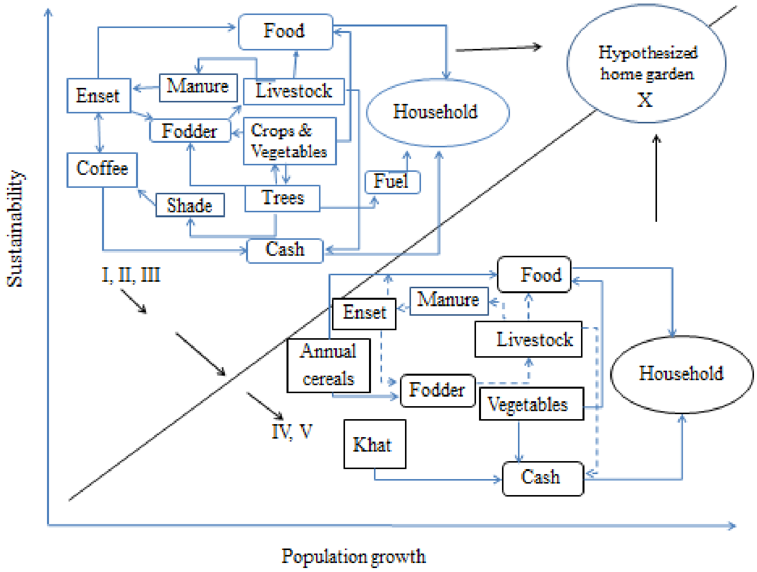

Fig. 1.2 A conceptual framework which shows the effects of the replacement of key species (enset and coffee) in the traditional systems (I, II and II) by khat, annual cereals and vegetables in the resultant less sustainable systems (IV and V) under increased rural population density; the hypothesized home garden system X represents a newly designed system that is both sustainable and can accommodate a large population density. Dotted line arrows indicate the decline in resource flow among livestock-enset and enset-household components of the system.

Khat leaves and tender twigs are chewed for their stimulating effect (Feyisa and Aune 2003). Most studies of the home gardens of southern Ethiopia claim that the expansion of khat and annual cereals has resulted in a homogenisation of the structure and composition of the traditional home garden systems (Abebe et al. 2010; Dessie and Kinlund 2008). Yet little is known about the rate at which those systems have shifted to monocropping systems, about the extent to which they did so in different regions, and about the factors that could explain the development. Some argue that the bias of research-and-development efforts towards improving annual food crop productivity (Alemayehu et al. 2011) and the neglect of enset are causes of the declining capacity of enset-coffee systems to support an increasing population density. The laborious and complicated harvesting and processing procedures of enset (Tsegaye and Struik 2001), which make it hard to obtain quantitative information about productivity, are claimed to explain its neglect by policy makers (Abebe 2005).

1.4 Quantitative analysis needed for the design of sustainable farming systems

Traditional home garden systems based on enset and coffee are believed to be socio-economically and ecologically sustainable up to a certain level of population density. When the population density exceeds a certain threshold, farmers tend to replace enset and coffee, key components of the traditional system, with high-value cash crops like khat or quickly-maturing crops like annual cereals and vegetables. Thus, the newly-evolved systems are believed to be socio-economically better performing while jeopardising ecological sustainability. While diversified production and income generation are generally seen as typical features of the home garden system (Kumar and Nair 2006; Pulami and Poudel 2006), the earlier studies either describe the system in a qualitative way only, or assess species composition and diversity (Kumar and Nair 2004) while overlooking the contribution the different components make to productivity, food security and dietary diversity. As a result, the economic and ecological rationale behind home garden practices is seldom recognized by policy makers, and little has been done to improve these systems and increase the productivity of perennial staple crops (Abebe 2005). Although the lack of quantitative information is blamed for the neglect of enset, few efforts have been made to develop better ways of estimating enset yields. Efforts to increase productivity are not only lacking with regard to enset production, but also in the case of coffee production, as most smallholders grow local varieties and the availability of improved coffee varieties is limited. The observed land-use change is expected to cause a change in system components such as herd size and species diversity, as well as in the interaction between these components, affecting soil fertility and agricultural productivity. Due to a lack of quantitative data, it is not yet known how changes in the home garden system influence ecological sustainability (e.g. species diversity, soil fertility, nutrient balances) and socio-economic sustainability (e.g. food security, dietary diversity and productivity). Such information is crucial for efforts to improve the design and management of the system, and enable an efficient use of resources and an increase of productivity.

In order to understand the value of traditional and newly-evolved home garden systems, empirical and analytical research needs to be conducted; on the basis of its results, more sustainable land use systems could be developed.

1.5 Objectives of the study

The aim of this study is to contribute to the design of sustainable agricultural systems in southern Ethiopia in the face of rising population density and market developments (see Fig. 2.2). This calls for an in-depth investigation into how population pressure and market developments influence the dynamics of the home garden systems. The development of allometric relations of enset and khat yields forms the basis for the quantitative assessment of home garden productivity. On the one hand, assessing the productivity of home garden systems helps to explain it in the light of variations in management related to input use and the recycling of organic matter. This will help to identify the challenges and opportunities for productivity improvement. On the other hand, it allows us to understand the food security status of smallholder farmers, and thus to assess the socio-economic sustainability of home garden systems. In order to compare traditional and newly-evolved home garden systems, the soil fertility status and nutrient balances of both systems need to be taken into account. Such a study could bring to light how the components of home gardens function and interact, and to identify entry points for creating a more sustainable system. This study was designed with a view to assess home garden system dynamics over the past two decades, and to analyse soil fertility, productivity and profitability in order to bring out the implications for food self-sufficiency, food security and dietary diversity.

The specific objectives are (in regard to home garden systems in southern Ethiopia):

i) to describe the two-decade dynamics of cropping pattern and herd size, and the diversity in home gardens systems;

ii) to develop and evaluate allometric models for estimating enset and khat yields;

iii) to assess the productivity, food self-sufficiency and food security of home garden systems;
iv) to analyse nutrient balances and profitability for specific crops and types of home garden systems;
v) to explore sustainable development options.

1.6 Outline of the thesis

The outline of the thesis is presented in Fig. 1.3. In Chapter 2 the dynamics of home garden systems is studied on the basis of a survey of 240 farm households, focus group discussions and a questionnaire. It provides information on changes in cropping pattern, herd size and offers and explanation of these changes. Based on land use, farms are grouped into five types of home garden systems, and a two-decade trajectory of each type is being mapped out. In Chapter 3 allometric models are developed and used for estimating the nutritional (food and feed) and commercial value of enset and khat crops. In Chapter 4 the productivity, food security and dietary diversity of different home garden systems are being compared and explained. In addition, this chapter shows how plant species diversity and farm productivity are influenced by the recent shift away from traditional home garden systems. Chapter 5 describes the ecological and economic sustainability of different crops and home garden systems. Soil nutrient stocks and nutrient balances are used as indicators of ecological sustainability, and gross margins for economic sustainability. Finally, in Chapter 6, the main findings and relevant conclusions are brought together and development options are discussed.

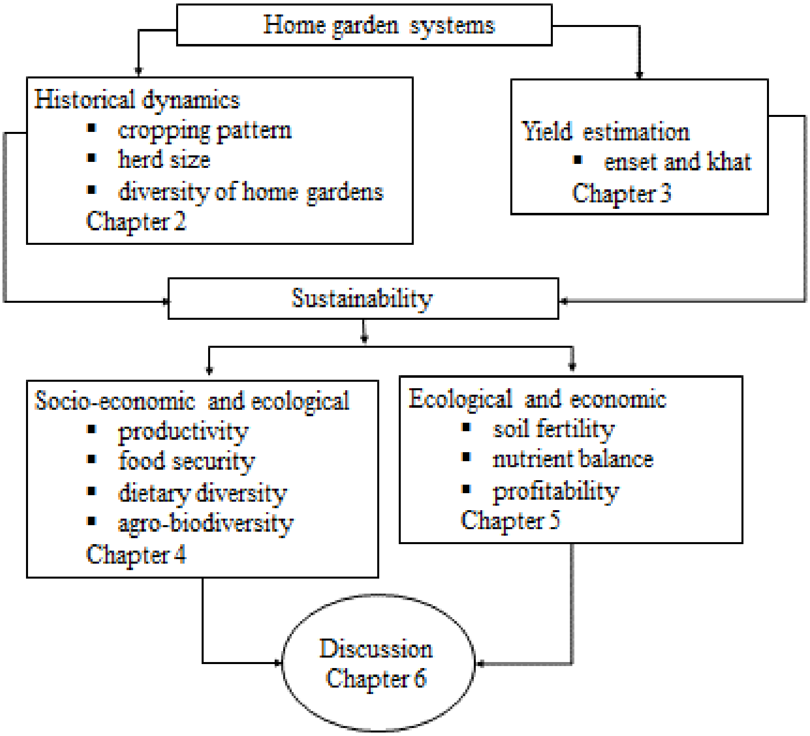

Fig. 1.3 Links among the different chapters of the study.

CHAPTER TWO

2. Home Garden System Dynamics in Southern Ethiopia

Abstract

Home gardens in southern Ethiopia are regarded as efficient farming systems, allowing interactions and synergies between crop, tree and livestock components. However, these age-old traditional home gardens are evolving rapidly in response to changes in both the socio-economic and biophysical environment. Altered cropping patterns, farm size and component interactions may affect the systems' sustainability. Home gardens exhibit a huge diversity in farms and farming systems, which needs to be understood in order to design interventions for improvement. Dynamics of home gardens were studied over two-decades (1991-2013) based on a survey of 240 farm households and focus group discussions. Farms were grouped into five types: Khat-based, Enset-cereal-vegetable, Enset-based, Enset-coffee and Enset-livestock. Farm trajectories revealed a shift from food-oriented Enset-based and Enset-livestock systems to (1) cash crop oriented khat-based systems, and (2) combined food and cash crop oriented Enset-cereal-vegetable systems. In densely populated, market proximate areas a major trend was expansion of khat, from 6% to 35% of the area share per farm, while the combined area share of enset and coffee decreased from 45% to 25%. Concurrently, the cattle herd size fell from 5.8 TLU to 3.9 TLU per household. In medium populated, less accessible areas the trend was consolidation of combined production of food and cash crops. Enset and coffee together maintained a share of over 45%. Easy transport and marketing of the perishable cash-generating khat compared with traditional crops favoured its cultivation among smallholders located close to markets. The insights in home garden change in response to increasing population pressure, decreasing farm size and market development may help to design interventions to increase system sustainability.

Key words: home garden types; cropping patterns; cash crops; commercialization;
diversification; *Catha edulis*

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2.1 Introduction

Home gardens are characterized by multipurpose trees and shrubs in intimate association with annual and perennial crops and livestock around the homestead (Kumar and Nair 2006). Home gardens ensure a sustained availability of multiple products and generate income (Kumar and Nair 2004). Despite their small size (Kumar and Nair 2006), home gardens fulfil most of the basic food and nutritional needs of the households, while the multi-storied configuration and high species diversity maintain their structure and function in the face of external stress (Kumar and Nair 2004).

In the Southern Nations Nationalities and Peoples' Regional State (SNNPRS) of Ethiopia, home gardens are the prevalent land use system covering about 576000 ha, which is 31% of the region's cultivable land (Abebe 2005). The traditional 'enset-coffee' home gardens are characterised by the combination of two perennial crops: enset (*Enset ventricosum* (Welw.) Cheesman) and coffee (*Coffea arabica* L.). Enset is a herbaceous, multipurpose crop and a staple food for more than 15 million people (Abebe et al. 2010). Enset leaves are a key livestock feed and used as mulch to reduce soil erosion and runoff (Amede and Diro 2005). Hence, enset fulfils both productive and protective functions (Kippie 2002). Coffee is mainly a cash crop, but is also consumed (Kippie 2002; Abebe 2005).

Increasing population pressure and subdivision of farms have led to fragmentation of land, a decline in the area under coffee and enset (Tsegaye and Struik 2001; Abebe 2005) and gradual replacement of the age-old diverse system. A major change is the expansion of a mono-cropping system of khat (*Catha edulis* Forsk) at the expense of enset-coffee home gardens (Tsegaye and Struik 2001; Abebe et al. 2010). Khat is grown for its economically important leaves and tender twigs, which are chewed for their stimulating effect. Due to the decline in enset cultivation, many households have become more dependent on the food market (Amede and Diro 2005). Market dependency for family food is further exacerbated by decreasing farm area and productivity of food crops (Amede et al. 2001). In countries like Ethiopia, where smallholder farmers have no access to insurance, the market dependency increases the vulnerability to economic or environmental shocks. The replacement of enset has also induced a shortage of livestock feed with direct repercussions on herd size, herd composition, livestock production and hence, nutritional quality of human diets (Tsegaye and Struik 2001). Most studies on the home gardens of southern Ethiopia claimed that expansion of khat has resulted in homogenization of the structure and composition of the traditional land use systems (Abebe et al. 2010; Dessie and Kinlund 2008). Yet, little is known about the rate at which those systems have shifted to mono-cropping systems, how that differs across the region, and which factors could explain it. Other studies (Herrero et al. 2009; Ebanyat et al. 2010) suggest trends in institutional support, resource endowment, prices, social conditions and technology as drivers of farming system change, but these have not yet been investigated for the particular case of home gardens in southern Ethiopia.

Similar to many other areas in sub-Saharan Africa, SNNPRS is characterized by a huge diversity in farms and farming systems, even though they are grouped under the common term home gardens. Recognizing this variability within and among farming systems and localities is the first step in the design of new technologies to improve agricultural production (Giller et al. 2011; Descheemaeker et al. 2016).

With the wider aim to contribute to the development of tailored interventions to improve agricultural production and productivity, this paper aims to: (i) understand the diversity in home garden systems of southern Ethiopia; (ii) analyse trends in farm size, cropping pattern and livestock population over the past two decades; (iii) explain the spatial patterns of change in home gardens in relation to market access, agro-ecological conditions and population density. We combined quantitative and qualitative methods, including secondary data collection on demography and farm size, a farm typology based on the area share of crops and grazing land, and constructed a 20-year timeline of farming system change based on detailed household interviews concerning current and past farm assets and practices.

2.2 Materials and methods

2.2.1 The study area

Sidama and Gedeo are representative zones of the SNNPRS region with a prevalence of enset-coffee home gardens. These home gardens are characterised by the production of enset, coffee and multi-purpose trees, accompanied by root and tuber crops, vegetables, annual cereal crops and livestock keeping (Kippie 2002; Abebe et al. 2010). Sidama is located within 5º45'- 6º45' N and 38º5'-39º41' E, covering a total area of 7,672 km^2 (Abebe 2005) with 3.50 million inhabitants (CSA 2007). Gedeo is located within 5°50'- 6°12' N, 38°03'-38°18' E, covering a total area of 1,347 km^2 (Kippie 2002) with 0.84 million inhabitants (CSA 2007). Most *kebeles* (smallest Ethiopian administrative unit, also called peasant association or PA) in both zones are classified as ‘rural’ (CSA 2007). The rainfall distribution is bimodal with a long (June to September) and short (March to May) rainy season. Both Sidama and Gedeo straddle two agro-ecological zones, the moist mid-altitude (In Amharic: *woinadega*) and the moist highland (In Amharic: *dega*). The moist mid-altitude zone ranges in elevation from 1500 to 2300 m a.s.l. and receives 1200-1600 mm rainfall annually; the average annual temperature ranges from 16 to 22^{o}C. The moist highland zone comprises an elevation range of 2300-3200 m a.s.l.; mean annual rainfall amounts to 1600-2000 mm and the average annual temperature ranges from 15 to 19^{o}C. The soils in the mid-altitude and highland agro-ecologies are mainly characterized by clay-loam to silt-loam and sandy-loam to sandy-clay textural classes respectively.

2.2.2 Selection of study sites and farm households

Within Sidama and Gedeo zones, four districts (In Amharic: *woreda*) were selected (Wondo Genet, Melga, Dale and Bule) and within each district, 6 PAs, giving 24 PAs in total (Fig 2.1). The multistage sampling approach for districts and PAs was designed to encompass differences in distance to markets, agro-ecological conditions and population density (Table 2.1). These factors were hypothesised to affect farmers' crop allocation decisions through their influence on the ease of transportation of agricultural products, crop suitability and farm size, respectively. Distance from a major market and altitude were measured using a global positioning system (GPS) following roads and foot paths. The population density of each PA was collected from the Ethiopian Central Statistics Agency (CSA 1991-2013). The PAs were categorized into (i) three classes of distance to market, i.e. near (<36 km), medium (36-70 km) and far (>70 km), roughly corresponding to travelling times of 1.5, 3 and more than 3 hours by car, respectively, (ii) two elevation classes, based on agro-ecological zoning, i.e. high (>2300 m a.s.l.) and medium (1500-2300 m a.s.l.) (Kippie 2002; Abebe et al. 2010) and (iii) three classes of population density, i.e. high (>800 person/km^2), medium (500-800 person/km^2) and low (<500 person/ km^2).

On average 10 households per PA, 240 households in total, were selected for the household survey. The districts' Bureau of Agriculture categorized farms as small, medium and large based on the area of their land holding and the number of livestock. Farms with > 1.25 ha of land and > 5 TLU were categorized as large, 0.5 -1.25 ha and 1- 5 TLU as medium, and < 0.5 ha and 0-1 TLU as small. Stratified random sampling ensured that the number of selected households in each group was in line with their share in each of the PAs.

2.2.3 Data collection

We combined qualitative and quantitative data collection approaches to triangulate the relevance and accuracy of the information gathered (Ebanyat et al. 2010). Eight focus group discussions (FGDs) were organized, four in midland PAs (Ywo, *Kocho*w, Soyama and Dero) and four in highland PAs (Gikeatoye, Guguma, Duba and Elalcha). In each FGD eight to ten farmers participated representing different age groups, both sexes and each farm size category. The discussion focused on positive and negative aspects of khat expansion, constraints to maintain enset and coffee, population growth and its impact on resource availability (land), change in income sources, emergence of new activities, economic infrastructure (roads and transport service), market development and price trends.

A detailed household survey was administered between August and November 2013 with 240 farm households. We used a semi-structured questionnaire to collect data on changes, trends and events in the past two decades with the aim to construct a timeline. To capture the changes in cropping and livestock systems, household heads were asked to recall the year of khat introduction, land allocation to various annual and perennial crops (food crops, cash crops), total land holding and herd size from 1991 to 2013 in a stepwise fashion. The year of the regime change in Ethiopia, 1991, and the following national election years (1994, 2000, 2005 and 2010) were used as benchmarks to help respondents' recall. Household heads were further asked about demographic characteristics (family size, level of education), production objectives, sources of income, constraints to crop production and livestock rearing and dependency on the market for food (number of months per year). Farmers also listed and ranked political, cultural, environmental and economic factors triggering the changes in land allocation and farming practices based on a score of one (low importance), two (average importance) or three (high importance). The mean score of each factor was calculated using the formula

$$M_i = \frac{\sum_{j=1}^{3} f_{ij} \times j}{n}$$

where M_i = mean score of factor i; f_{ij} = the percentage of respondents that gave a score of j for factor i and n = the total number of respondents that listed factor i.

Enumerators with a certificate in agriculture and speaking the local language were recruited from the localities and trained in data collection. Retail prices of coffee, khat, *kocho* (the processed edible part of enset), tef (*Eragrostis tef* (Zucc.) Trotter) and maize (*Zea mays* L.) were collected from CSA.

Table 2.1 Peasant associations (PA), numbers of surveyed households in each of the three farm size categories, distance to market, elevation and population density. source: Ethiopian Central Statistical Authority (CSA 1991-2013)

No	Site (PA)	District (Woreda)	Sample size	Sampled farms by farm size			Distance to major market place (km)ᵃ		Elevation (m a.s.l.)	Population density (person/km^2)^b	
				Large	Medium	Small					
Mid-land agro-ecology (1500-2300 m a.s.l.))											
1	Ywo	Wondo Genet	11	1	4	6	N	12.4	1679	H	958
2	Chuko	"	12	1	3	8	N	26.4	1756	H	1551
3	Weterakechema	"	7	1	2	4	M	36.4	1755	M	714
4	*Koch*ow	Melga	10	2	4	4	N	24.4	2145	H	834
5	Manicho	"	11	1	8	2	N	25.4	2190	H	858
6	Berana	"	9	1	6	2	N	30.9	2216	H	915
7	Soyama	Dale	9	1	6	2	M	36.3	1787	H	852
8	Megera	"	10	1	4	5	M	47.8	1746	M	566
9	Awada	"	11	2	2	7	M	44.7	1753	L	433
10	Dero	Bule	11	1	4	6	F	126.8	2245	M	792
11	Bassura	"	11	3	3	5	F	114.8	2253	M	773
12	Osselemajo	"	8	2	2	4	F	118.5	2250	M	737
	Sub total		120	17 (14%)	48 (40%)	55 (46%)					
Highland agro-ecology (2300-3200 m a.s.l.)											
13	Weteragedo	Wondo Genet	8	3	3	2	M	38.1	2597	H	945
14	BaboChorora	"	9	2	4	3	M	40.5	2624	M	646
15	Gikeatoye	"	13	3	5	5	M	44.9	2599	H	1565
16	Fitoketemuna	Melga	12	4	4	4	M	41.1	2561	H	950
17	Gerewe	"	9	3	4	2	N	34.6	2634	M	508
18	Guguma	"	9	3	2	4	M	47.1	2677	M	583
19	Hayello	Dale	8	2	2	4	F	70.2	2328	H	1023
20	Duba	"	10	1	2	7	M	47.4	2338	H	1153
21	Gedamo	"	12	1	3	8	M	64.7	2339	L	102
22	Elalcha	Bule	11	3	4	4	F	126.9	2902	L	469
23	Akollo 1st	"	11	2	4	5	F	142.9	2787	L	272
24	Suko	"	8	2	2	4	F	135.1	2709	L	43
	Sub-total		120	29(24%)	39 (33%)	52 (43%)					
	Total		240	46(19%)	87(36%)	107(45%)					

[a] N = near, M = medium, F = Far; [b] H = high, M= medium, L = low

The price in Ethiopian birr was converted to US$ at a rate of 2.5, 6.3, 8.6, 17.5 and 19.1 Eth. birr to one US$, the average exchange rate in 1991-1994, 1995-1999, 2000-2008 and 2009-2012 and 2013-2014 respectively (NBE 1991 - 2014). The revenue per hectare was calculated by multiplying the price of each crop with the average yield (assumed to be constant over the study period).

2.2.4 Farm typology

We constructed a farm typology based on crop allocation data from the household survey after exploring the data using Ward's minimum variance method (Joe and Ward 1963), followed by a K-means clustering (Blazy et al. 2009). The area shares of nine crops (enset, coffee, khat, maize, other annual cereals, beans, root and tuber crops, vegetables and sugarcane) and grazing land were considered. Each of the identified farm types was named after the crops with the major area shares in 2013. In order to classify farms based on the same criteria over time, thresholds of area shares were derived based on the variation within each farm type, following (Falconnier et al. 2015). Considering these thresholds, we developed a decision tree to classify each farm into a distinct farm type for the six benchmarks in the timeline 1991-2013.

2.2.5 Data analysis

A one way analysis of variance (ANOVA) was used to test the difference between the means of five home garden types in family size, farm size, land to person ratio, herd size, income and market dependency. Differences were deemed significant at $P < 0.05$. Analyses were performed using the Statistical Package for Social Sciences (SPSS) version 20. Qualitative data was used to support the discussion of results.

2.3 Results

2.3.1 Characteristics of the home garden types

The variability in land use indicated a large diversity in farming systems in Sidama and Gedeo zones of southern Ethiopia. Five different home garden types were identified and characterized by the area share of the dominant crops and grazing land (Table 2.2, Fig. 2.2). Our decision tree

(Fig. 2.2) dictated that throughout the study period, farms with an area share of khat over 30% were classified as Khat-based systems. With less than 30% khat, home gardens were described as Enset-coffee if at least 35% of their area was covered with coffee. Subsequently, Enset-livestock systems were identified if grazing land covered more than 20%. Of the remaining two types, Enset-based and Enset-cereal-vegetable systems were distinguished based on an enset area share of at least and less than 35% Enset, respectively.

In Khat-based and Enset-based home gardens khat and enset covered 51 and 58% of the farm land respectively (Table 2.2). The combined area of enset, cereals and vegetables covered more than 60% of the area in the Enset-cereal-vegetable system, while 89% of the area in Enset-coffee home gardens was covered by enset and coffee. In Enset-livestock home gardens the combined area of enset and grazing land covered more than 50% of the farm area. The highest proportion of cash crops was observed in Khat-based home gardens (60%) while the highest proportion of food crops was observed in Enset-based home gardens (74%). The largest proportion of grazing land was documented in Enset-livestock systems (34%). The average family size in Khat-based home gardens was significantly larger than that in Enset-based and Enset-livestock home gardens (Table 2.2). The average farm size showed no significant difference between home garden types, and the Khat-based home gardens had the smallest land to labour ratio.

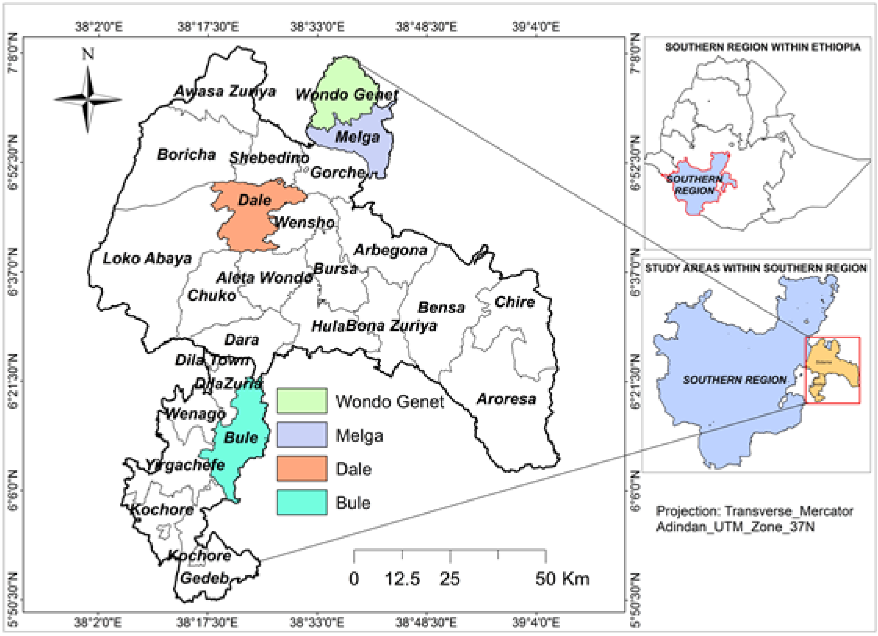

Fig.2.1 Map of the study districts (*woredas*) within Sidama and Gedeo zones, SNNPRS, Ethiopia

Table 2.2 Average (± standard error of the mean) crop allocation and household characteristics for the five home garden types; significant differences in household characteristics at P<0.05 are indicated with different letters within a row; dominant crops and grazing land that lend their name to the type are indicated in bold

			Home garden types				
		Description	Khat-based (K-b)	Enset-cereal- vegetable (E-c-v)	Enset-based (E-b)	Enset-coffee (E-c)	Enset-livestock (E-l)
		Number of farms	58	51	43	30	58
Share in the farm area (%)	Food crops	Enset	26.9±1.7	**18.8±1.3**	**57.6±2.2**	**39.9±2.2**	**21.7±1.4**
		Annual cereals	5.9±1.4	**24.3±1.9**	11.6±2.2	1.8±1.0	13.5±1.5
		Other food crops[1]	0.4±0.2	11.8±1.3	4.8±1.6	2.3±1.1	7.1±1.5
		Total food crops	33.2±2.1	54.9±2.5	74.0±2.6	44.0±2.4	42.3±2.2
	Cash crops	Coffee	3.0±0.6	5.6±1.3	10.8±1.8	**49.4±2.0**	3.4±1.0
		Khat	**51.2±2.0**	11.0±1.7	4.1±1.4	2.0±1.3	14.7±1.6
		Vegetables	3.8±1.0	**18.7±2.2**	5.8±1.8	1.4±0.8	4.8±1.0
		Other cash crops[2]	1.7±0.8	3.4±1.1	1.8±0.9	2.1±0.8	0.8±0.2
		Total cash crops	59.7±2.2	37.8±2.6	21.8±2.6	54.9±2.5	23.7±1.8
		Grazing land	7.1±1.2	7.3±1.1	4.2±1.3	1.1±0.5	**34.0±1.7**
Household characteristics		Family size (#)	9.0±0.5a	8.8±0.4a	7.0±0.5b	8.8±0.8ab	7.3±0.5b
		Farm size (ha)	0.8±0.1a	0.8±0.1a	1.0±0.1a	0.80±0.2a	1.0±0.1a
		Land: labour ratio	0.13±0.0b	0.18±0.0ab	0.27±0.1a	0.25±0.0a	0.25±0.0a
		Cattle (TLU[3])	3.8±0.4a	3.8±0.4a	2.8±0.5b	1.6±0.2b	4.5±0.4a
		Small ruminant (TLU[3])	0.4±0.0b	0.7±0.1a	1.0±0.2a	1.5±0.3a	1.0±0.1a
		Income (10^3 Eth. Birr)	28.0 ±8.0a	18.0±2.0ab	7.0±1.0c	12.0±3.0b	16.0±3.0b
		Market dependency for food (months)	5.3± 0.4a	2.9±0.4b	3.9±0.5a	3.1.±0.6ab	3.2±0.4b
Number of household heads according to educational level		Illiterate	10 (17%)	7 (14%)	13 (30%)	2(7%)	21(36%)
		Write and read	7 (12%)	3 (6%)	7 (16%)	5 (16%)	14(24%)
		Elementary	33 (57%)	27 (53%)	17 (40%)	17 (57%)	20(34%)
		Secondary	8(14%)	14 (27%)	6(14%)	6 (20%)	3(5%)

[1] Other food crops include: beans, root and tuber crops; [2] other cash crops include: sugarcane; [3]TLU: Tropical Livestock Unit

2.3.2 Distribution of home garden types across districts and socio-economic and biophysical environments

The four districts of the study area showed a different prevalence of the five home garden types. Wondo Genet and Melga were characterized by the dominance of two home garden types, namely Khat-based and Enset-cereal-vegetable in Wondo Genet and Khat-based and Enset-livestock in Melga. In both districts Enset-coffee systems were absent. Dale and Bule showed a more even representation of four home garden types. The Khat-based home garden type was not present in Bule and nearly absent in Dale.

The presence of the home garden types differed in relation to market access, population density and agro-ecology (Fig. 2.3). Close to markets, 56% of the farms were Khat-based (Fig. 2.3a). At medium and far distance their share was 17% and 0% respectively. The shares of Enset-cereal-vegetable, Enset-based and Enset-coffee home garden types all decreased with proximity to the market. The distribution of home garden types in relation to population density showed a similar pattern (Fig. 2.3b), with Khat-based systems gaining importance with increasing population density and an opposite trend for Enset-cereal-vegetable, Enset-based and Enset-coffee home garden types. Population density had no clear effect on the presence of Enset-livestock home gardens. In the mid-altitude zone Khat-based and Enset-coffee home gardens were more prevalent, while in the high-altitude zone Enset-based and Enset-livestock systems were more common (Fig. 2.3c).

2.3.3 Dynamics in cropping pattern and livestock holding in the four districts

The overall trend in cropping patterns in Wondo Genet and Melga indicated a shift from food to cash crop production over time, while in Dale farmers continued to produce a combination of food and cash crops and in Bule they remained food crop oriented (Fig. 2.4). In 1991 the combined area share of enset and coffee amounted to more than 45% in all districts of the study area. In 2013 it had fallen below 25% in Wondo Genet and Melga, whereas the area share of khat increased from about 5% in 1991 to about 35% in 2013 (Fig. 2.4). Even though khat cultivation was observed in 1991 also in Dale, it expanded less there from 0.9% in 1991 to 8% in 2013. In Bule, khat has not played any role worth mentioning in the past two decades (Fig. 2.4). Unlike the cropping pattern, the grazing land area was not noticeably influenced by the expansion of khat and was maintained at 8-12% in Wondo Genet and 20-23% in Melga for the last two decades. Grazing land area remained below 10% in Dale, and in Bule it varied between 8% and 17%, with a share of 13% in 2013.

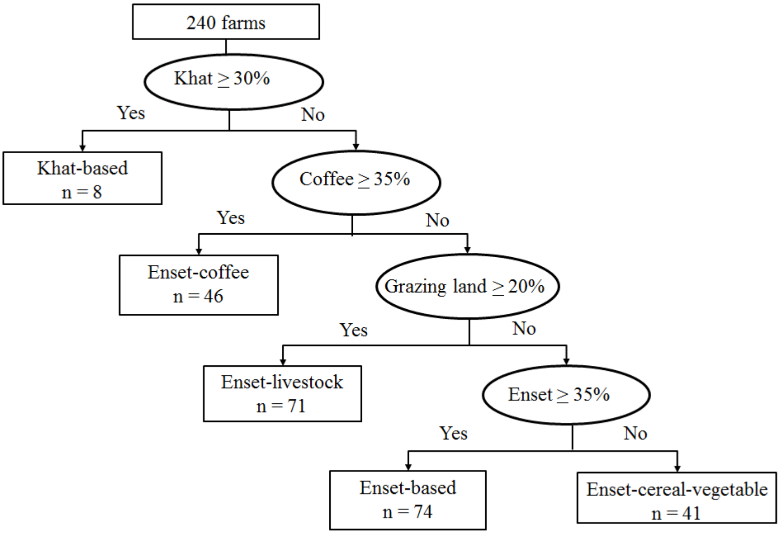

Fig. 2.2 Decision tree and threshold values for area share used for farm classification in five home garden types. Number of farms (*n*) refers to the year 1991

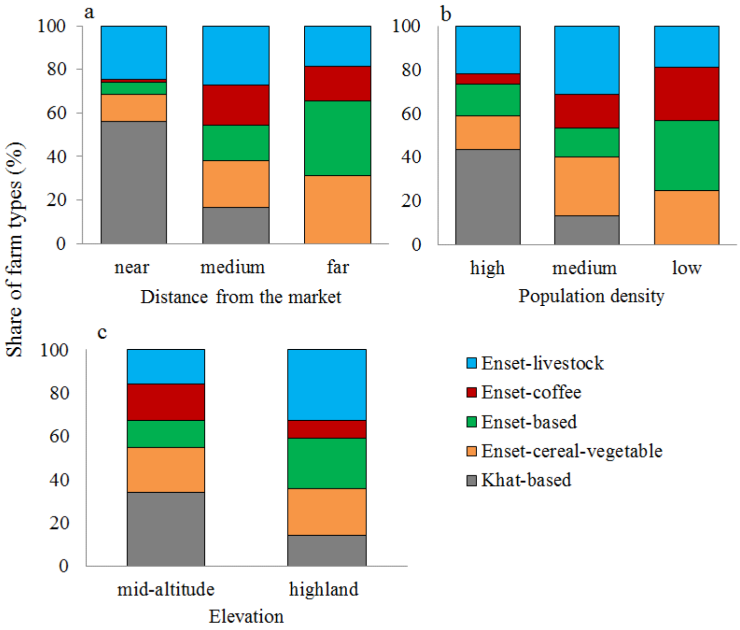

Fig. 2. 3 Share of home garden types in 2013 classified according to (a) market access, (b) population density and (c) elevation

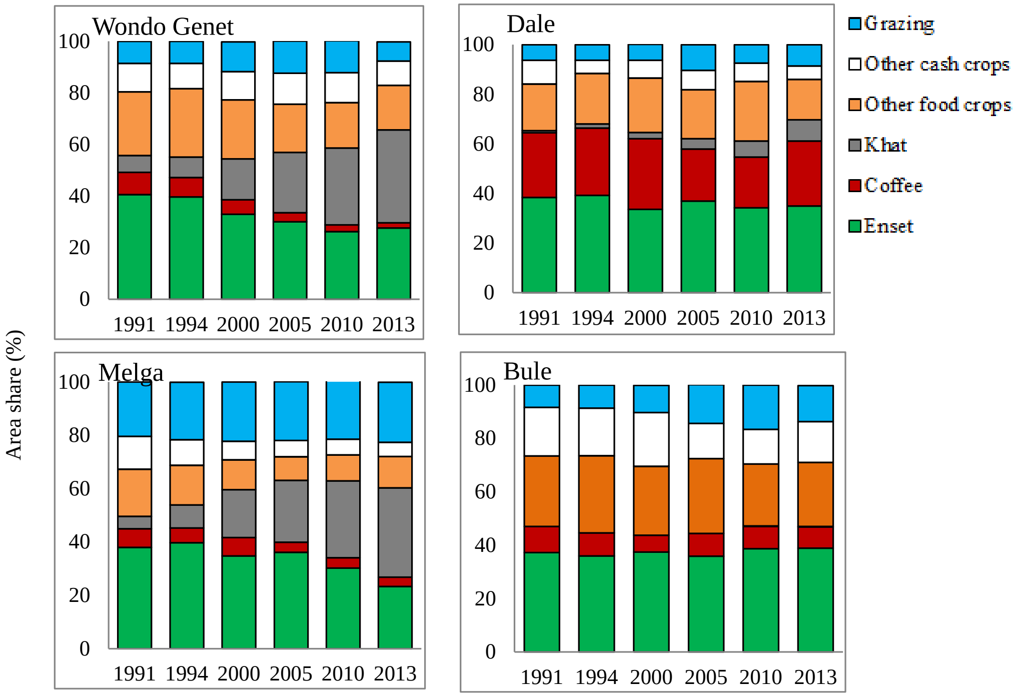

Fig. 2.4 Land use dynamics in the four districts of the study area in the period 1991-2013

2.3.4 Dynamics in the prevalence of home garden types in the period 1991-2013

In 1991, about 30% of the sampled farms were engaged in Enset-based and 30% in Enset-livestock farming, while only 3% was engaged in Khat-based farming (Fig. 2.5). The proportion of Enset-livestock and Enset-based home gardens decreased to 24% and less than 20% of the farms respectively in 2013 (Fig. 2.5). The share of Enset-coffee home gardens declined from 19% in 1991 to 13% in 2013. In contrast, the share of khat-based farms increased from 3% in 1991 to 24% in 2013. The percentage of farms in the Enset-cereal-vegetable system slightly increased from 17% in 1991 to 21% in 2013 (Fig. 2.5).

The transitions in home garden systems varied across the four districts of the study area (Fig. 2.6). In Wondo Genet most Enset-based home gardens in 1991 transitioned to Khat-based or Enset-cereal-vegetable home gardens in 2013, and the proportion of Enset-based farms dropped from 44% in 1991 to 7% in 2013. The farms practicing Enset-coffee farming in 1991 have all transitioned to either Khat-based or Enset-cereal-vegetable home gardens in 2013, as have half of the Enset-livestock home gardens. Also in Melga the major emerging type was the

Khat-based home garden, increasing from 3 to 39% of the farms at the expense of Enset-based and Enset-coffee home gardens, which fully disappeared by 2013.

The farm transitions were different in Dale and Bule districts. The main transition in Dale the emergence of the Khat-based home garden type was restricted to only 3% of the farms, but an increase in the proportion of the Enset-coffee system was noticed (Fig. 2.6). In Bule the Enset-based and Enset-cereal-vegetable home gardens gained some importance at the expense of the Enset-livestock and Enset-coffee home gardens (Fig. 2.6).

2.3.5 Determinants of farming system dynamics

Respondents identified population pressure, policy, infrastructure, profitability, decline in soil fertility, cultural change, lack of input, labour availability and harvesting frequency of khat as major determinants of land use change in the area. Among these nine factors, population pressure was ranked as the major driver of land use change. In all four districts population pressure increased (Fig. 2.7a) and contributed to the decline in farm size and land fragmentation. In Wondo Genet where population density doubled between 1991 and 2013 the rate of decline in land holding per household increased from 0.5% per year in the period 1992/94 to 5.1% per year in the period 2011/13 (Fig. 2.7). In Melga, Dale and Bule districts, where the increase in population density was less pronounced, the rate of decline in land holding did not exceed 3%.

A market liberalization policy implemented in 1991 and constitutionalized in 1995, which eliminated crop and livestock sale quota and price controls, was ranked as a second determinant. As a third factor farmers mentioned the cultivation of khat, which became popular thanks to its frequent harvesting and high return per unit area. According to the respondents, the shift to khat cultivation was further fuelled by the development of infrastructure (road, mobile phone) and urban expansion.

Declining soil fertility coupled with a lack of farm inputs (seed, fertilizer and manure) also influenced the land use dynamics of the study area. Farmers further referred to cultural change, and in particular to changing diets. Labour availability was ranked last in terms of its influence on land use change.

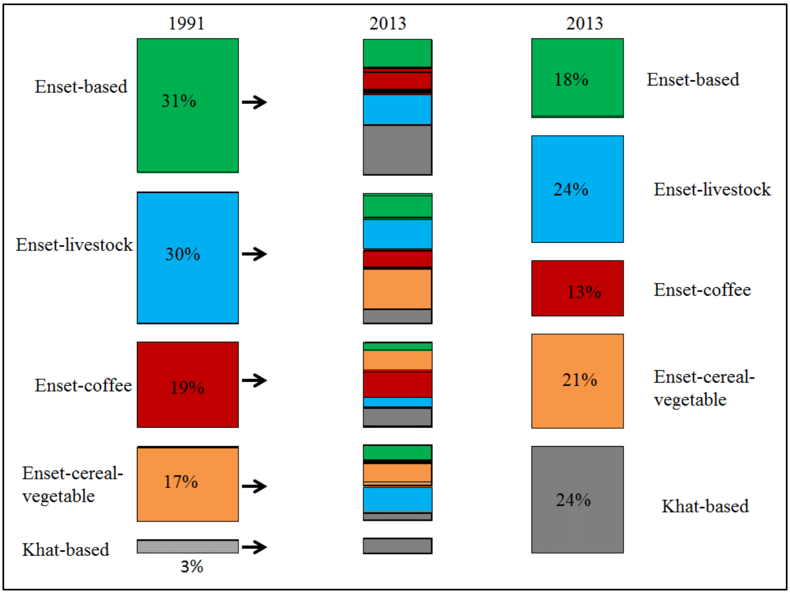

Fig. 2.5 Proportion of each farm type in 1991 and 2013 and their transition during this period in Sidama and Gedeo zones (*n* = 240 farms). The stacked bar in the middle represents the transition of farms from a given type in 1991 to the types in 2013; the height of each stacked cell and bar is representative of the number of farms

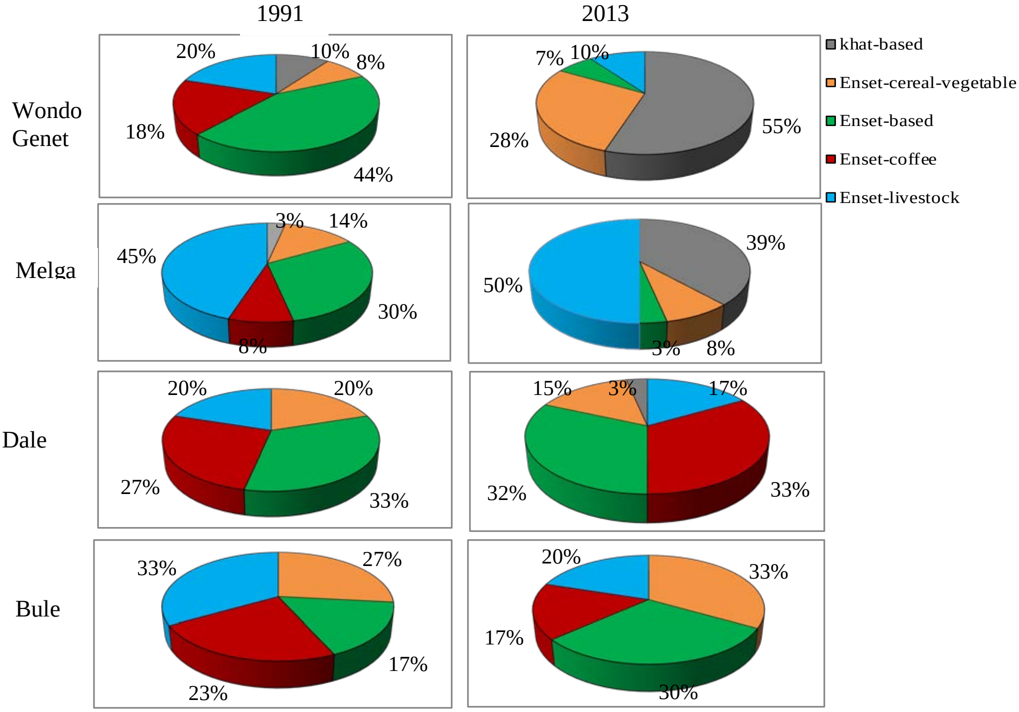

Fig. 2.6. Changes in the prevalence of home garden types in the four districts of the study area over the period 1991 to 2013

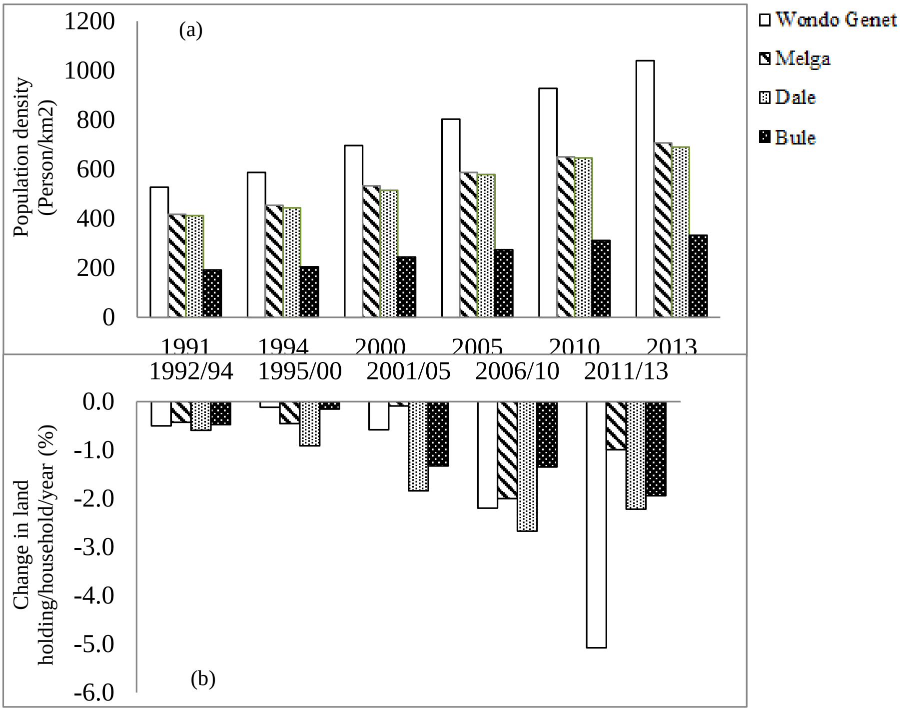

Fig. 2.7 Population density (a) and change in land holding per household (b) in the four districts between 1991 and 2013

The price of staple foods (maize, *kocho* and teff) rose gradually over the two decades (Fig. 2.8a). Among the food crops, the teff price showed the largest increase, from 0.4 US$ per kg in 1990/1 to 0.8 US$ in 2013/14. The price of maize was very close to that of *kocho*, increasing from about 0.2 to 0.3 US$ per kg over the whole period. The price of khat fluctuated around 3.5 US$ per kg of fresh weight in 1990/1 to 2013/14, and for coffee, it fluctuated between 1.3 and 4.3 US$ per kg in the same period (Fig. 2.8a).

Besides the price fluctuation, the greater income per hectare from khat may have further discouraged production of coffee. The average revenue per hectare from khat by far exceeded the average revenues from food crops (maize, teff and *kocho*) (Fig. 2.8b). As a result of the continuous fragmentation of land, the inability to produce sufficient amount of family food also discouraged smallholders to allocate land to food crops. Based on the assumption that 50% of the energy demand is provided by enset and 50% by maize, the area required to produce year-round food for an average household of three adults and five children was 0.46 ha. A yield of 6.2 ton per ha for enset and 2.3 ton per ha for maize were considered (ATA 2012). If these households shift to khat and buy all their food, they need only 0.05 ha, assuming a khat revenue of 9368 US$ per ha (Fig. 2.8b) and a price 0.3 US$ per kg for enset (*kocho*) and maize (Fig. 2.8a).

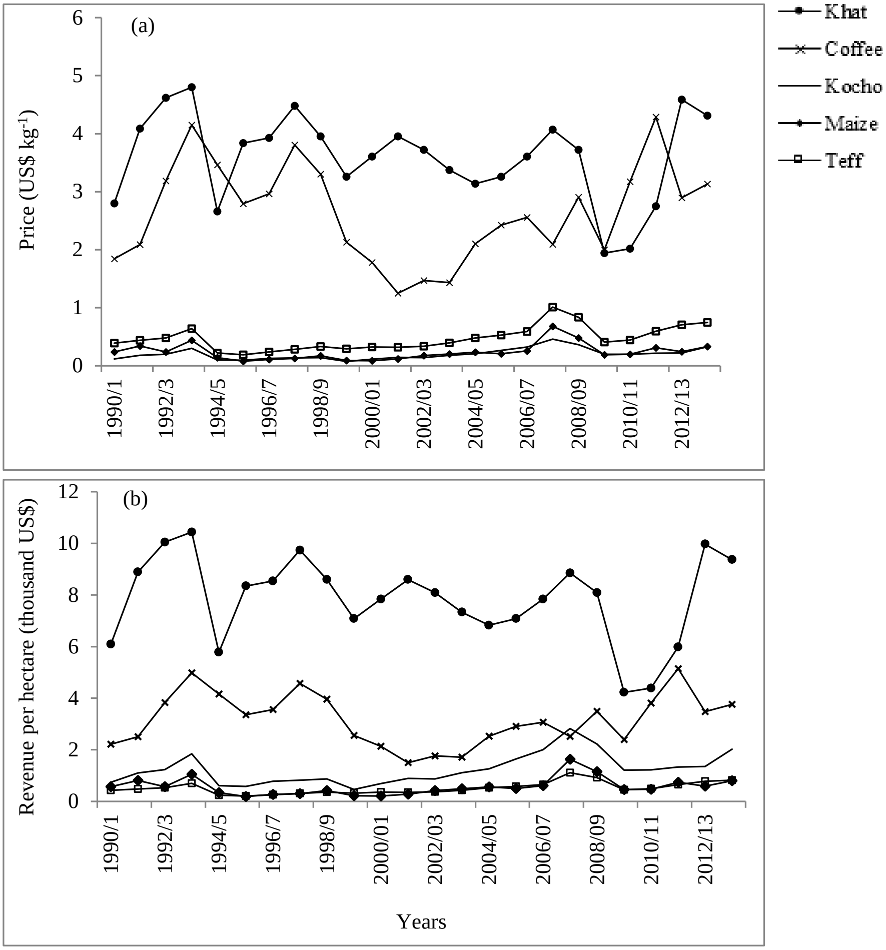

Fig. 2.8 Annual retail prices of food and cash crops (a) and revenue per hectare (b) over the period 1991-2014. (Source: Retailer prices calculated and summarized from price lists for the period 1991-2014 from CSA and Regional Custom Offices; the average maize, teff and coffee yield per ha summarized from the CSA statistical bulletin (2000-2013); average yield for *kocho* and khat per ha from ATA (2012)

2.4 Discussion

2.4.1 Expansion of khat cultivation

Cropping patterns in Sidama and Gedeo zones of southern Ethiopia changed most strongly in areas where khat was introduced and expanded over the last two decades (1991-2013). This trend was observed in particular in Wondo Genet and Melga (Fig.2.4) and simplified the cropping pattern with khat monoculture now occupying more than one third of the farm area. A similar expansion of khat was observed in the eastern highlands of Ethiopia, where it replaced sorghum (Feyisa and Aune 2003; Mekbib 2009) and in the Jima zone of southern Ethiopia where it replaced coffee (Dube et al. 2014).

Khat's popularity with smallholders is related to its profitability, its regular harvesting (two to three times per year) and its quick establishment (one to two years). On the one hand, the process of commercialization and specialization in cash crop monoculture may expose smallholder farmers to unpredictable market fluctuations, disease outbreaks and other adverse shocks, with a risk to become food aid dependent (Amede and Diro 2005). Farmers are particularly vulnerable if institutions, policies, and markets are non-supportive (Von Braun 1995), as in the case of the study area, where e.g. crop insurance schemes are non-existent. Similarly, other studies reported the incapability of small commercialized farms to continue cash crop cultivation following a decline in output prices, after which they reverted back to subsistence cropping (Wiggins et al. 2011). On the other hand, the increased income from cash crops may enable smallholders to buy food crops rather than having to produce everything themselves (Timmer 1997).

Khat's popularity with smallholders is further driven by disadvantages of the traditional crops, such as the long time before enset plants can be harvested (3 to 4 years after transplanting) and the unreliable price and long establishment period of coffee. Thus, in the context of the study area, the incorporation of khat in the production system may be viewed as an innovation to take advantage of market opportunities towards achieving food security and improving household income (Rehima et al. 2013).

2.4.2 Farming system transitions

The historical analysis of farming system transitions indicated a shift away from the traditional home gardens based on enset, coffee and livestock (Fig. 2.5), illustrating the inability of these systems to accommodate the increasing population. Whereas the traditional systems are known to support very dense populations of up to 500 persons km^{-2} (Kippie 2002; Abebe 2005), the population density of all study districts, except Bule, has surpassed this density since 2000 (Fig. 2.7).

In areas far away from major roads and markets farmers were less inclined to shift to khat, because of less stringent land constraints on the one hand and difficulties related to the marketing of the perishable khat twigs on the other hand. Hence, farms transitioned to Enset-based systems or modified the traditional systems by incorporating annual crops like cereals and vegetables, leading to the expansion of Enset-cereal-vegetable systems in Bule (Fig 2.6). Similar diversification with French beans or tomatoes was reported among smallholder coffee growers in central Kenya (Dorsey 2015). The degree of crop-livestock integration varied between farming systems, and the prevalence of competitive versus complementary roles of crops and livestock partly explains dynamics in livestock herd sizes. The advantage of combining crop and livestock activities in the traditional systems was related to the availability of cheap fodder for livestock, such as enset leaves, and of animal manure, contributing to enset and coffee growth. In the traditional home gardens, livestock also played a critical role in providing a protein and nutrient rich diet to the household, given the low nutritious value of enset (Brandt et al. 1997; Tsegaye and Struik 2001). The transition towards khat cultivation reduced herd sizes due to decreased fodder availability, especially from enset, and also lowered the interest in livestock rearing as a source of cash and manure. For example, in Wondo Genet the khat expansion went hand in hand with a decline in small ruminant numbers. If the demand for cash is met by khat, the need for keeping small ruminants recedes. Moreover, khat is typically fertilized with mineral fertilizer, reducing the need for animal manure. In addition, the feeding behaviour of small ruminants, browsing leaves and twigs, is incompatible with khat, as leaves and twigs are the economic product. Similarly, less interest in keeping draught animals was reported where khat, which does not require ploughing, replaced annual cropping systems in eastern Ethiopia (Kandari et al. 2014). Contrastingly, small ruminant herd sizes did not decrease in Dale and Bule, where the share of enset and coffee remained fairly constant (Fig. 2.4). This could be related to the availability of browse tree species for goats and understory grazing for sheep in coffee fields.

The decrease in cattle holding per household in the khat-dominated district of Wondo Genet occurred together with the replacement of enset (Fig. 2.4). Enset leaves have a high protein content (Brandt et al. 1997; Tsegaye and Struik 2001; Solomon et al. 2008) and a feeding value that is comparable to a good quality grass (Fekadu and Ledin 1997). Similarly, Kandari et al. (2014) reported a decline in per capita herd size following complete replacement of major fodder crops by khat in Harar region of eastern Ethiopia. In Melga we observed the opposite trend of a slight increase in cattle ownership, which could be related to the absence of feed shortage in this district, allowing farmers to expand their herd size. This hypothesis is supported by the relatively large grazing land area per household and the fact that smallholders move their cattle to nearby lowland areas during the rainy season and conserve their own pasture land for dry season grazing (focus group discussion). The smallest herd sizes were observed in Dale, where the area of grazing land was particularly small. Indeed, livestock feed scarcity due to lack of grazing land is often reported as the major constraint of livestock production also in other districts of Sidama zone (Samuel 2014).

2.4.3 The main drivers of changes in land use and farm type transition

The main land use change, the replacement of Enset-oriented systems by Khat-based systems, was observed in areas close to markets (Fig. 2.3). The improved road networks and the proximity to the regional capital city, Hawassa, opened up market opportunities for the farmers, especially in Wondo Genet. The importance of a nearby market is related to khat’s perishable nature, with a maximum shelf-life of four days after picking (Distefano 1983). Also in the Hararghe highlands of eastern Ethiopia, the proximity of a market and easy transportation were determinants of khat expansion (Woldu et al. 2015). In addition, the high income potential motivated smallholders to allocate more land to khat cultivation. The revenue per ha from khat exceeded that of maize and teff sixteen times and of coffee three times (Fig. 2.8b). Dessie (2013) reported similar values, fifteen times for cereals and four times for coffee. In Wondo Genet, the expansion of khat was further stimulated by the growing population density (Fig. 2.7). The resulting land fragmentation, particularly after 2005 when population density exceeded 800 persons km^{-2} (Fig. 2.4, 2.7), left khat cultivation as one of the few alternatives to make a living from the tiny farm areas. The strong positive relationship between area share of khat and population density was also confirmed in eastern Ethiopia (Tefera 2009). In Wondo Genet the total area allocated to cash crops increased over time to almost 50% (Fig. 4). The inclination of smallholders towards cultivating cash crops when smaller farm sizes impair food self-sufficiency was also described by Woldu et al. (2015).

In contrast to Wondo Genet, in Bule none of the identified drivers for khat introduction and expansion was present. The district is far from the market (> 100 km), population density in 2013 was medium (750 people km^{-2}) in the mid-altitude zone and low in the highlands (250 people km^{-2}). Furthermore, the highland altitude of 2700-2900 m a.s.l. is above the suitable range for khat (Lemessa 2001). Melga closely resembled the situation in Wondo Genet, with the difference that population growth and also land fragmentation where somewhat lower. As a result, the area share of khat-based systems and the area under cash crops were smaller than in Wondo Genet in 2013. Dale also took an intermediate position. It is at medium distance from the market, leading to a risk of quality loss for khat during transport (Distefano 1983). It had a medium population density, similar to Melga, and the altitude did not exceed 2350 m a.s.l., posing no agro-ecological constraint to khat. The improved road networks around Hawassa also benefitted the districts further from the market, such as Dale.

An increase in population also results in a growing labour force. Khat requires about three times more labour than cereal crops on a per hectare basis (Getahun and Krikorian 1973). However, in the densely populated study area there are no labour shortages that could have constrained khat expansion. Some authors argue that khat may expand even further (Dessie 2013). On the other hand, the controversy and uncertainty about a possible prohibition of its cultivation seem to restrain smallholders from allocating all of their land to khat (Dessie and Kinlund 2008).

2.4.4 Implication and options for future developments

The traditional home garden systems in the SNNPRS can no longer absorb the increasing population. Part of them have transitioned to intensive khat-based systems, replacing the cultivation of enset and coffee by khat and hence producing less food. This development is associated with various risks such as an increased dependency on one crop, khat, and hence vulnerability to harvest failure, price fluctuations, and pests and diseases. This study has shown that the trends in land use and farm types differed between districts depending on market access, local population density and elevation. Taking into account this observed heterogeneity is crucial in order to identify adapted interventions to achieve social and economic development of smallholder farmers. We have identified several options for locally adapted interventions. For the khat-based home gardens, diversifying agricultural produce by intercropping khat with annual crops such as cereals and legumes could reduce the risk of depending primarily on one crop. Khat is the main crop receiving artificial fertilizer, which in intercropping systems will also benefit the food crops, contributing to food security. Crop residues can be left in the field to improve soil fertility. The integration with livestock is difficult as not much feed becomes available from this intercropping system.

Enset-oriented home gardens offer scope in areas with lower population densities as enset takes several years to yield. A more intense coupling of enset with crossbred (i.e. Boran-Holstein Friesian) milking cows or small ruminants could be of mutual benefit, as the enset leaves can be used as animal feed and enset needs manure for a good production. The time required for enset to reach maturity is up to eight years without manure application, compared to three to four years with manure application (Shumbulo et al. 2012). Milk and meat could improve the nutritional quality of family diets, whereas other livestock functions like banking functions also contribute to rural livelihoods (Moll 2005; Thornton et al. 2007). In areas where grazing land is scarce the integration with livestock is not feasible. Here, introducing locally adapted improved coffee and enset varieties could contribute to enhance the income and food security of smallholder farmers through improving the productivity. The shortage of manure to maintain soil fertility can be addressed by the use of compost, prepared from coffee husk waste (Abebe 2013) and the inedible portions of enset leaves and, pseudostem sheath and corm (Tamire and Argaw 2015). There is also scope to integrate high value and productive fruit trees with the aim to maintain the diversified nature of the system and smallholders' sources of income. A continuous soil cover with diversified living plants facilitates the capture and infiltration of rainwater and protects the soil, besides being a source of organic matter through litter accumulation (Mollison and Slay 1991). However, in-depth research is required to quantify the effects of intercropping of the khat-based systems on productivity and of further integration of enset and crossbred animals.

2.5 Conclusion

We found a huge diversity of home garden systems in southern Ethiopia and their dynamics over the last two decades. Five home garden types were distinguished based on cropping patterns. Smallholders specialized in khat production typically allocate about half of their farm land to khat, as such depending on the market for about half of the year for family food requirements, but earning a good income. Contrastingly, farmers specialized in food production allocated about 75% of their farm to food crops, thus generating significantly less income. Over the past two decades cropping patterns had changed considerably, showing: i) a shift from food crop to cash crop production in densely populated areas close to markets; ii) a continuation of combined food and cash crops in medium populated, less accessible areas. In line with changes in land use and livestock populations, two main trends in home garden systems were observed: i) a transition to cash crop oriented home gardens, and ii) development of combined food and cash crop oriented home gardens. These dynamic changes were influenced by changes in population density and market access, changes in prices, a decline in soil fertility and a policy of market liberalization. Our insights on how enset and coffee based home gardens of southern Ethiopia have responded to increasing population pressure and commercialization provide insights that can inform the design of alternative options for sustainable development.

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CHAPTER THREE

3. Allometric equations for yield predictions of enset (*Ensete ventricosum*) and khat (*Catha edulis*) grown in home gardens of Southern Ethiopia

Abstract

Enset (*Enset ventricosum* (Welw.) Cheesman) is a large, single-stemmed perennial herbaceous plant domesticated as a staple food crop only in Ethiopia. Khat (*Catha edulis* Forsk) is a perennial plant cultivated for its economically important leaves and buds that are the sources of stimulant when chewed. We address the issue of yield estimation of both crops , as they are important for the livelihoods of smallholders in the home garden systems in Southern Ethiopia and have received little attention so far. The objective of this study was to develop allometric models for estimating the edible (food and feed) and commercial yields of enset and khat plants respectively. Data were collected from 20 enset and 100 khat plants. Diameter at 50 cm height (d_{50}), pseudostem height (h_p) and their combination gave good predictor variables for the food products of enset with adjusted R^2 values above 0.85 while d_{50}, h_p, edible pseudostem height (h_{ep}), total height (h_t) and their combination gave good predictor variables for the feed products of enset with adjusted R^2 values above 0.70. For dwarf khat plants crown area (*ca*) combined with total height (h_t) resulted in the best prediction with an adjusted R^2 of 0.77, while the leave and twig dry weight for tall khat plants was best predicted by crown area (*ca*) with adjusted R^2 of 0.43 using linear models.

Keywords: Home gardens, plant yield, plant structure, model performances

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3.1 Introduction

Enset (*Enset ventricosum* (Welw.) Cheesman) is produced in the home gardens of south and south-western Ethiopia and provides food for more than 15 million people (Abebe et al. 2010). Enset is a large, single-stemmed perennial herbaceous banana-like plant, domesticated as a staple food crop only in Ethiopia (Brandt et al. 1997; Negash and Niehof 2004). Besides being a food source, enset leaves are a key livestock feed and used as mulch to reduce soil erosion and runoff (Amede and Diro 2005).

Khat (*Catha edulis* Forsk) is a flowering woody perennial plant, grown for its economically important leaves and tender twigs, which are chewed for their stimulating effect (Megerssa et al. 2013). Ethiopia is widely believed to be the world’s largest producer of khat (Seyoum 2015). More than two million farmers are engaged in khat farming, most of whom are smallholders. The scarcity of farmland combined with the profitability of khat (Mellisse et al. 2017b) explains the surge in khat cultivation among smallholder farmers across the country (Dessie 2013).

Enset and khat are important crops for the livelihoods of the smallholders in the home garden systems and have received little attention so far. Monitoring impacts of innovations and their implications on the livelihoods of smallholder farmers require rapid and reliable means of quantifying the yields of these crops.

Existing studies on enset have focused on its management and ecological roles (Brandt et al. 1997), genetic pool and landraces (Tesfaye 2008a, 2008b) and its carbon sequestration potential (Negash et al. 2013). The studies on khat dealt with the impact of the plant on public health (Geresu 2015), livelihood, policy and trade conditions (Njiru et al. 2013; Dessie 2013; Kandari et al. 2014). The laborious and complicated harvesting and processing procedures of enset (Tsegaye and Struik 2001) and the piece-meal harvesting of khat (Feyisa and Aune 2003) have been reported as major challenges for reliable yield assessments. Nevertheless, little attention has been given to develop easy ways of estimating the yields of both perennial crops. A recent study reported allometric models for the above and belowground biomass of enset (Negash et al. 2013), but neglected its processed edible products called *kocho* and bula. Allometric equations using simple measurable plant variables as predictors for edible or commercial plant yield are time-saving tools providing valuable information for identifying productivity challenges and solutions for improving smallholders’ food production and cash income.

The overall objective of this study was therefore to develop and evaluate allometric models for estimating the edible and commercial yields of enset and khat grown in home gardens of southern Ethiopia.

3.2 Materials and methods

3.2.1 Measurement of plant structural variables and biomass

3.2.1.1 Enset

A total of 20 enset plants from four farms (five enset plants from two farms in each of the mid-altitude and highland agro-ecology) were selected randomly for measurement and harvesting. The two agro-ecologies are characterised by predominant clay-loam to silt-loam soils in the mid-altitude zone (1500-2300 m a.s.l.) and sandy-loam to sandy-clay soils in the highland zone (2300-3200 m a.s.l.). The 20 enset plants covered the different landraces and age range of harvestable enset in the study area of three to seven years after transplanting. Before felling the diameter of the pseudostem was measured with a caliper at a height of 20 cm (the height where the stem is widest, d_{20}), at 50 cm (diameter, d_{50}), at 130 cm (breast height, d_{130}) and at edible pseudostem height (d_{ep}) (Table 3.1). Edible pseudostem height (h_{ep}), pseudostem height (h_p), and total height (h_t) were measured with a tape measure and crown height (h_c) was calculated by subtracting h_p from h_t. The total height refers to the distance from the ground to the distal lamina of the last leaf to emerge. After measuring, the sample plants were dug up and separated into three components: corm, pseudostem and foliage. The corm is the edible underground portion of enset plants. The pseudostem is formed of leaf sheaths, lying one over the other in a concentric fashion; the foliage (leaf) component is comprised of the petiole, leaf midribs and leaf lamina. The fresh weight of each component was determined on-site and samples were taken to the laboratory, chopped, sun dried for 5 to 6 days and then oven dried at 65^{o}C for 24 hours. To obtain *kocho* from the pseudostem, the common processing procedure by farmers was followed. The pseudostem was cut into several pieces and the pulp (parenchymatous tissue) was scraped using a sharp-edged bamboo tool. The corm was pulverised using a wooden tool with a flat sharp edge. The scraped pseudostem mixed with pulverized corm of each plant was stored in a pit for 18 to 21 days for fermentation. A small separate pit was dug to collect the fine starchy liquid draining from the mixture in the large pit. The fine starchy liquid was sun-dried and the resulting flour is called bula. Bula was collected from 14 enset plants, as it can only be extracted from older plants (>4 years of age). After three weeks of fermentation, the fresh *kocho* and bula were collected and weighed on site. To determine the dry weight content, a sample of *kocho* and bula was taken to the lab, sun dried for 5 to 6 days and then oven dried at 65°C for 24 hours.

3.2.1.2 Khat

Marketable leaves and twigs of khat were collected for two different khat growth habit types: tall khat is grown for three to four years up to height of 4 m without pruning and dwarf khat is pruned at an earlier stage and maintained at maximum height of 1 m. For each type, samples were taken from 50 plants (five khat plant from ten farms of both mid-altitude and highland agro-ecology) on the harvesting day. The 100 khat plants captured the genetic variability in the region by covering the three different ecotypes known as '*wondo beleche'*, '*wugigra*' and '*chenge'*, which are both managed as dwarf or tall plants. The diameter at a height of 10 cm (basal diameter, d_{10}), at 130 cm (breast height, d_{130}), crown width in two directions (the widest diameter and its perpendicular), crown height (h_c) and total height (h_t) were measured (Table 3.1). Marketable leaves and twigs were harvested from each plant and weighed on site. All leaves and twigs were taken to the laboratory, sun dried for 2-3 days and then oven dried at 65°C for 24 hours. In case of multi-stemmed plants, each stem was measured and the equivalent diameter of the plant was calculated using the formula developed by Snowdon et al. (2002) as:

$$de = \sqrt{\sum_i^n d_i^{\,2}} \tag{1}$$

Where de = equivalent diameter, n = number of stems, i = 1, 2,…,n and d_i = single stem diameter of the same plant at a selected height.

Crown area was calculated as follows, assuming an elliptic crown shape:

$$ca = \pi \; x \; \left(\frac{l \; x \; w}{4}\right) \tag{2}$$

Where ca = crown area (m^2), l = crown length (m), w = crown width (m)

Table 3.1 Summary statistics of crop structure variables of harvested enset and khat plants

Parameters	Mean	Minimum	Maximum	SD
Enset (n = 20)				
d_{20} (cm)	47.1	26	60	10.6
d_{50} (cm)	39.2	16	57	13.4
d_{130} (cm)	26.4	14	40	8.0
d_{ep} (cm)	22.4	14	30	5.0
Edible pseudostem height (m)	1.670	0.60	3.28	0.669
Pseudostem height (m)	2.174	0.80	3.60	0.778
Crown height (m)	3.161	1.05	6.20	1.502
Total height (m)	5.335	2.82	8.79	1.703
Dwarf khat type (n = 50)				
d_{10} (mm)	17.31	9.7	29.7	4.68
Crown area (m^2)	0.195	0.07	0.35	0.071
Total height (m)	0.745	0.45	1.03	0.161
Tall khat type (n = 50)				
d_{10} (mm)	61.88	27.1	185.8	24.18
d_{130} (mm)	44.08	10.5	154.3	25.41
Crown area (m^2)	0.757	0.26	1.33	0.264
Crown height (m)	1.207	0.47	2.73	0.443
Total height (m)	2.453	1.31	3.64	0.555

SD= standard deviation of the original data

3.2.2 Allometric model development

Allometric linear regression models using untransformed and log-transformed data were determined for each of the food products (*kocho* and bula) and feed product (foliage) of enset and leaves and twigs of khat separately. When the original data did not show a linear pattern, log transformations of the data were used. Single log transformations based on the response variable (biomass component) only and double log transformations based on both the biomass and crop structure variables were performed. Model performance was tested using the adjusted coefficient of determination (adj. R^2), root mean square error (RMSE), prediction residuals sum of squares (PRESS), index of agreement (D) and absolute bias (AB) (Kozak and Kozak 2003). These model fit statistics were calculated based on all observations that were used in constructing the models.

$$adj.R^2 = 1 - (1 - R^2)\frac{(n-1)}{n-p-1} \tag{3}$$

$$R^2 = 1 - \frac{\sum_{n=1}^{n}(\mathrm{Y_i}-\hat{\mathrm{Y}}\mathrm{i})^2}{\sum_{n=1}^{n}(\mathrm{Y_i}-\bar{\mathrm{Y}})^2} \tag{4}$$

$$RMSE = \sqrt{\frac{\sum_{n=1}^{n}(\mathrm{Y_i}-\hat{\mathrm{Y}}_\mathrm{i})^2}{\mathrm{n}}} \tag{5}$$

$$PRESS = \sum_{n=1}^{n}(Y_i - \hat{\mathrm{Y}}\mathrm{i}, -\mathrm{i}\,)^2 \tag{6}$$

$$D=1- \frac{\sum_{n=1}^{n}\left(\hat{\mathrm{Y}}_\mathrm{i}-Y_i\right)^2}{\sum_{n=1}^{n}(|\hat{Y}_i-\bar{Y}_i|+|Y_i-\bar{Y}|)^2} \tag{7}$$

$$AB= \frac{\sum_{n=1}^{n}|\hat{\mathrm{Y}}_\mathrm{i}-Y_i|}{n} \tag{8}$$

where n = number of observations, i = 1, 2,…,n; p = number of predictors, $\mathrm{Y_i}$ is the observation of the response variable, $\hat{\mathrm{Y}}_\mathrm{i}$ is the predicted value of $\mathrm{Y_i}$, $\bar{\mathrm{Y}}$ is the average of $\mathrm{Y_i}$, $\hat{\mathrm{Y}}_{\mathrm{i,-i}}$ is the prediction of the $\mathrm{i^{th}}$ data point by an equation that did not make use of the $\mathrm{i^{th}}$ point in the estimation of the parameters. A good model has high adj.R^2 and D and low RMSE, PRESS and AB values.

3.2.3 Model selection

To select the best performing models, first-cut model selection criteria were applied. The approach was to select linear models consisting of one or more crop structural variables as predictors of the crop biomass. This selection was obtained with the *leaps* package in RStudio (RStudio 2015) based on two algorithms; the first based on the highest adjusted R^2 and the second based on the lowest BIC (Bayesian Information Criterion). Dependent on the adjusted R^2, the ten best performing models were listed for more detailed analysis. This was done for both the single and double log transformation, yielding around 20 models per response variable. Only models with coefficients significantly different from zero were retained. This prerequisite was not applied to the intercept. The models were ranked according to each goodness-of-fit statistic and then summed. The lowest total ranking value was deemed the best model. The best predictor of the crop structure variables was plotted against the plant biomass and their equal spread of points in residual plots was evaluated. For simplicity in use and interpretation of the equation, a linear model is preferred over non-linear models for this study. These models could be used as a basis for developing enset and khat crops growth or yield simulation models.

3.3 Results

The five best performing models for *kocho*, bula, foliage of enset and leaves and twigs of dwarf and tall khat are shown in Table 3.2. The single log transformed model with d_{50} performed best for dry weight of *kocho*. The model explained up to 89% of the variation in *kocho* dry weight. The double log transformed model for *kocho* dry weight using pseudostem height (h_p) and crown height (h_c) combined with diameter variables ($d_{20}\, d_{50}$) had a slightly smaller adjusted R^2 of 0.87 (Table 3.2). The combination of d_{50} with two height variables in a double log transformed model explained 85% of the variation in bula dry weight. The same combination in a single log transformed model performed only slightly worse. The other models which combine d_{50} with h_c and d_{50} with h_t respectively explained 78% and 79% of the variation in bula dry weight (Table 3.2). The double log transformed model constituted d_{50} and combined with height variables explained 72% of variation in foliage dry biomass. The linear model performances for edible products of enset plants were better than the foliage (Table 3.2). The best performing *kocho* and bula dry biomass models had an index agreement (D) values greater than 0.94 and values of less than 0.5, 4 and 0.4 for RMSE, PRESS and AB respectively; indicating a good agreement between modelled and measured biomass values of all models.

Of the four diameter variables (d_{20}, d_{50}, d_{130}, dep) diameter(d_{50}) was the best predictor variable for *kocho*, bula and foliage. Diameter at breast height (d_{130}) and diameter at edible pseudostem height (d_{ep}) were not included in any of the models for *kocho*, bula and foliage. Of the four height variables (h_{ep}, h_p, h_t, h_c) pseudostem height (h_p) and total height (h_t) were not included in the five best performing models for *kocho* while all height variables were included in those for bula and foliage (Table 3.2).

Single log transformed model combining crown area (*ca*) and total height (h_t) performed best for dwarf khat leaves and twig weight while models using only *ca* performed best for tall khat (Table 3.2). The models explained 77% and 43% of the variation in leaf and twig dry weight for dwarf and tall khat, respectively. Both diameter at basal height (d_{10}) and diameter at breast height (d_{130}) were not included in any of the models.

The adjusted R^2 and index of agreement (*D*) values of untransformed models for tall khat improved when crown height (h_c) or total height (h_t) was included; however the degree of agreement in terms of *RMSE, PRESS* and *AB* between modelled and measured biomass values decreased (Table 3.2).

Table 3. 2 The five best performing model equations with their coefficients and performance statistics for estimation of dry weight of *kocho*, bula, enset foliage and twigs and leaves of khat grown in home gardens of Sidama zone, southern Ethiopia, ranked according to performance statistics.

Model equations	Coefficients					Performance statistics					
	b_1	b_2	b_3	b_4	b_5	Adj. R^2	*RMSE*	*PRESS*	*D*	*AB*	Sum of Ranks
Kocho dry weight ($n = 20$)											
$\ln(dwk) = b_1 + b_2d_{50}$	-0.594	0.064				0.89	0.30	2.13	0.97	0.22	5.5
$\ln(dwk) = b_1 + b_2\ln d_{50} + b_3\ln h_{ep} + b_4\ln h_c$	-3.408	2.434	-0.270*	-0.362*		0.87	0.33	2.99	0.97	0.24	9.5
$\ln(dwk) = b_1 + b_2\ln d_{20} + b_3\ln d_{50}$	-7.293	0.874*	1.631			0.84	0.36	3.48	0.96	0.27	19.0
$\ln(dwk) = b_1 + b_2\ln d_{50}$	-5.896	2.171				0.84	0.36	3.42	0.96	0.28	19.5
$\ln(dwk) = b_1 + b_2\ln d_{20} + b_3\ln d_{50} + b_4\ln h_{ep}$	-6.601	0.604*	1.874	-0.103*		0.84	0.37	3.98	0.96	0.27	21.5
Bula dry weight ($n = 14$)											
$\ln(dwb) = b_1 + b_2\ln d_{50} + b_3\ln h_{ep} + b_4\ln h_p$	-7.844	1.890	4.223	-3.872		0.85	0.38	2.86	0.97	0.17	5.0
$\ln(dwb) = b_1 + b_2d_{50} + b_3h_{ep} + b4h_p$	-2.458	0.054	0.020	-0.015		0.81	0.43	3.57	0.96	0.30	13.0
$\ln(dwb) = b_1 + b_2d_{50} + b_3h_c$	-1.873	0.063	-0.003			0.81	0.43	3.01	0.95	0.32	14.5
$\ln(dwb) = b_1 + b_2\ln d_{50} + b_3h_c$	-3.415	2.121	-0.785			0.78	0.46	3.53	0.95	0.32	20.5
$\ln(dwb) = b_1 + b_2d_{50} + b_3h_t$	-1.679	0.075	-0.003			0.79	0.44	3.72	0.95	0.33	22.0
Enset foliage (leaf) ($n=20$)											
$\ln(dwl) = b_1 + b_2\ln d_{50} + b_3 \ln h_{ep} + b_4\ln h_p + b_5\ln h_t$	-1.390*	1.236	-1.631	2.392	-0.986	0.72	0.34	3.36	0.94	0.25	5.0
$\ln(dwl) = b_1 + b_2\ln d_{50} + b_3\ln h_c$	-1.911*	1.412	-0.313			0.66	0.38	3.61	0.90	0.29	12.0
$\ln(dwl) = b_1 + b_2\ln d_{50}$	-3.476	1.356				0.62	0.41	3.77	0.88	0.29	16.5
$\ln(dwl) = b_1 + b_2d_{50} + b_3h_{ep} + b_4h_c + b_5h_t$	0.272*	0.04	-0.014	-0.014	0.012	0.60	0.42	4.37	0.90	0.27	16.5
$\ln(dwl) = b_1 + b_2d_{50}$	-0.009*	0.036				0.52	0.45	4.73	0.84	0.32	25.0
Dwarf khat leaves and twigs dry weight ($n=50$)											
$\ln(dwt) = b_1 + b_2\ln h_t + b_3\ln ca$	1.983	0.495	0.522			0.77	0.15	1.25	0.93	0.12	5.0
$\ln(dwt) = b_1 + b_2h_t + b_3ca$	2.165	0.008	2.505			0.73	0.17	1.44	0.92	0.13	10.5

$\ln(dwt) = b_1 + b_2 \ln ca$	4.453	0.727				0.71	0.17	1.55	0.91	0.14	14.5
$\ln(dwt) = b_1 + b_2 ca$	2.498	3.684				0.66	0.19	1.81	0.89	0.15	20.0
$\ln(dwt) = b_1 + b_2 \ln h_t$	-1.471	1.093				0.57	0.21	2.28	0.85	0.16	25.0
Tall khat type leaves and twigs dry weight ($n = 50$)											
$\ln(dwt) = b_1 + b_2 ca$	3.359	1.102				0.43	0.33	5.55	0.79	0.25	9.5
$\ln(dwt) = b_1 + b_2 \ln ca$	4.444	0.724				0.41	0.33	5.79	0.77	0.26	13.5
$dwt = b_1 + b_2 h_t + b_3 h_c + b_4 ca$	24.627*	-0.116	0.282	55.897		0.57	21.71	25788.71	0.85	16.91	19.0
$dwt = b_1 + b_2 ca$	10.030	82.580				0.46	23.87	30273.74	0.79	17.45	25.5
$dwt = b_1 + b_2 h_c + b_3 ca$	-0.865	0.246	57.756			0.53	22.42	27535.20	0.83	17.59	31.5

n number of observations, *dwk* dry weight of *kocho* (kg), *dwb* dry weight of bula (kg), *dwl* dry weight of enset leaf (kg), *dwt* dry weights of twigs and leaves (g), h_c crown height (cm), h_{ep} edible pseudostem height (cm), h_p pseudostem height (cm), h_t total height (cm), d_{20} diameter at 20 cm height (cm), d_{50} diameter at 50 cm height (cm), *ca* crown area (m^2), *b1*, *b2 b*, *b4 and* b_5 model coefficients significantly different at $p < 0.05$ except*. R^2 *adj.* adjusted coefficient of determination, *RMSE* root mean square error, *PRESS* predicted residual sum of squares, *D* index of agreement and *AB* absolute bias. Sum of ranks: best performance =1, second best 2, etc. score is summed over the 5 performance statistics.

Similar to *kocho* and bula, log transformed models performed well for predicting leaf and twig dry weight of khat. The overall degree of agreement between modelled and measured biomass values of the five best performing models decreased in the order: *kocho* > bula > dwarf khat > enset foliage > tall khat yield prediction. The adjusted R^2 and index of agreement (D) values for the models estimating the yield of the edible enset parts was higher than those for the enset foliage and khat yield (Table 3.2). Linear models had substantially higher adjusted R^2 for enset and dwarf khat and their residual plot showed a better equal spread around zero compared to tall khat (Table 3.2, Fig 3.1).

3.4 Discussion

The best performing models explained 84-89% of the variation in *kocho*, 78-85% in bula and 60-72% in foliage dry biomass (Table 3.2). These values are higher than those reported by Negash et al. (2013) for the pseudostem and corm components of enset, from which *kocho* and bula are processed and for foliage biomass of enset. The model performance of the linear allometric equations derived in this study is comparable and sometimes better than the non-linear models developed for biomass components of enset reported by Negash et al. (2013). The good performance of the linear models in this study could be related to the sampling of all harvestable age ranges (3 to 7 years) of enset plants, unlike the focus on only 3 and 5 year enset plants by Negash et al. (2013). Diameter measurements were better predictor variables for *kocho* than height, indicating that *kocho* yield is more influenced by diameter growth than by the height growth. This is similar to the findings of another study, which reported a strong correlation between pseudostem biomass and diameter measurements (Negash et al. 2013). Bula yield was best predicted by combined measurements of diameter and height variables, indicating that the yield is influenced by both diameter and height growth. This is in line with Tsegaye and Struik (2003) who reported a strong correlation of pseudostem circumference and height variables with pseudostem and corm, which are the enset components from which bula is extracted. This is also in line with the observations that bula is only harvested from older plants (>4 years).

To our knowledge there is no information on either quantitative determination of khat yield or an attempt to predict its biomass using allometric equations. The khat yield is mostly expressed in terms of financial returns (Feyisa and Aune 2003), which do not enable the quantification of field or farm level dry matter production.

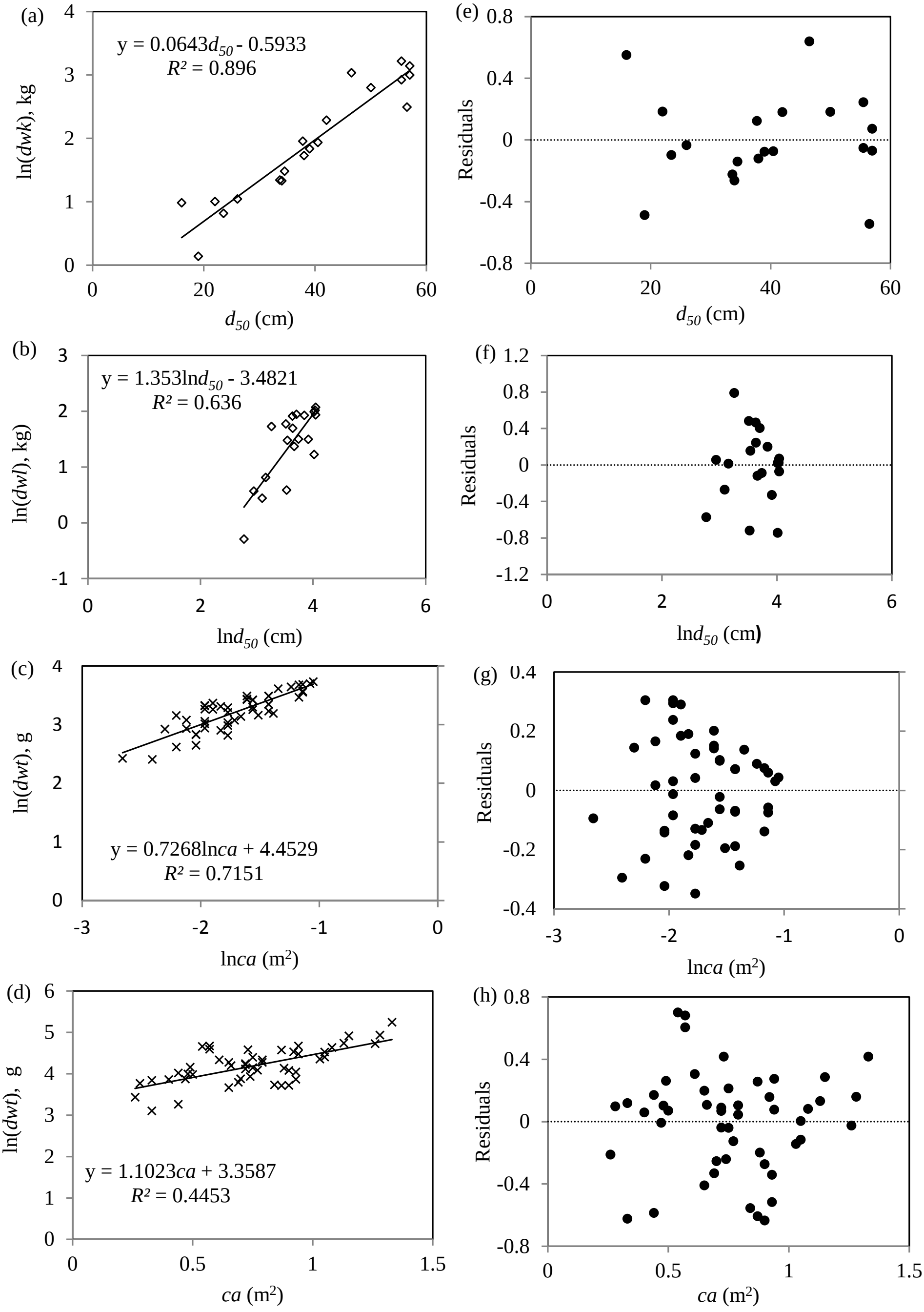

Fig 3.1 Relationships between basal diameter (d_{50}) with *kocho* dry weight (ln*dwk*) and enset leaf (ln*dwl*) (a, b), crown area (*ca*) with leaves and twigs dry weight (*dwt*) for dwarf and tall khat type (c, d) and their corresponding plots of residuals (e, f, g, h) respectively

Crown area turned out to be the best predictor for leaf and twig dry weight of both dwarf and tall khat plants, which seems logical, since the harvestable leaves and twigs constitute the crown. Among the height variables, total height (h_t) was the best predictor for dwarf khat plant while it was not for tall khat plants (Table 3.2). This implies that dwarf khat twig yield is influenced by expansion of crown area and height growth while the tall khat leaf and twig yield is mainly influenced by crown area expansion. This may be related to the management practices such as growing multiple stems by pruning at lower height for dwarf khat and growing of a single stem plant at larger height with larger crown area for tall khat (Table 3.1). The observed higher values of *RMSE, PRESS* and *AB* with the inclusion of height variables in the model developed for tall khat plants implies lower performances of model equations in predicting leaf and twig dry weight of khat plants.

Destructive sampling of enset is difficult due to its size and the lengthy harvesting and processing procedure. For khat the difficulties are in farmers' refusal to sample, which is related to costs and protectiveness. In such situations allometric equations can help to rapidly quantify the yields of these crops, which paves a way to quantify the productivity of home garden systems, which has rarely been done (Kumar and Nair 2004). This helps to explore sustainable development options in order to improve social and economic development of smallholder farmers. In addition, allometric equations can be a basis for the development of crop growth simulation models. This requires monitoring of biomass growth over time, for which allometric relations, based on simple measurements of plant structure can be used. Allometric equations for banana, a crop resembling enset, were successfully developed and applied to assess the water and nutrient limited banana production (Taulya 2013) and to develop a banana growth simulation model in Uganda (Nyombi et al. 2009). We purposively sampled enset and khat plants from the existing range in agro-ecological conditions, land races and age classes. Hence, notwithstanding the small sample size, the allometric equations derived for these plants can be applied reliably to assess the yields of the diverse land races or ecotypes grown under a wide range of biophysical and management conditions.

3.5 Conclusion

The log transformed linear model including diameter (d_{50}) performed best for predicting *kocho* dry weight while models including d_{50} and height variables predicted bula and foliage dry biomass best. The log transformed linear model including total height (h_t) and crown area (ca) was the best performing model for predicting leaf and twig dry weight of khat. The performance of linear models was better for enset biomass prediction compared with khat. Simple linear equations based on easily measurable crop structure variables can provide reliable predictions of harvestable biomass for enset and khat plants grown in home gardens of southern Ethiopia. This paves the way for a thorough quantification of the productivity of home gardens.

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CHAPTER FOUR

4. Are traditional home gardens in southern Ethiopia heading for extinction? Implications for productivity, plant species richness and food security

Abstract

While home garden systems are acknowledged for their capacity of supporting a very dense population, the productivity of these systems and their contribution to food security and dietary diversity is poorly quantified. Although several articles document the decrease in species richness in home gardens due to processes of modernization, relatively little attention has been given to how the change in diversity impacted productivity. Five predominant home garden systems identified in a previous study were intensively monitored during 12 months within four districts of Sidama and Gedeo zones of southern Ethiopia. Data from 24 farms were collected on plant species, soil characteristics, crop inputs, field sizes and crop yields and livestock production. The productivity of enset for both food and feed was lowest in Enset-coffee home gardens. Barley and khat yielded significantly more per ha in Khat-based systems than in other ones. Maize and coffee productivity did not differ significantly between home garden types. Overall crop productivity was lowest in the traditional Enset-coffee systems (1820 kg DM ha^{-1}) and highest in the newly evolved Enset-cereal-vegetable systems (3020 DM kg ha^{-1}). Energy productivity from food crops was higher in Enset-based systems (43 GJ ha^{-1}) than in other systems whereas revenue was lowest in Enset-based systems (719 US$ ha^{-1}) and highest in newly evolved Khat-based systems (6817 US$ ha^{-1}). The rate of N application in compost explained 30% of the variability in *kocho* standing biomass. The rate of N application in inorganic fertilizer explained 43% and 25 % of the variability in khat and barley yield respectively. There was no positive effect of plant species richness on total crop and energy productivity except for the revenue in enset-oriented systems. Khat-based and Enset-cereal-vegetable systems were more food secure than the traditional home gardens, and these newly evolved systems also did not lead to a loss in plant species richness. The modification of traditional home garden systems by introducing the high value cash crop khat and annual cereals in response to farmland constraints and market opportunities enabled smallholders to maintain food security and dietary diversity without jeopardizing plant species richness. With population density expected to continually increase in the region, improvement options tailored to the specific systems are required for sustainable development.

Key words: Cash crop; dietary diversity; energy availability; food self-sufficiency; home garden systems

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4.1 Introduction

Home gardens are characterized by combined production of multipurpose trees together with crops and livestock around the homestead (Kumar and Nair 2006). In southern Ethiopia, home gardens are fields around the houses that form the principal means of living for more than 15 million people without extra land elsewhere (Abebe 2005). They are characterized by the combined production of the staple crop enset (*Enset ventricosum* (Welw.) Cheesman) and cash crop coffee (*Coffea arabica* L.) together with annual crops, livestock and multipurpose trees on a small plot of land. Growing enset and coffee in an intimate association with annual crops, trees and livestock is claimed to reduce risk, sustain productivity and enable food security of smallholders (Kippie 2002; Kumar and Nair 2006; Abebe 2013). The presence of several plant species with diverse canopy structure, in this case annual crops and enset, is acknowledged for better utilization of light, water and nutrient resources (Soemarwoto 1987; Niñez 1987). The advantage of combining crop and livestock activities in the traditional systems is related to the availability of cheap fodder for livestock in the form of enset leaves, and of animal manure, recycling nutrients to support enset and coffee growth (Mellisse et al. 2017b). Livestock also play a critical role in providing protein and nutrient rich products that complement the nutrition-poor enset diet (Brandt et al. 1997; Tsegaye and Struik 2001). These features of traditional home garden systems are claimed to contribute to the capacity of home gardens to support dense populations of up to 500 persons km^{-2} (Kippie 2002; Abebe 2005). In addition home gardens are acknowledged for their biodiversity maintenance and avoidance of environmental deterioration (Kumar and Nair 2004). However, recently there is a rapid shift away from the traditional home gardens to cash crop Khat-based systems, particularly in areas close to markets (Mellisse et al. 2017b). In such areas, khat (*Catha edulis* Forsk) expanded from 6% to 35% of the farm area in the period from 1991 to 2013. In response, the share of farm area devoted to both enset and coffee decreased from 45% to 25%, which was interpreted as a simplification of the traditional land use systems (Abebe et al. 2010; Dessie and Kinlund 2008). On the one hand, uniformization of the landscape is believed to threaten food security and ecological services that the traditional home gardens provide. On the other hand, it is recognized that the changes in the structure and composition of home gardens have enabled the systems to respond to socio-economic changes through so-called productive bricolage processes at micro scale (Abebe and Bongers 2012). The latter is defined as the flexible and dynamic crafting of various livelihood options and its associated impacts on the landscape (Ros-Tonen 2012). However, the question whether or not the recent changes impaired the sustainability of the home gardens remains unresolved as hardly any quantitative information on the productivity of the traditional and the newly evolved systems is available. Also, the relation between productivity and plant species diversity has rarely been assessed. Furthermore, the inductive nature of earlier studies about home gardens, that either describe the system or assess species composition and diversity (Kumar and Nair 2004) overlooked the contribution of the diverse system components to productivity, food security and dietary diversity, which are important sustainability indicators in areas characterized by severe land pressure.

Given the rapid transitions of the traditional home garden systems to cash crop oriented systems, we test the hypothesis that the system transitions enhance productivity and food security at the expense of agrobiodiversity. Our objectives were: i) to analyse and explain crop productivity of different home garden systems; ii) to assess plant species richness of different home garden systems and analyse its relation with crop productivity; iii) to assess and explain food self-sufficiency, food security and dietary diversity of different home garden systems.

4.2 Materials and methods

4.2.1 Analytical framework and scope of the study

The complex interactions between the various components of a home garden system (crops, trees, livestock and farm household) require a systems approach to understand how these components operate together and interact with the larger-scale context. As the latter is characterized by land and food scarcity and the need to sustain ecosystem services, including agrobiodiversity, we chose to evaluate the sustainability of the system based on productivity, species richness and food security, including dietary diversity. An earlier study characterized five distinct home garden systems in the region (Mellisse et al. 2017b) based on the area share of the dominant crops and grazing land (Fig. 4.1). Farms with more than 30% of the area under khat were classified as Khat-based systems. With less than 30% khat, home gardens were classified as Enset-coffee if at least 35% of their area was covered with coffee. Grazing land and enset covered at least 20% and 35% of Enset-livestock and Enset-based systems respectively. In Enset-cereal-vegetable systems less than 35% of the land was cultivated with enset and annual cereals and vegetables were present. Khat-based and Enset-coffee home gardens were present in both mid-altitude (<2300 m.a.s.l.) and high-altitude zones (>2300 m.a.s.l). The other three home garden systems were prevalent in the high-altitude area (Mellisse et al. 2017b). As all systems had at least one crop (enset) in common and the new Khat-based and

Enset-cereal-vegetable systems evolved from the traditional home gardens, a system comparison was deemed appropriate. As the home gardens comprise several crops with distinct advantages (e.g. biomass production, cash generation), integrating the productivity of all crops into one indicator of productivity is challenging. We therefore expressed productivity in three ways, based on annually harvested biomass, energy and revenue. For the land constrained smallholders of southern Ethiopia, the portions that are harvested annually as food or cash sources are more meaningful than standing biomass. However, for enset the standing biomass was considered as it indicates the readily available food reserve, which could be harvested any time whenever the need for food arises. As the home garden systems differ in management related to input use and recycling of organic matter (including manure, added to compost) we used soil fertility and input use as explaining factors for yield differences.

4.2.2 Description of crops grown in home gardens of southern Ethiopia

Enset and coffee are the main crops of traditional home garden systems (Fig 4.1a and b). Enset is an evergreen perennial crop, domesticated as a staple food crop only in Ethiopia (Brandt et al. 1997; Negash and Niehof 2004). Enset is propagated by suckers and transplanted several times. After growing at least three years at its final place, it can be harvested for food. The starch accumulated in the leaf sheaths and the corm is the main edible product of enset. During harvesting, the corm together with pseudostem is dug out, the leaf sheaths are peeled off and scrapped with a knife to separate pulp from fiber. Finally, the pulp mixed with decorticated corm is collected in a pit lined with fresh enset leaves and is ready for consumption after two to three weeks of fermentation. This product is known as *kocho* and the fine starchy liquid drained from the mixture is called bula. Only plants older than 4 years yield bula. Coffee is a perennial cash crop and usually intercropped with trees and food crops. Khat (Fig 4.1d) is a woody perennial plant, commonly grown in monoculture for its economically important leaves and tender twigs, which are chewed for their stimulating effect (Megerssa et al. 2013). Depending on the pruning management, khat plants can be up to 4 m high or maintained at 1 m (Mellisse et al. 2017a). The leaves and twigs of khat are rapidly perishable, with a maximum shelf-life of four days after picking (Distefano 1983). Annual food crops such as cereals (wheat, barley and maize) and vegetables (onion and cabbage) are grown as monoculture (Fig 4.1e and f).

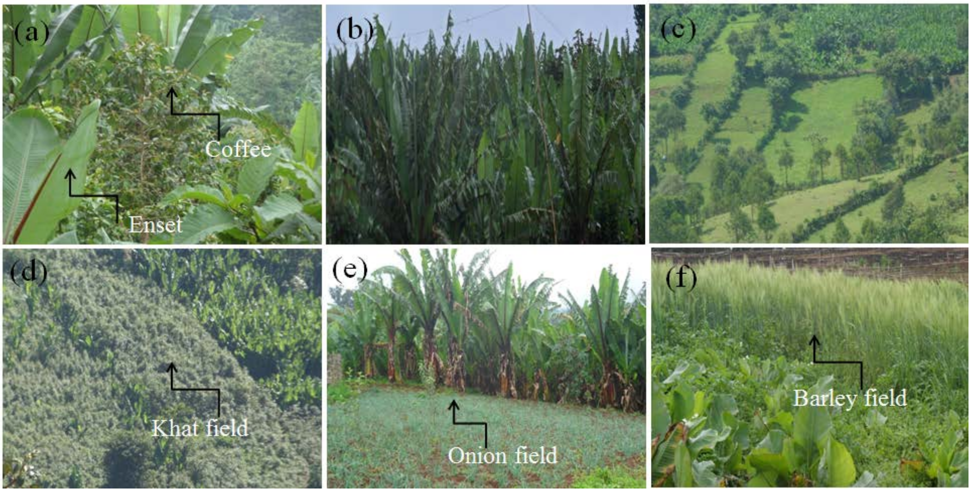

Fig. 4.1 Traditional Enset-coffee (a), Enset-based (b) and Enset-livestock (c) and newly evolved Khat-based (d) and Enset-cereal-vegetable (e and f) home garden systems in southern Ethiopia

4.2.3 Selection of study sites and farm households

Based on our own 2013 household survey dataset covering 24 PAs within four districts (Wondo Genet, Melga, Dale and Bule) of Sidama and Gedeo zones, a total of 7 PAs harbouring farms that represent the five home garden types were selected (Mellisse et al. 2017b). For Khat-based home gardens, two mid-altitude PAs (Ywo and Manicho), and one highland PA (Fitoketemuna) were selected (Fig. 4.2). For Enset-coffee home gardens one mid-altitude PA (Soyama) and one highland PA (Bassura) served as study area. Bassura and Elalcha, both highland PA's, were selected for Enset-based and Enset-cereal-vegetable home gardens respectively. Enset-livestock home gardens were selected in the highland PA Gerewe. A total of 63 farm households, 9 from each PA, were sampled from three resource endowment groups (high, medium and low) for a household survey. Farms with more than 1.25 ha of land and more than 5 tropical livestock unit (TLU) were categorized as high resource endowed, those with 0.5 - 1.25 ha and 1- 5 TLU as medium, and those with less than 0.5 ha and less than 1 TLU as low. See Mellisse et al. (2017b) for more details on the sampling and survey procedures. Out of the 63 households, a subsample of 24 was selected for close monitoring. Within each home garden type and agro-ecology combination, one household per resource endowment group was selected. Hence, we ended up with three households for each of the Enset-based, Enset-cereal-vegetable and Enset-livestock home garden types, six for Enset-coffee and nine for Khat-based.

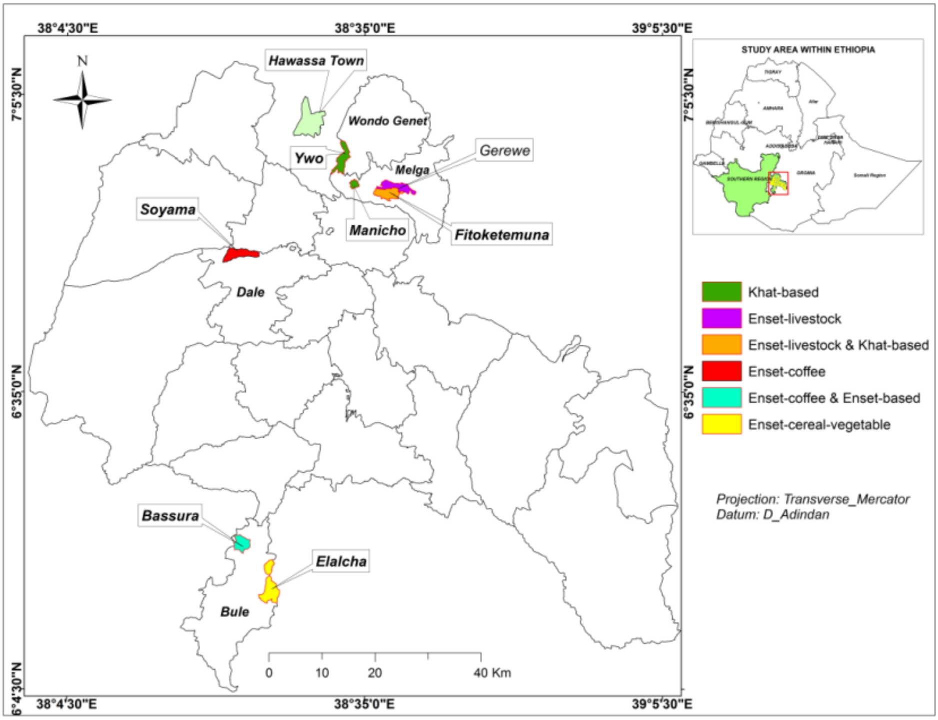

Fig. 4.2 Map of the study districts and peasant associations (coloured) harbouring different home garden systems within the districts of Sidama and Gedeo zones, SNNPRS, Ethiopia

4.2.4 Data collection

A household survey was administered with the heads of all 63 households in August 2015. Questions comprised the type of crops cultivated, areas and amounts harvested and herd size. Data on inputs (inorganic fertilizer, compost (defined as a mix of manure, household refuse and organic sweepings)) and outputs (*kocho*, bula, coffee, khat, maize, barley, vegetables, milk, eggs) were collected for a full year (September 2014 to August 2015). The farmer reported information was complemented with actual measurements of soil fertility, crop yield, and monitoring of inputs and outputs for the subsample of 24 households. These farm households were closely monitored for 12 months (September 2014 to August 2015) to capture the quantities of all produced, sold, consumed and purchased items. The weights or volumes of each item were recorded in local units and converted to kg. Energy production per farm was calculated by multiplying each food product with its caloric content. Annual revenue was calculated from the quantity of sold products and local market prices. Twenty Ethiopian birr equalled one US$, the average exchange rate during the survey period (NBE 2015). A family member, usually a male adolescent or the female household head was trained to register the above items every day for the entire family. At the end of every month each household was visited to collect the data and check the information.

4.2.4.1 Crop biomass sampling

For the 2014 and 2015 cropping seasons, yields of annual and perennial crops were measured on the 24 farms. The location and area of each field (enset, coffee, khat, maize, barley, vegetables) were registered using GPS. Most farmers had one field of each crop and for the few with more than one field, the total area per crop was considered. Three quadrats on each field were sampled. The quadrat size was 25 m^2 (5 m x 5 m) for perennial crops, 4 m^2 (2 m x 2 m) for maize and 1 m^2 (1 m x 1 m) for other annual crops. The annual cereals were harvested when ripe, separated into crop residues and grain and weighed on site. Vegetables were also harvested and weighed on site. A subsample of both annual cereals and vegetables were sun-dried for 2 to 3 days first and then oven dried.

For the perennial crops enset, coffee and khat the number of plants within a quadrat was counted and dendrometric variables were measured on 15 plants, five from each quadrat. For enset, only plants that had reached the harvestable age ($\geq$ 3 years) were considered. Unlike the annual crops, not all enset plants above the harvestable age are harvested at once, but only the amount required for feeding the household. For this study, the biomass of all plants above the harvestable age is further referred to as standing biomass. The harvested biomass was quantified both through the household survey and monitoring. Allometric equations developed by Mellisse et al. (2017a) were used to estimate the standing biomass of the three enset products and harvested biomass of coffee and khat. Finally, yield per hectare of each crop was calculated by multiplying the biomass per plant with measured plant density

Kocho: $ln(dwk) = -0.594 + 0.064(d_{50})$ (1)

Bula: $ln(dwb) = -7.844 + 1.890\ln(d_{50}) + 4.223\ln(h_{ep}) - 3.872\ln(h_p)$ (2)

Enset foliage: $ln(dwl) = -1.390 + 1.236\ln(d_{50}) - 1.631\ln(h_{ep}) + 2.392\ln(h_p) - 0.986\ln(h_t)$ (3)

Coffee bean: $ln(dwc) = -1.203 + 0.079(ca) + 0.006(d_{40})$ (4)

Khat, dwarf type: $ln(dwt_d) = 1.983 + 0.495\ln(h_t) + 0.522\ln(ca)$ (5)

Khat, tall type : $ln(dwt) = 3.359 + 1.102(ca)$ (6)

where: *dwk* dry weight of *kocho* (kg plant^{-1}), *dwb* dry weight of bula (kg plant^{-1}), *dwl* dry weight of enset leaf (kg plant^{-1}), *dwc* dry weight of coffee bean (kg plant^{-1}), dwt_d dry weight of twigs and leaves for dwarf khat type (g plant^{-1}), *dwt* dry weight of twigs and leaves for tall khat type (g plant^{-1}), d_{50} diameter at 50 cm height (cm), d_{40} diameter at 40 cm height (cm), h_{ep} edible pseudostem height (cm), h_p pseudostem height (cm), h_t total height (cm), *ca* crown area (m^2)

Tree and shrub species were identified with their vernacular name and counted for each field and its boundaries. Herbaceous species were identified in the grazing lands.

4.2.4.2 Soil sampling and analysis

Soil properties (soil pH, soil organic carbon, total nitrogen, available phosphorus and exchangeable potassium) were assessed for each cultivated field of the 24 farms. Topsoil (0 -15 cm) samples were taken with an auger at five points per field, two from opposite endways along the longest side and one in the middle. The five samples were thoroughly mixed and the fresh weight of the composite subsample was taken on site using a digital balance. The samples were oven dried at 105°C for 48 hours and passed through a 2 mm sieve prior to analysis. Total N was analysed following the Kjeldahl method (Bremner and Mulvaney 1982). Potassium and phosphorus were determined by flame emission spectrophotometry (Black et al. 1965). Soil organic carbon was determined by the wet oxidation method (Walkley and Black 1934) and soil pH was determined in a 1:2 (soil: H_2O) diluted soil solution.

4.2.5 Data analysis

4.2.5.1 Calculation of indicators of productivity, food self- sufficiency and food security

The household survey data from the 63 farm households was harmonized with the monthly monitored and measured data collected from the subsample of 24 farm households. We regressed measured and reported crop yields based on the data from the 24 farms and the regression equation was used to adjust the reported values of the other farms (Fig. A1 and A2). For each home garden type, the average land productivity for enset (*kocho*, bula and leaf), coffee, khat, maize, barley and vegetables, land to adult equivalent ratio, inorganic fertilizer and compost input, area share of cash crops, and fulfilment of daily energy needs were calculated. For each separate crop, yield was used as an indicator of land productivity. At farm level, the total crop dry matter yield, energy and revenue were used as indicators of land productivity. The total crop yield was calculated as:

$$TCY = \frac{\sum_{i=1}^{n} Qc_i}{A} \tag{7}$$

Where TCY is the total dry matter crop yield of a household (kg ha^{-1}), A is total crop area of the farm (ha), Qc_i is the dry matter of crop i produced on-farm (kg) and n is the number of crops on the farm. For *kocho* and bula only the harvested production was considered. Likewise, energy productivity was calculated by dividing the total energy production from food crops with total farm area.

$$\mathrm{TE} = \frac{\sum_{i=1}^{m} Ec_i * Qf_i}{F} \tag{8}$$

Where TE is the total energy from the food crops of a household (GJ ha^{-1}), F is total farm area (ha), Ec_i is the energy content of food crop i produced on-farm (kcal kg^{-1}), Qf_i is the dry matter of food crop i produced on-farm (kg) and m is the number of food crops on the farm

Financial productivity was calculated by dividing total revenues with total farm area.

$$\mathrm{TR} = \frac{\sum_{i=1}^{k} P_i * Qd_i}{F} \tag{9}$$

Where TR is the total revenue of household (US$ ha^{-1}), F is total farm area (ha), P_i is the price of item i produced on-farm (US$), Qd_i is the quantity of sold item i (kg) and k is the number of items sold.

Total energy available for household consumption, both from on-farm production and food purchases, and energy requirement based on adult equivalent were computed to assess household food self-sufficiency and food security. The share of the household energy need met by own production is further referred to as the food self-sufficiency ratio (FSSR). The food crops enset (*kocho* and bula), maize, barley, wheat, teff and beans, and livestock products milk, meat and eggs were considered for calculating energy availability. All meat was assumed to be purchased, as farmers indicated that they did not slaughter animals but only bought meat from the market. Fruits and vegetables were not included, as these were mainly produced for sale and played a minor role in the family’s energy supply. The food security ratio (FSR) is the total energy available for consumption from both on-farm and purchased products, divided by the energy requirements.

$$\mathrm{FSSR} = \frac{\sum_{i=1}^{l} Qp_i * E_i}{\mathrm{Er} * \mathrm{h}} \tag{10}$$

$$\mathrm{FSR} = \frac{\sum_{i=1}^{z}(Qp_i - Qs_i + Qm_i) * E_i}{\mathrm{Er} * \mathrm{h}} \tag{11}$$

Qp_i is the quantity of on-farm produced food product i (kg or l), l is number of on-farm produced food products, E_i is the energy content of food product i (MJ kg^{-1} or MJ l^{-1}), Er is the energy requirement of one adult equivalent (MJ), and h is total number adult equivalents in the household. Qs_i is the quantity of sold food product i (kg or l), Qm_i is the quantity of purchased food product i (kg or l). z is the number of consumed items. If the energy available for consumption per adult equivalent exceeds 10 MJ day^{-1}, households were considered food secure (Rufino et al. 2013).

The nutritious value of the diet was evaluated using the household dietary diversity score, which was based on the monitoring data aggregated to monthly periods. The food consumed while away from the farm was not taken into account as it is negligible in the study area. Foods were categorized in 10 food groups as recommended by the WHO including: (1) cereals, (2) root and tubers, (3) vegetables, (4) fruits, (5) meat and poultry, (6) eggs, (7) pulses, legumes and nuts, (8) milk and milk products, (9) oil or fats and (10) sugar or honey (Swindale and Bilinsky 2006). A food group received a score of one if food from this group was consumed and of zero if not consumed (Swindale and Bilinsky 2006). The household dietary diversity score was the sum of the scores of each of the food groups. A threshold was set by the average of the 33% of households with the highest diversity score (Swindale and Bilinsky 2006). The monthly energy consumption and dietary diversity score were considered for the four seasons of the year. *Tseday* (Amharic) (September to November) is characterised by occasional showers. In the dry *Bega* (December to February) annual crops are harvested. *Belg (*March to May) is characterized by occasional showers, whereas Kiremt (June to August) is the main rainy season.

The land to adult equivalent ratio is total farm size divided by total number of adult equivalents. The area share of cash crops is the total area occupied by cash crops (coffee, khat and vegetables) divided by total farm size. Cash crops are grown entirely for sale. However, farmers in the study area also generate income from food crops. The proportion of harvested food crops sold was about 23% across all systems.

The relationships between productivity, food self-sufficiency, food security and dietary diversity indicators on the one hand and various explanatory factors on the other hand were investigated using linear regression. Assuming no large year-to-year fluctuation in herd size, manure handling techniques, and therefore N input, the relationship between last year's compost input and standing biomass of enset was assessed. A one way analysis of variance

(ANOVA) was used to test the difference between the means of five home garden types in crop yield, fertilizer inputs and soil macronutrient contents. Differences were deemed significant at $P < 0.05$. Analyses were performed using the Statistical Package for Social Sciences (SPSS) version 20.

4.3 Results

4.3.1 Farm characteristics

A large diversity in farm characteristics was observed in the study area. No clear differences in farm size among the home garden types were observed (Fig. 4.3a). Land to people ratio varied between types, with typically less land available per person in the Khat-based and Enset-based systems (Fig. 4.3b). Most of the Khat-based and Enset-based farmers had less than 0.25 ha per adult equivalent, which is the minimum holding size to formally register a new farm unit in southern Ethiopia (FDRE 2005).

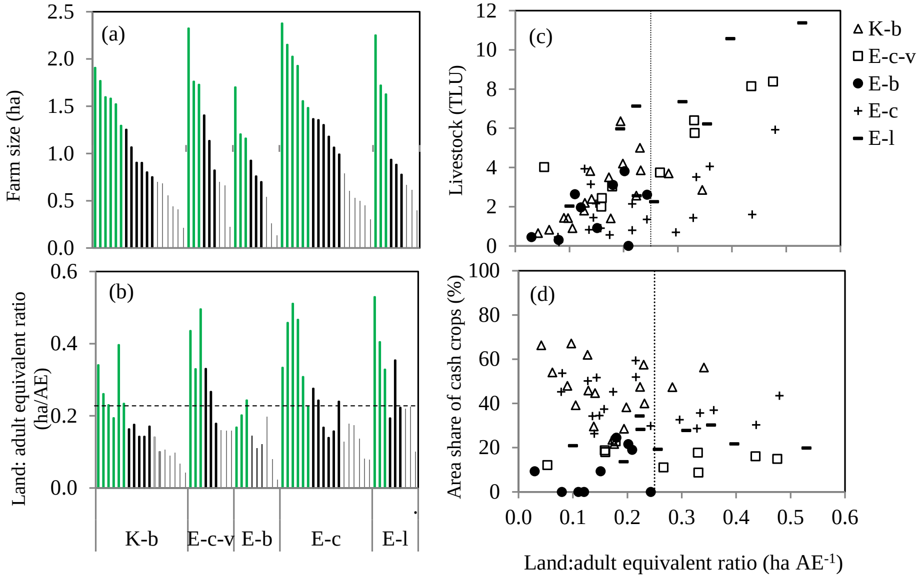

Fig. 4.3. Farm size (a) and land to adult equivalent ratio (b) for the high (green), medium (black) and low (grey) resource endowed farms ranked according to farm size. The relation between land to adult equivalent ratio and livestock holding (c) and area share of cash crops (d); K-b: Khat-based; E-c-v: Enset-cereal-vegetable; E-b: Enset-based; E-c: Enset-coffee; E-l :Enset-

livestock. The horizontal dotted line in (b) and vertical dotted lines in (c) and (d) indicate the minimum per capita farm size to be registered as a new farm unit in southern Ethiopia (n=63)

Land availability was positively related with herd size in most home garden types (Fig. 4.3c), whereas the relation with land allocation to cash crops was less clear and dependent on home garden type (Fig. 4.3d). For example, Khat-based and Enset-coffee farmers with less land per adult equivalent allocated a larger portion of their farm to cash crops than those with more available land.

4.3.2 Crop productivity

Crop yields per unit area were significantly different between the different home garden types in the study area (Table 4.1). For the food crops, both standing and harvested *kocho* biomass were significantly less in Enset-coffee (14697 and 1522 kg ha^{-1}) home gardens than in Enset-cereal-vegetable (21366 and 4034 kg ha^{-1}) and Enset-livestock (19640 and 3478 kg ha^{-1}) home gardens. Standing bula biomass in Enset-coffee home garden types (463 kg ha^{-1}) was significantly less than in all other systems. Significantly more bula (135 kg ha^{-1}) was harvested by Enset-cereal-vegetable farmers than by all other farmers. This suggests that these farmers harvested more mature enset plants than those in other home garden systems as bula is extracted only from older plants. Maize yields were not significantly different between home garden types. Barley yield was significantly smaller in Enset-cereal-vegetable (436 kg ha^{-1}) and Enset-based (623 kg ha^{-1}) home garden types than in the Khat-based (1281 kg ha^{-1}) home garden type. For the cash crops, no significant difference in coffee bean yield was observed among the different home garden types. Significantly more khat per hectare (2160 kg ha^{-1}) was harvested by Khat-based farmers than by those in Enset-coffee (1466 kg ha^{-1}) and Enset-livestock (1730 kg ha^{-1}) home garden types. Vegetables (onion and cabbage) were only cultivated by the farmers in Enset-cereal-vegetable systems. With respect to livestock feed, significantly more standing enset leaf biomass (9356 kg ha^{-1}) was present in Enset-cereal-vegetable than in Enset-coffee (4483 kg ha^{-1}) home gardens. Significantly smaller amounts of enset leaves were harvested in the Enset-coffee and Enset-based systems than in the other systems. Total crop yield per hectare was significantly larger in Enset-cereal-vegetable home gardens than in Khat-based, Enset-coffee and Enset-livestock home gardens. The lowest total crop yield per hectare was obtained in Enset-coffee home gardens. While energy productivity from food crops was significantly higher in Enset-based systems than other home garden systems, total revenue was the lowest.

Table 4.1. Annual dry matter (DM) yield (kg ha^{-1}) of different crops and farm level energy productivity of food crops (GJ ha^{-1}) and total revenue (US$ ha^{-1}) for the different home garden systems (*n = 63*); the figures in parentheses indicate the standard deviation. Values with different letters within a row are significantly different between home garden types at $P < 0.05$.

Components		Home garden type				
		Khat-based (K-b) (18)	Enset-cereal-vegetable (E-c-v) (9)	Enset-based (E-b) (9)	Enset-coffee (E-c) (18)	Enset-livestock (E-l) (9)
Food crops	*Kocho* standing	16176 (8572)ab	21366 (9450)a	17156 (6980)ab	14697 (6134)b	19640 (9257)a
	Kocho harvested	3059 (2127)a	4034 (1684)a	3949 (1763)a	1522 (723)b	3478 (1698)a
	Bula standing	801 (6228)a	1131 (844)a	609 (545)a	463 (301)b	642 (715)a
	Bula harvested	70 (48)b	135 (85)a	69 (53)b	33 (37)b	74 (97)b
	Maize grain	3375 (543)a	-	3328 (513)a	3156 (567)a	2656 (539)a
	Barley grain	1281 (246)a	436 (210)b	623 (159)b	-	-
Cash crops	Coffee bean	1278 (171)a	-	1233 (140)a	1331 (127)a	-
	Khat	2160 (593)a	-	-	1466 (49)b	1730 (475)b
	Onion (Shallot)	-	8588 (1131)	-	-	-
	Cabbage (kale)	-	3880 (1539)	-	-	-
Feed crop	Standing enset leaves	6001 (2887)ab	9356 (2076)a	5836 (3306)ab	4483 (2380)b	7146 (3538)a
	Harvested enset leaves	2138 (849)a	2321 (861)a	1107 (690)b	1139 (991)b	2769 (1333)a
Farm level productivity	Total crop yield	2438 (427)b	3021 (813)a	2864 (426)ab	1817 (372)c	2540 (701)b
	Energy	20 (8)b	21 (6)b	43 (17)a	17 (7)b	20 (7)b
	Revenue	6817 (1842)a	1675 (567b)b	719 (346)c	1763 (843)b	2368 (1305)b

-: not applicable

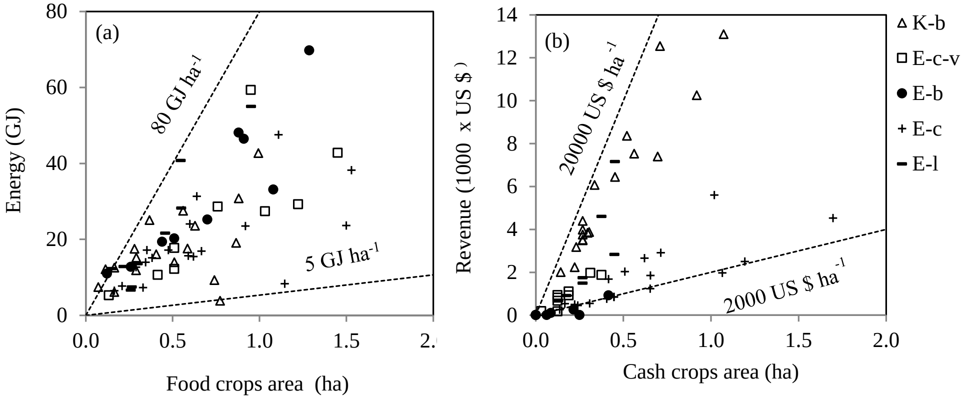

Fig. 4.4 The relationship between the area of food crops and energy production (a) and between the area of cash crops and total revenue (b) for the different home garden systems in Sidama and Gedeo zones of southern Ethiopia. K-b: Khat-based; E-c-v: Enset-cereal-vegetable; E-b: Enset-based; E-c: Enset-coffee; E-l :Enset-livestock. Upper and lower boundary lines are fitted by eye.

No clear difference in energy productivity between home garden types was observed, and the annual energy productivity from food crops ranged from 5 to 80 GJ per ha (Fig. 4.4a). As an average of five adult equivalent household members require 19 GJ annually, households who produce about 5 GJ ha^{-1} need to supplement the energy requirement of their family from the market. Unlike for energy, clear patterns of financial productivity were observed (Fig. 4.4b). Khat-based farmers generated the largest total revenue per hectare (10000 - 20000 US $ ha $^{-1}$) while Enset-coffee farmers generated the least (2000 – 5600 US $ ha^{-1}). Enset-cereal-vegetable and Enset-livestock farmers had an intermediate position. Enset-based farmers generated hardly any revenues from cash crops (Fig. 4.4b).

4.3.3 Factors explaining crop productivity

4.3.3.1 Input use and soil attributes

In all home garden types, only compost was applied to enset and coffee, while only inorganic fertilizer was applied to annual cereals and khat (Table 4.2). Vegetables received both organic and inorganic fertilizer. Enset received significantly less compost in Khat-based home gardens (1323 kg DM ha^{-1}) than in Enset-cereal-vegetable (2210 DM kg ha^{-1}), Enset-livestock (2542 kg DM ha^{-1}) and Enset-based (2839 kg DM ha^{-1}) home gardens. It received the least compost in

Enset-coffee farms (640 kg DM ha^{-1}). Enset fields in Khat-based and Enset-coffee home gardens had a significantly smaller soil organic C and N content than in the other home garden types, which corresponds with the lower compost application. N from compost explained about 30% of the variation in *kocho* standing biomass (Fig 4.5c). Compost, consisting for 98% of manure, is the major N input to enset. Another significant explanatory factor was soil organic carbon content whereas soil macro nutrient content (N, P and K) and pH were not significantly related to *kocho* standing biomass.

Maize received significantly less N (33 kg ha^{-1}) and P (10 kg ha^{-1}) from inorganic fertilizer in Enset-livestock home gardens than in other home garden types. The maize fields in Enset-coffee home gardens had significantly lower soil pH, P and K than in Khat-based and Enset-based home gardens (Table 4.2). No regression model could explain maize yield variability by N input and/or soil attributes. Barley received significantly less N (25 kg ha^{-1}) and P (8 kg ha^{-1}) from inorganic fertilizer in Enset-cereal-vegetable home gardens than in other home garden types.

N in inorganic fertilizer explained 25% and 43% of the variation in barley and khat yield respectively. Soil macronutrient content (P and K), SOC and pH were not significantly related to khat yield. Coffee received significantly more compost (851 kg DM ha^{-1}) in Enset-coffee home gardens than in other home garden types, but no significant variation in soil attributes of coffee fields was observed. Also N in compost could not explain coffee bean yield. A large variation in nitrogen productivity among the Enset-coffee farmers was observed. Relatively large coffee bean yields were attained in Khat-based systems given the low N application rates (Fig. 4.5e). In these home gardens, where coffee is often replaced by khat, coffee remains as a border crop around the khat field. Hence, the coffee could have benefited from the inorganic fertilizer applied to khat. There was no clear relationship between N input and vegetable yields, but a large variation in N productivity was observed among the Enset-cereal-vegetable farmers (Fig. 4.5f).

Table 4.2 Fertilizer input and soil attributes for the different crops in the five home garden systems of southern Ethiopia; the figures in parentheses indicate the standard deviation. Values with different letters within a column for a specific crop are significantly different between home garden types at $P < 0.05$

Crops	HT	Fertilizer application (kg ha^{-1}) (n = 63)			Soil properties (n = 24)				
		N (DAP+urea)	P (DAP)	Compost (DM)	pH	SOC (g kg$^{-1)}$	TSN (g kg^{-1})	P (mg kg^{-1})	K (cmol kg^{-1})
Enset	K-b	-	-	1323 (824)b	7.5 (0.7)a	32.5 (5.0)bc	3.5 (0.8)b	56.0 (27.6)a	4.5 (2.9)a
	E-c-v	-	-	2210 (1006)a	5.7 (0.2)b	48.8 (9.7)a	4.6 (0.6)a	41.1 (8.1)a	1.8 (0.5)ab
	E-b	-	-	2839 (936)a	6.5 (0.7)b	30.6 (2.6)bc	4.7 (1.0)a	48.8 (29.1)a	2.6 (1.6)ab
	E-c	-	-	640 (413)c	6.5 (0.3)b	28.3 (5.2)c	3.1 (0.4)b	43.7 (22.9)a	1.3 (0.2)b
	E-l	-	-	2542 (1180)a	7.3 (0.1)a	38.5 (8.5)b	4.7 (1.0)a	51.9 (9.6)a	1.7 (0.3)ab
Maize	K-b	54 (27)a	18 (7)a	-	6.8 (0.9)a	30.1 (7.1)a	3.1 (1.3)a	35.8 (32.7)a	2.0 (1.0)a
	E-b	68 (13)a	16 (3)a	-	6.0 (0.5)ab	25.5 (4.8)a	3.8 (1.8)a	13.7 (12.6)b	2.7 (2.1)a
	E-c	56 (15)a	18 (5)a	-	5.7 (0.5)b	21.4 (3.5)a	3.7 (1.7)a	3.8 (0.3)c	0.6 (0.1)b
	E-l	33 (16)b	10 (5)a	-	-	-	-	-	-
Barley	K-b	46 (25)a	17 (6)a	-	-	-	-	-	-
	E-c-v	25 (25)b	8 (5)b	-	5.2 (0.5)	35.5 (14.8)	2.2 (0.2)	1.4 (0.6)	1.5 (0.2)
	E-b	53 (23)a	16 (5)a	-	-	-	-	-	-
Coffee	K-b	-	-	119 (94)b	6.6 (0.3)a	25.8 (1.9)a	2.7 (0.3)a	25.3 (31.8)a	3.0 (2.9)a
	E-b	-	-	514 (408)b	6.1 (0.4)a	26.3 (2.8)a	3.4 (0.6)a	36.0 (13.7)a	1.9 (1.2)a
	E-c	-	-	851 (690)a	6.7 (0.3)a	26.8 (2.0)a	3.1 (0.4)a	33.6 (25.8)a	1.5 (0.6)a
Khat	K-b	73 (44)a	16(8)a	-	6.7 (1.0)a	32.9 (4.8)a	3.2 (1.0)a	17.0 (12.1)a	2.0 (1.2)a
	E-c	54 (37)a	13 (5)a	-	6.1 (0.3)a	23.9 (2.6)b	2.2 (0.4)a	7.4 (3.9)a	0.7 (0.1)a
	E-l	69 (44)a	17 (6)a	-	5.7 (0.3)a	24.8 (0 .2)b	2.6 (0.3)a	11.8 (3.1)a	2.6 (0.7)a
Vegetables	E-c-v	30 (20)	21 (9)	731 (460)	4.1 (0.6)	46.7 (5.8)	2.7 (0.1)	15.7(2.3)	1.6 (0.2)

-, not applicable; HT, home garden type; SOC: soil organic carbon; TSN: total soil nitrogen; vegetables: onion and cabbage; DAP (diammonium phosphate: 18% N, 46% P_2O_5; urea 46% N); K-b: Khat-based; E-c-v: Enset-cereal-vegetable; E-b: Enset-based; E-c: Enset-coffee; E-l :Enset-livestock

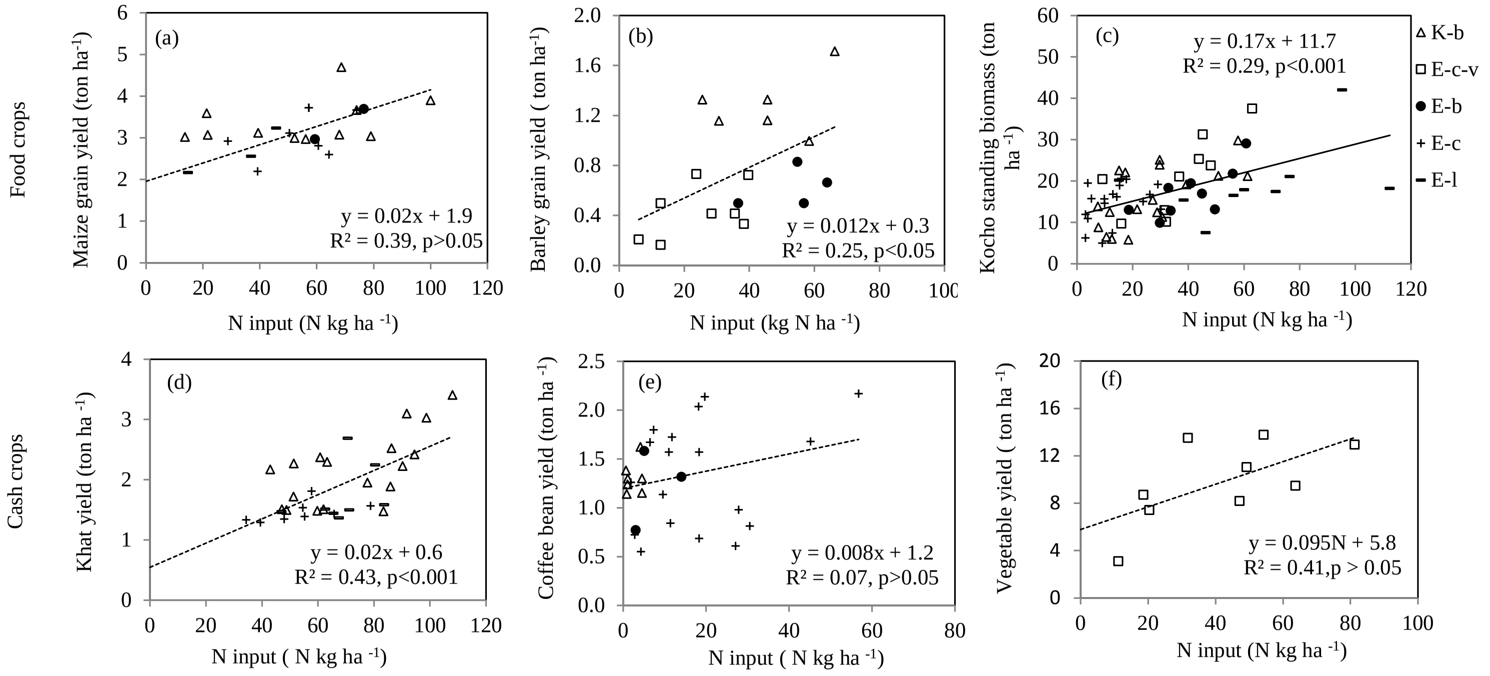

Fig.4.5 Relationship between N input and the yield of the food crops maize (a), barley (b) and *kocho* standing biomass (c) and the cash crops khat (d), coffee (e) and vegetables yield (f) for the different home garden systems in Sidama and Gedeo zones of southern Ethiopia. K-b: Khat-based; E-c-v: Enset-cereal-vegetable; E-b: Enset-based; E-c: Enset-coffee; E-l :Enset-livestock

4.3.3.2 Plant species richness

The traditional Enset-coffee home garden systems had the largest plant species richness among all systems (Fig. 4.6). Somewhat surprisingly, the cash-crop oriented system based on khat did not have the smallest species richness. This was mainly explained by the presence of many plant species in the grazing land and coffee fields of the Khat-based systems. The smallest plant species richness observed in Enset-based and Enset-cereal-vegetable systems could be partly explained by their situation in the cool highlands.

The relation between plant species richness and farm level crop and energy productivity across the five home garden types showed a negative trend (Fig. 4.6a and b). Enset-cereal-vegetable and Enset-based systems with fewer plant species per farm achieved higher total crop and energy yield than those in Enset-coffee with a higher number of plant species per farm. Khat-based and Enset-livestock systems took an intermediate position.

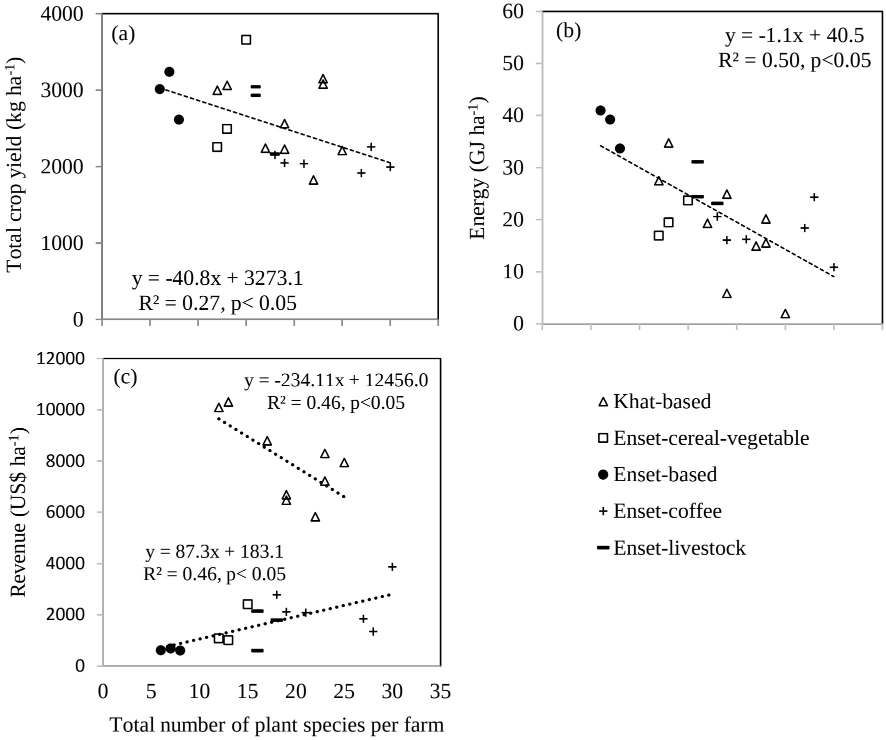

Fig 4.6. Relationship between the total number of plant species per farm and total crop yield (a), energy from food crops (b) and revenue (c) for the five home garden types in the Sidama and Gedeo zones of southern Ethiopia (*n = 24*)

The relation between plant species richness and annual revenue across enset-oriented home garden types showed a slightly positive trend whereas a negative trend was observed for cash crop oriented Khat-based systems (Fig 4.6c).

4.3.4 Food self-sufficiency and food security

4.3.4.1 Energy availability

The daily energy consumption from food produced on-farm was below the threshold of 10 MJ per adult equivalent per day in all home gardens except for high resource endowed households in Enset-livestock and Enset-cereal-vegetable home gardens (Fig. 4.7a). Households in Khat-based and Enset-coffee home gardens were more dependent on the market for food than those in the other three home garden types. All high resource endowed households were food secure, whereas all of the low resource endowed households and some medium endowed households were not. The monthly energy consumption patterns highlighted the influence of the seasons and cropping calendar on energy availability (Fig. 4.7b). In all home garden types the consumption increased during the *tseday* and *belg* seasons and dropped during the *bega* and *kiremt* seasons of the year. On average, households in Enset-cereal-vegetable systems were food secure during the whole year. In the other four home garden systems energy availability fluctuated around the threshold of 10 MJ per adult equivalent per day during the whole year. The beginning of *tseday*, the entire *bega* and the end of the *kiremt* season were challenging times for food provision in all home garden systems. The lowest food security was observed in August in Enset-based households, when only 70% of the household energy requirements could be met.

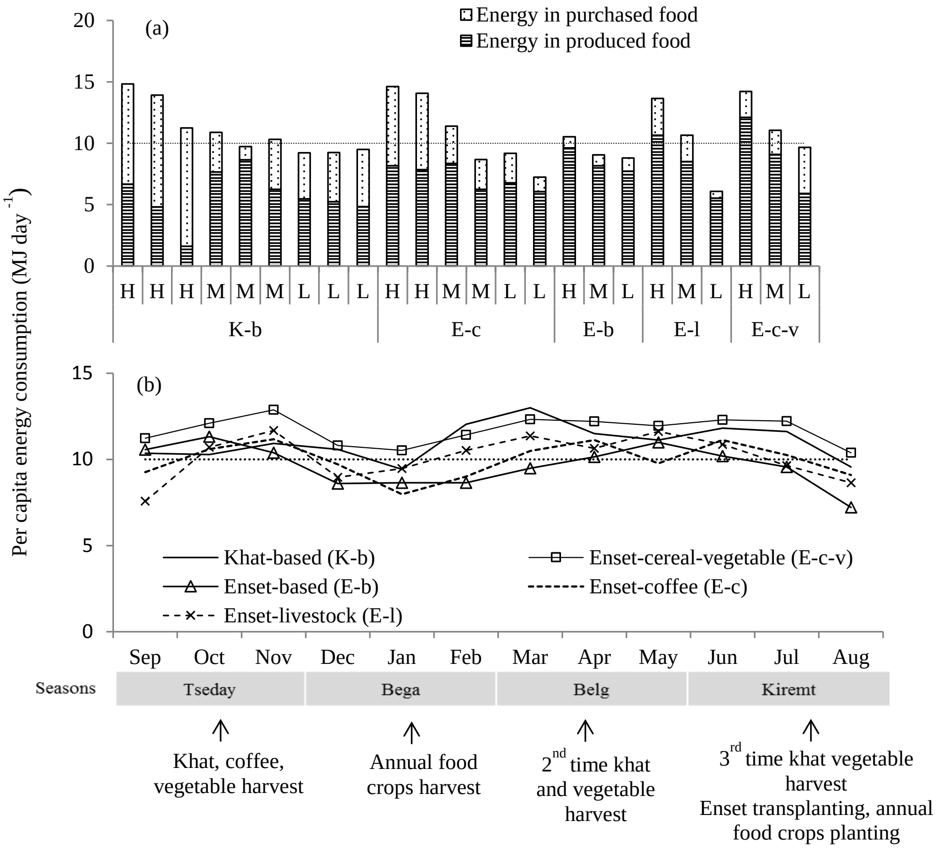

Fig. 4.7. Energy consumption per household member for all farm households (a) and average monthly energy consumption patterns in the five home garden types and simplified cropping calendar (b) (*n* = 24). Resource endowment: H = high, M = medium and L = low. The dotted line at 10 MJ indicates the standard daily per capita energy requirement

4.3.4.2 Dietary diversity

The household dietary diversity score varied among farm resource groups within and between different home garden types. Most households, apart from a few high resource endowed households, consumed products from less than six food groups on average (Fig. 4.8a). The monthly patterns of access to food groups also varied between the different home garden types and seasons of the year (Fig. 4.8b).

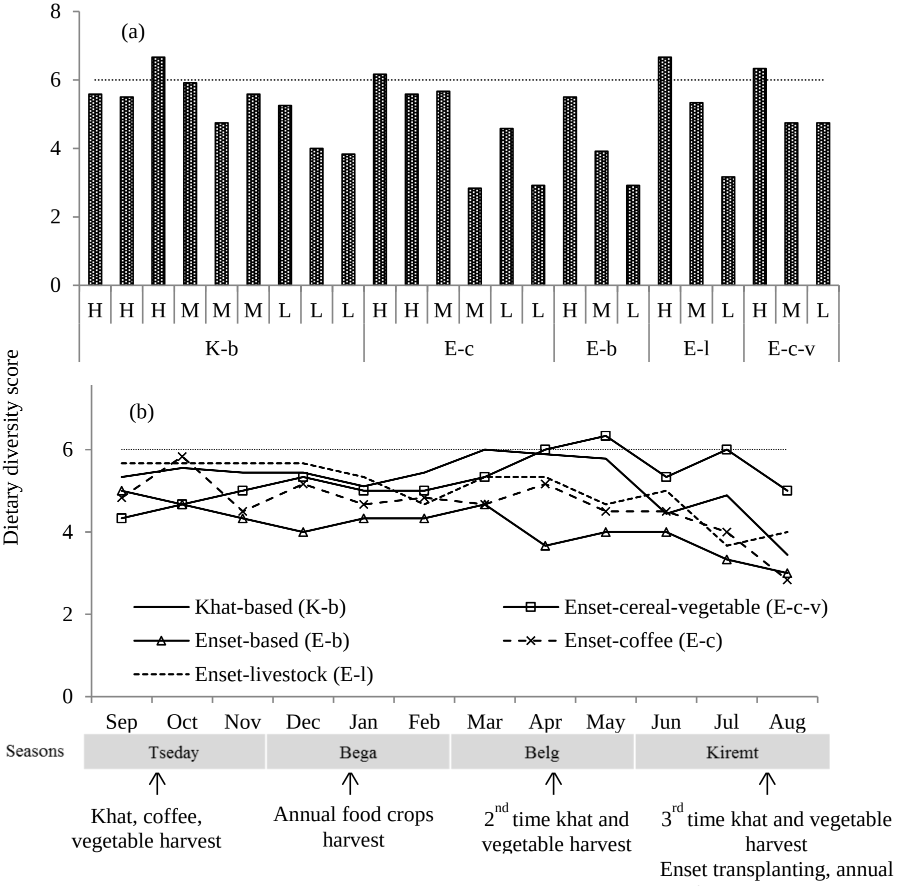

Fig. 4.8. Annual dietary diversity score per household (a) and average monthly dietary diversity score for the five home garden types and a simplified cropping calendar (b) (*n* = 24). H= high, M = medium and L = low resource endowment, respectively. The dotted line indicates the benchmark value of 6 food groups for the dietary diversity score

During the *belg* season households in all home garden types except those in the Enset-cereal-vegetable system, consumed products from less than six food groups (Fig. 4.8b). Enset-based farmers accessed the lowest number of food groups during the entire year. Dietary diversity was lowest at the end of *kiremt* season, when only 50% of the threshold value of six food groups was accessed, except in the Enset-cereal-vegetable households that still had access to 5 food groups.

4.3.5 Factors explaining food self-sufficiency, food security and dietary diversity

As expected, food self-sufficiency was positively influenced by farm size and land to adult equivalent ratio while negatively influenced by area share of cash crops (Fig. 4.9). Livestock holding did not significantly relate to food self-sufficiency. Many of the households in Khat-based and Enset-coffee systems were not food self-sufficient. These farms typically had less than one hectare of land and allocated more than 30% of their farm to cash crops. Conversely, most households in Enset-cereal-vegetable and Enset-livestock who had more than a hectare of land, and allocated less than a 30% of their farm to cash crops were food self-sufficient. Most of the Enset-based households with a land to adult equivalent ratio below 0.25 and a small portion of their farm under cash crops were also food self-sufficient.

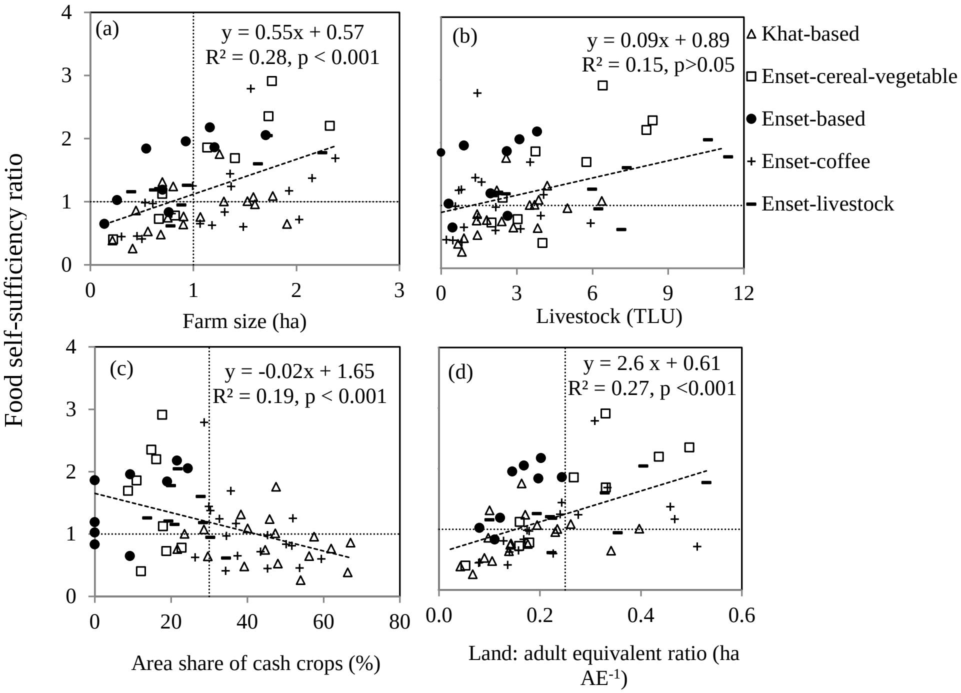

Fig. 4.9. The relationship between food self-sufficiency ratio and farm size (a), livestock size per household (b), area share of cash crops (c) and land:adult equivalent ratio (d) for the five home garden types (*n = 63)*. Dotted horizontal line: threshold value for food self-sufficiency ratio; vertical line distinguishes households based on average farm size (1 ha), minimum per capita farm size (0.25ha) to be registered as a new farm unit in southern Ethiopia respectively and area share of cash crops (30%).

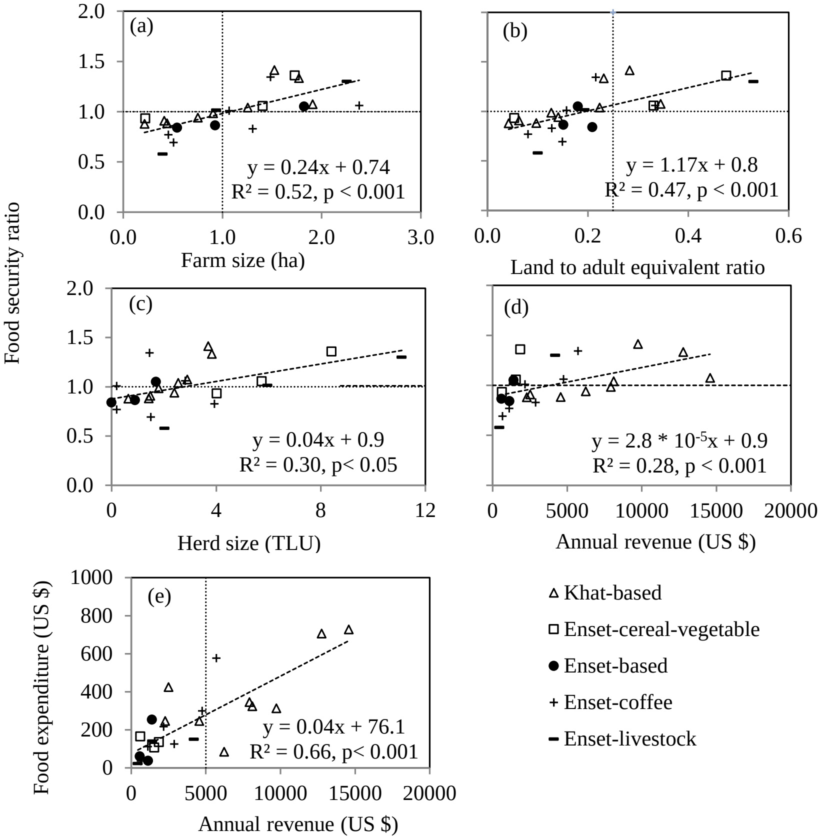

Fig. 4.10. The relationship between food security ratio and farm size (a), land to adult equivalent ratio (b), herd size (c), annual revenue (d) and the relationship between food expenditure and annual revenue (e) for the five home garden types (*n = 24*). The dotted horizontal line: threshold value for food security ratio; the vertical line: distinguishes farm households based on the average farm size (1 ha), on minimum per capita farm size to be registered as a new farm unit in southern Ethiopia (0.25 ha) and annual revenue (US$ 5000)

Similar to food self-sufficiency, food security was positively related to farm size and land to adult equivalent ratio (Fig. 4.10). Food security also increased with livestock holding and total annual revenue. Households in Khat-based home gardens were not more food secure than in other systems (Fig. 4.10). This was partly related to the small earnings of low resource endowed Khat-based farmers (< 5000 US $). Households with more than one hectare of land and more than 0.25 ha per adult equivalent were more food secure than those with less land (Fig. 4.10).

The dietary diversity score was also positively related to farm size, livestock holding and land to adult equivalent ratio, with total annual revenue partly explaining variability.

4.4 Discussion

4.4.1 Are traditional home gardens in southern Ethiopia heading for extinction?

The age-old enset-coffee home gardens are commonly acknowledged for their capacity of supporting very dense populations of up to 500 persons km^{-2} (Kippie 2002; Abebe 2005). This capacity is usually attributed to the possibility of producing larger amounts of biomass from enset compared to annual crops (Tsegaye and Struik 2001) and the use of its leaves as livestock feed and as mulch to reduce soil erosion and runoff (Amede and Diro 2005). As compost is the only nutrient input used on enset and coffee (Table 4.2), livestock are a key component of the traditional systems. However, where the population density exceeds 500 persons km^{-2} and the per capita land holding falls to below 0.25 ha, most families can no longer meet their own food requirements (Fig. 4.3). In this case, farmers are forced to harvest unripe enset or replace it with other crops that require a shorter maturing time in order to feed their families. The consequent decrease in fodder availability results in smaller herd sizes and less manure. In turn, enset and coffee yields are negatively affected (Tables 4.1 and 4.2). Also relying on coffee as a cash crop to cover household expenses becomes less feasible on smaller farms, as coffee is harvested only once in a year and requires a long establishment period. Consequently, farmers shift to other high value cash crops like khat, which has the added advantage of multiple harvests and hence a regular cash inflow. This way of modifying the structure and composition of traditional home gardens in response to farmland constraints and market opportunities has been described as a productive bricolage process (Abebe and Bongers 2012), a term also used to denote the domestication of gum and resin trees as cash crops in the drylands of Ethiopia (Lemenih et al. 2014; Woldeamanuel 2012). As khat allows farmers to increase revenue threefold, the crop has become an integral component of smallholders' livelihoods and the landscape, thus replacing traditional home gardens. Whereas we did not find a subsequent decrease in species richness, the shift from compost to inorganic fertilizer led to a decline in soil organic carbon (Table 4.2) (Kim et al. 2016). The replacement of enset, a crop with multiple function in the traditional systems could weaken the interaction among the livestock, crop and soil components of home gardens which could have a direct repercussion on the sustainability of these systems. Commercialization processes have been reported elsewhere to result in negative environmental consequences, such as the loss of plant species diversity as a result of the modification of forest coffee to specialized coffee systems in southern Ethiopia (Wiersum 2010). Similar effects of commercial rubber-based systems in Kerala, India (Peyre et al. 2006) and vegetable-based systems in Java, Indonesia (Abdoellah et al. 2006) have been observed. In these examples the major crops in the traditional home gardens included coconut, banana, cassava, vegetables and multipurpose fruit trees in India; and papaya, sweet potato, coconut, coffee, vegetables and fruit trees in Java.

4.4.2 Does agro-biodiversity influence agricultural productivity?

The presence of diverse plant species in the traditional home gardens is commonly assumed to enhance or sustain productivity of the system (Kumar and Nair 2004; Wiersum 2004). However, our data showed that the total number of plant species per farm had no positive relation with either total crop or energy productivity (Fig. 4.6). However, for enset-oriented home gardens species richness was positively related with annual revenue. With a similar plant species richness, the larger annual revenue generated by Khat-based than enset-oriented farmers implies that the profitability of traditional home gardens can be enhanced without jeopardizing plant species diversity. The large variation in plant species richness between the different home garden systems (Fig. 4.6) was related to the type of crops grown. The large species richness in Enset-coffee home gardens was related to the traditional practice of incorporating both deciduous and evergreen trees to offer shade for the coffee bushes. Hence, the presence of coffee as main cash crop in most enset-oriented systems explained the positive relation between total plant species richness and annual revenue in these systems. The small species richness in Enset-based systems was caused by thinning of trees to increase enset plant density in response to land constraints. Contrary to our hypothesis on the role of system transitions in agro-biodiversity, the introduction of khat did not lead to the expected decline in plant species richness. This is because even after introducing khat, farmers commonly continue cultivating a variety of crops mixed with trees on multiple small plots. Hence, the commercialization of small farms does not necessary imply a loss in agro-biodiversity (Fig. 4.6), as was reported for commercialized vegetable-based home gardens in Sudan (Wiehle et al. 2014).

4.4.3 Do system transitions increase productivity and food security?

The Khat-based and Enset-cereal-vegetable systems that recently evolved in the densely and less populated areas of the study region respectively showed better productivity and food security than the traditional Enset-coffee home garden systems (Table 4.1 and Fig. 4.7b). In areas with high population pressure and land constraints, the cultivation of high value crops is a strategy to attain food security and a diverse diet. Indeed, households in Khat-based systems were relatively well-off in terms of food security (Fig. 4.7b) mostly because of purchased food which contributed more than 50% of the energy consumption (Fig. 4.7a). However, the low resource endowed Khat-based farmers were neither food secure nor had a diverse diet (Fig. 4.7, 4.8) because of the small farm size. The less land-constrained medium and high resource endowed Khat-based farmers allocated a larger area to khat and earned a high income (>5000 US $). The total annual revenue of these farmers was 10, 6, 4 and 3 times more than their counterparts in Enset-based, Enset-cereal-vegetable, Enset-livestock and Enset-coffee systems respectively (Fig. 4.10). This implies that the medium and high resource endowed Khat-based farmers could invest in other assets or businesses that contribute to their livelihood. Although not monitored in detail, we observed that farmers with higher income tended to invest in valuable items such as motorbikes, which are crucial for transporting the leaves and twigs of khat.

The other newly evolved home garden type, typical for the less densely populated regions of the study, characterized by enset, cereals and vegetables showed the greatest farm level productivity (Table 4.1). Farmers in these systems cultivated larger areas, enabling them to keep more livestock and produce more manure compared to the other systems (Fig. 4.3, Table 2). Khat is not (yet) introduced here due to the large distance to markets, which is not convenient for the highly perishable khat with a maximum shelf-life of four days after picking (Distefano 1983). With a larger farm size, Enset-cereal-vegetable farmers diversified food production, previously based on enset, by growing annual cereals. This eases pressure from enset, allowing it to grow until fully matured, which explains the higher productivity of food (*kocho* and bula) and feed (foliage) biomass compared to other systems (Tsegaye and Struik 2001) (Table 4.1). Farmers in these home garden were food secure and had diverse diets regardless of their resource endowment. Cash income from the cultivation of vegetables enabled these farmers, and in particular the low resource endowed ones, to fulfil their energy requirements from purchased food (Fig. 4.7a).

Whereas food security was not affected by commercialization through khat, gender roles in family food provision might undermine this in the longer term. Earlier studies (Tsegaye and Struik 2001; Abebe 2005) reported a reduction in women’s opportunities in agriculture as a consequence of the replacement of enset by khat. All activities for enset are executed by women, who have control over the cash earned. For khat, all marketing activities are exclusively controlled by men. Given the traditional gender norms that assign women with the responsibility of feeding the family, their exclusion could impair food availability and nutritional security of the households. This could explain that khat introduction improved dietary diversity only marginally compared to traditional systems. As most studies on khat dealt with the impact of chewing khat on public health (Geresu 2015), the social implications of its expansion in southern Ethiopia need further investigation.

4.4.4 Future sustainable management of home garden systems

For land constrained farmers of densely populated areas, cultivation of khat seems a viable strategy to enhance both income and food security. However, the increasing dependency of Khat-based farmers on the income from one crop to provide food for their family could induce risks associated to harvest failure and price fluctuations. This risk is stronger for low resource endowed Khat-based households as they spend a larger proportion of their earnings on food than those in other home garden types (Fig. 4.10e). Hence, there is an urgent need to identify and develop interventions to address social and economic development of smallholder farmers. One promising option is to intensify production systems through intercropping khat with annual crops such as cereals and legumes. Khat is the main crop receiving inorganic fertilizer, which can also benefit the intercropped food crops, thus contributing to food self-sufficiency and reducing the risk of entirely relying on the market for food. Additionally, as the availability of livestock feed from enset is dwindling in Khat-based systems, the crop residues provide a welcome fodder source for the livestock. In densely populated areas where land constraints are getting severe and farmers are not able to meet the food demands of the family, some farmers have already started intercropping of khat with maize. For the less land-constrained Enset-cereal-vegetable farmers, improving the barley yield, which was about three fold smaller than the average barley yield obtained in Khat-based systems, could contribute to food self-sufficiency of the low resource endowed Enset-cereal-vegetable farmers in particular.

For Enset-coffee, Enset-based and Enset-livestock home gardens, improving the production and productivity of crops is vital to secure their food and nutrition provision as they mainly depend on farm produce. The observed relation between *kocho* standing biomass and compost input points at the opportunity of improving enset productivity through increased use of compost. However, the dwindling herd size (Mellisse et al. 2017b) urges the need to improve compost use efficiency, which is commonly very poor (Ferew 2012). Supplementation with inorganic fertilizer is another option. According to Ayalew (2015), increasing N application from 90 to 140 kg ha^{-1} $year^{-1}$ not only increased *kocho* biomass from 26 to 32 ton ha^{-1} but also decreased the enset maturity time by about two months. In our study all but two farms applied less than 80 kg N ha^{-1} to enset. This suggests that food security of farm households could be enhanced by increasing the nutrient input to enset. Besides, given the possibility of intercropping enset with coffee, introducing locally adapted improved coffee varieties is another option that could be tested. Such new varieties suited to the highland and mid-altitude agroecology can yield more than two times the average yield observed in this study (Belete et al. 2014).

4.5 Conclusion

Our study reveals major challenges posed by increasing population pressure and land fragmentation on securing family food in the densely-populated highlands of southern Ethiopia. The transition from traditional Enset-coffee home garden systems to Khat-based and Enset-cereal-vegetable systems has led to a decline in livestock herds and a shift from manure to inorganic fertilizer use. These two recently evolved systems showed better productivity and food security than the traditional Enset-coffee systems. Plant species richness was not jeopardized by the transition to Khat-based systems and our findings did not support the widely held belief of a positive relation between agro-biodiversity and crop productivity. Shifting to the high value crop khat by low resource endowed Khat-based farmers with a farm size below 0.4 ha was not a guarantee to become food secure or to access a diverse diet. Sustainable development options for the current home garden systems include intercropping khat with food crops, integrated soil fertility management comprising compost and mineral fertilizer use, and improved crop varieties. As home gardens have evolved to comprise a large variability in structure and functioning, these options need to be tailored to the specificity of each home garden type.

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CHAPTER FIVE

5. Implication of agricultural transformation on ecological and economic sustainability of home garden systems in southern Ethiopia

Abstract

Increasing population pressure and the resulting fragmentation of farmland have caused land use change from traditional home garden systems to commercialized Khat-based systems in southern Ethiopia. Here we report how the recent shift away from the traditional home gardens (Enset-coffee, Enset-livestock, Enset-based) to Khat-based and Enset-cereal-vegetable has influenced nutrient stocks, balances and profitability of these systems. The five home garden systems, as identified in previous work, were monitored during an intensive farm monitoring campaign of 12 months within four districts of Sidama and Gedeo zones. Data from 24 farms was collected on soil characteristics, crop inputs, field sizes, crop yields and income sources. Our result showed that Khat-based systems generated about 87% of their income from cash crops and the farm gross margin was 4, 4, 2, and 2 times larger than in Enset-cereal-vegetable, Enset-based, Enset-coffee and Enset-livestock systems respectively. Growing of khat was 17, 5, 5 and 2 times more profitable than annual cereals, enset, coffee and vegetables respectively. The shift away from enset and coffee, which received only organic fertilizer, to khat, which received solely inorganic fertilizer lead to a decline in N, P and K stocks by 20%, 70%, 30% respectively. Sustainable development options for the current home garden systems include intercropping khat with food crops, integrated soil fertility management comprising efficient manure use and handling. As home gardens have evolved to comprise a large variability in structure and functioning, these options need to be tailored to the specificity of each home garden type.

Key words: Economic performance; home gardens; nutrient balances; nutrient flows; nutrient stocks

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5.1 Introduction

The notion of sustainable agriculture implies a strategy of farming that enhances agricultural productivity without deteriorating the resource base (Smit and Brklacich 1989). Despite the lively debate about the exact meaning of sustainable agriculture (Yunlong and Smit 1994), there is consensus on its three basic ecological, economic and social dimensions (Brown et al. 1987; Yunlong and Smit 1994). An ecologically sustainable agricultural system maintains its physical, chemical and biological integrity (Neher 1992; Rasul et al. 2004) and it can be quantified by measuring the use of fertilizer and crop protection agents, nutrient balances, crop diversification and resource conservation (Hansen 1996; Rigby and Cáceres 2001; Hayati et al. 2011). From an economic perspective, sustainability refers to the viability of farming with the intention to provide long term benefits to the producer (Yunlong and Smit 1994; Ali et al. 2008). Indicators such as crop yield, gross margin, expenses for inputs, employment opportunities and income diversification have been suggested to evaluate the economic components of agricultural sustainability (Izac and Swift 1994; Rasul et al. 2004). Social sustainability refers to self-reliance, equity and quality of life (Rasul and Thapa 2004; Buchmann 2009) and it can be evaluated by assessing food self-sufficiency, dietary diversity and social equity (Rasul and Thapa 2003; Van Cauwenbergh et al. 2007; Marta et al. 2011). Home gardens, characterised by the combined production of crops, livestock and multipurpose trees (Abebe 2005; Kippie 2002) are considered as an epitome of sustainability (Kumar and Nair 2004). Ecological sustainability of home gardens is related to their crop diversity and the role those crops play for soil fertility maintenance through continued organic matter supply, nitrogen fixation and soil protection (Kumar and Nair 2004; Wiersum 2004). Economic sustainability of home gardens is commonly attributed to the low cost of production and the possibility to produce multiple products and generate income from multiple sources (Kumar and Nair 2004), whereas social sustainability results from the possibility of accessing diverse food sources and its egalitarian distribution among the family members (Thaman 1995).

Traditional Enset-coffee home garden systems of southern Ethiopia are characterized by the combined cultivation of the staple food crop enset (*Enset ventricosum* (Welw.) Cheesman) and the cash crop coffee (*Coffea arabica* L.), both perennial crops, together with annual crops, livestock and multipurpose trees usually on less than a hectare of land (Abebe 2005). Besides the role of multiple species and a good soil cover in soil fertility maintenance, the ecological sustainability of Enset-coffee home gardens is supported by the cyclic nutrient flows between the enset/coffee fields and the livestock component of the system (Amede and Diro 2005). The provision of manure by livestock for enset and coffee, and the reliance on enset leaves for livestock feed explains the recycling of nutrients (Brandt et al. 1997; Tsegaye and Struik 2001). Annual harvesting of a limited number of enset plants and only coffee berries results in a limited amount of nutrients exported from the system (Abebe et al. 2006). The year-round production of annual and perennial crops with the input of solely organic fertilizer and the strong reliance on family labour are the commonly mentioned economic sustainability attributes of these systems (Kippie 2002; Abebe 2005). Those features of traditional home garden systems serve to explain their long term existence in densely populated regions of southern Ethiopia (Kippie 2002; Abebe 2005).

Over the last two decades, increasing population pressure and the resulting fragmentation of farmland has put the traditional home gardens of southern Ethiopia under pressure. In southern Ethiopia where population increase resulted in declining land holdings, khat (*Catha edulis* (Vahl) Forssk. ex Endl.) has expanded from 6% to 35% of the farm area in the period from 1991 to 2013 (Mellisse et al. 2017b). Khat is a narcotic crop, grown for its economically important leaves and tender twigs, which are chewed for their stimulating effect (Megerssa et al. 2013). In response to khat expansion, the combined area share of enset and coffee decreased from 45% to 25%, which led to a decline in the share of traditional Enset-coffee home gardens. In contrast, the share of Khat-based farms increased strongly from 3% in 1991 to 24% in 2013 (Mellisse et al. 2017b). The shift away from Enset-coffee to Khat-based systems increased the dependency on external inputs and the cost of production (Abebe 2013). The shift away from a system in which manure is the main provider of crop nutrients, is also expected to result in a decreased organic matter supply to the soil with a direct repercussion on the status of soil fertility (Torquebiau 1992). Yet, quantitative analyses of profitability and soil fertility in the traditional and the newly evolved systems have hardly been conducted. Also, studies on the effects of land use change on nutrient balances at crop and farm level are rare. Hence, we lack quantitative information and understanding of the ecological and economic sustainability of home gardens and on how this is affected by the currently observed land use dynamics. Yet, a better understanding of the ecological and economic sustainability of these systems is required for designing sustainable agroecosystem management options to enhance the livelihoods of smallholder farmers.

Given the increasing population pressure and resulting fragmentation of farm land, we hypothesise that shifting from traditional towards commercialized home gardens has enhanced income but negatively influenced the soil fertility status. As the social dimensions of home garden system sustainability such as food self-sufficiency, food security and dietary diversity issues were covered in a previous study (Mellisse et al. resubmitted), the focus of this study is on the economic and ecological sustainability dimensions of home garden systems. Our specific objectives were: i) to examine nutrient balances at field and farm level as indicators of ecological sustainability; ii) to assess the field and farm level changes in nutrient balances and herd size between 1991 and 2015 for the different home garden systems in southern Ethiopia; iii) to analyse the profitability of different crops and home garden systems as an indicator of economic sustainability.

5.2 Materials and methods

5.2.1 Conceptual framework

For the assessment of nutrient and economic flows of the different home garden systems, a conceptual framework that shows farm components, in-flows and out-flows was designed (Fig 5.1). We defined the land use (LU), livestock (L), and household (HH) as major components of the farm. The land use includes enset (E), coffee (Co), vegetables (V), khat (K), annual cereals (AC) and grazing land (G). The household includes the family members who share the same house and play a role as resource manager or system beneficiary. The boundaries of the farm coincide with its physical borders, the atmosphere-soil or atmosphere-plant interface, and the bottom of the rooted zone, below which crops cannot retrieve nutrients. Three types of nutrient flows were distinguished: flows into the farm (IN), flows out of the farm (OUT) and flows within the farm (FL). Flows into the farm included inorganic fertilizer (IN1), organic inputs (IN2a in food and IN2b in feed), deposition (IN3) and N-fixation (IN4). Out flows comprised removal of harvested crop products (OUT1a), livestock products (OUT1b), removal of crop residue (OUT2), leaching (OUT3), gaseous loss (OUT4) and erosion (OUT5). Internal flows manure to fields (FL1), fodder and crop residue to livestock (FL2 + FL3), crop harvest and livestock products to household (FL4 + FL5), pruned khat branches and stems to household as fuelwood (FL6) (Fig 5.1). The flows of N, P and K, as essential nutrients for crop growth, were quantified by multiplying the dry matter of each item with its respective nutrient content (Table 5.A1) and derived from monitoring, measurements and empirical relations. The field level nutrient balance was calculated as the difference between the inputs and outputs at field level. Finally, the farm level annual balance was calculated by aggregating all values of N, P and K from external input sources and the amount of N, P and K exported from each farm component.

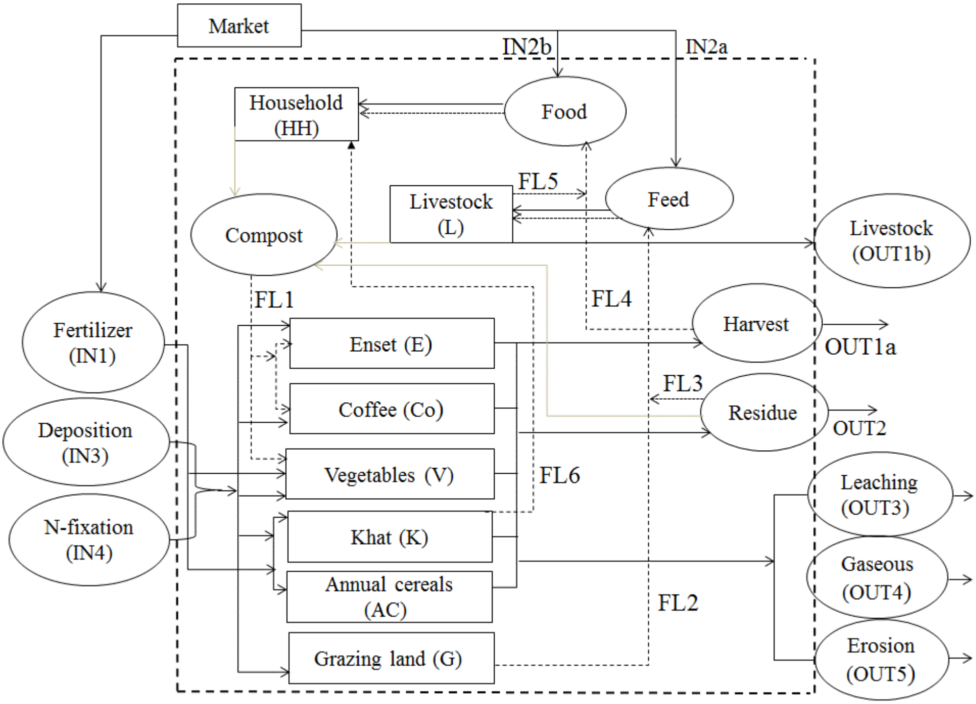


Fig. 5.1. Schematic nutrient flow model for home gardens of southern Ethiopia. The rectangular broken line indicates the farm boundary, broken line arrows indicate internal flows and solid line arrows indicate in- and outgoing flows, solid grey arrows were not quantified. For explanation of abbreviations see the text in Section 5.2.1.

Economic flows were quantified by multiplying each item with its respective price (Table 5.A2). The economic flows into a farm, as off-farm income, and out-flows through purchased farm inputs were also established. Economic calculations were based on logbooks kept by farmers.

5.2.2 Data collection

5.2.2.1 Data collection through farm monitoring

A subsample of 24 farm households selected in Chapter 4 were considered for this study. These farm households were closely monitored for 12 months (September 2014 to August 2015). The destination and quantity of all purchased items and the origin and quantity of all sold items were recorded on a daily basis. The other flows were quantified by recording the amount of (i) manure applied to crop fields, (ii) enset leaves, annual crop residues, weeds and grass supplied to livestock, and (iii) items consumed by the household. A family member, usually a male adolescent or the female household head was trained to register the above items every day for the entire family. At the end of every month each household was visited to collect the data and the information was checked and corrected where needed.

Farmers commonly apply manure to their fields at the end of the main rainy season (September) and with the occasional showers at the end of the main dry season (March to May). The main reason of applying manure at the end of rainy season is to conserve moisture around the roots of enset and coffee plants whereas the latter is to benefit from the nutrients. They usually have a manure heap on their grazing land to which they add the daily cow dung collected from the livestock pen where animals stay during the night. The amount of manure applied from the heap to arable fields was calculated from the number of baskets applied and the average fresh weight per basket measured on six farms. The total annual manure production per fam was calculated by considering average daily manure production of 3.3 kg dry matter per TLU (Abebe 2012). Half of the total produced manure was assumed to be added to the manure heap as farmers mainly collect the cow dung dropped during the night from the pen. The proportion of manure used was calculated by dividing manure applied to fields with manure added to the heap. Farmers were asked to record the daily feed provision to livestock as enset leaves, annual crop residues and weeds from the perennial crop fields in man loads (locally called *shekim*). The feed provided to livestock was calculated by multiplying the number of *shekim* with the average fresh weight per *shekim* measured on six farms. Sub samples of manure, crop residue and weeds were taken, sun-dried for 2 to 3 days first and then oven dried at 65^{o}C for 24 hours for dry matter and N, P and K content determination.

5.2.2.2 Data collection through on-farm measurements

Field level crop and forage biomass was measured on all 24 farms for the 2014 and 2015 cropping seasons. The location and area of each field were registered using GPS. Most farmers had only one field per crop and grazing land. If there were more, the total area per crop was considered. Crop yield was measured in three randomly placed quadrats per field. The quadrat size was 25 m^2 (5 m x 5 m) for perennial crops, 4 m^2 (2 m x 2 m) for maize and 1 m^2 (1 m x 1 m) for other annual crops. The annual cereals were harvested when ripe, separated into crop residues and grain and weighed on site. Vegetables were also harvested and weighed on site. For the perennial crops enset, coffee and khat, allometric equations developed by Mellisse et al. (2017a) were used to estimate the harvested biomass. For khat, allometric equations were applied only to estimate the marketable harvests (leaves and twigs) of both tall and dwarf khat types whereas branches and stems of khat removed through pruning were calculated by using the ratio between leaves and twigs to branches and stem (Desalegn 2016). For the detailed procedure of crop yield harvest see Mellisse et al. (resubmitted). To quantify grass production, forage biomass was sampled twice (September-October 2014 and June-July 2015) from two permanent quadrats protected against grazing on 15 farms. The other farmers were unwilling to establish a quadrat in their grassland. The grass was cut at 5 cm above the ground and weighed immediately on site. Sub samples of grain and grass were taken, sun-dried for 2 to 3 days first and then oven dried at 65°C for 24 hours for dry matter and N, P and K content determination. The N, P and K contents of livestock products, khat branches and stems were obtained from literature data (Table 1). For manure the N, P and K contents were analysed for all farms except one low resource endowed farmer with no manure heap in his front yard. To analyse the N, P and K contents of enset products, samples were taken from harvestable enset plants of 3 to 7 years of age for *kocho* and leaves and 5 to 7 years of age for bula, as bula is only extracted from older plants. *Kocho* is the bulk of the fermented starch obtained from the mixture of the decorticated (scraped) enset leaves and grated corm. Bula is a fine starchy liquid drained from this mixture. For leaves and twigs of khat, four composite samples, one from each of the tall and dwarf khat type collected from their respective agroecologies were taken for N, P and K analysis. For maize, onion and coffee composite samples were taken with the assumption that farmers grow the same varieties of each crop. For barley, one sample each from lime treated and untreated soils were taken. Thus, given the variation in the type of items, the number of samples taken for N, P and K content analysis varied (Table 5.A1).

5.2.3 Empirical relations

To quantify the field level nutrient flows which could not be derived from monitoring and measurements, empirical relations from the literature were used. Atmospheric deposition (kg ha^{-1}) of N, P and K was calculated as the square root of the average annual rainfall (R, in mm) using the regression equation derived by Stoorvogel and Smaling (1990) for tropical conditions.

$$\mathrm{Deposition} = \mathrm{a}\sqrt{\mathrm{R}} \tag{1}$$

Where a = 0.14 for N, 0.023 for P and 0.092 for K.

No legume crops were cultivated in the study area, thus nitrogen fixation by free-living bacteria (IN4, kg ha^{-1}) was estimated using the regression model of FAO (2005), which is based on the amount of rainfall (R, in mm):

$$\mathrm{N\ fixed} = 0.5 + 0.1\sqrt{\mathrm{R}} \tag{2}$$

For nitrate leaching (kg N ha^{-1}) we used a regression equation (Equation 3; De Willigen (2000), based on annual rainfall (R, in mm), clay content (C, in %), rooting depth of crops (D, in m), mineral and organic fertilizer nitrogen application (IN1 + FL1, in kg N ha^{-1}), soil organic matter decomposition rate (S_d, assumed 1.6% year^{-1}), the amount of N in soil organic matter (N_s, in kg N ha^{-1}) and N removal through crop harvest (OUT1 + OUT2 FL3 +FL4 +FL6, in kg N ha^{-1}). K leaching (kg K ha^{-1}; equation 4) is a function of the exchangeable K in the soil (kg K ha^{-1}), mineral and organic fertilizer K application (IN1 + FL1, in kg K ha^{-1}) and mean annual rainfall (R, in mm; (Smaling et al. 1993).

$$\mathrm{N\ leaching} = 0.0463 + 0.0034\,\frac{\mathrm{R}}{\mathrm{CD}}\left((\mathrm{IN1} + \mathrm{FL1}) + \mathrm{S_d N_S} - (\mathrm{OUT1} + \mathrm{OUT2} + \mathrm{FL3} + \mathrm{FL4} + \mathrm{FL6})\right) \tag{3}$$

$$\mathrm{K\ leaching} = (\mathrm{Exch.K} + \mathrm{IN1} + \mathrm{FL1})(0.00029\mathrm{R} + 0.41) \tag{4}$$

The gaseous N losses (OUT4) were estimated using a regression model (FAO 2005), which accounts for denitrification and volatilization in tropical conditions. The gaseous N loss (kg N ha^{-1}) was calculated as a function of rainfall (R, in mm), mineral and organic fertilizer N application (IN1 + FL1, in kg N ha^{-1}) and organic carbon content (O, in %) (Equation 5).

$$\mathrm{gaseous\ N\ loss} = 0.025 + 0.000855\mathrm{R} + 0.13025(\mathrm{IN1} + \mathrm{FL1}) + 0.117\mathrm{O} \tag{5}$$

Soil erosion (OUT5, Mg ha^{-1}) was based on the Universal Soil Loss Equation (USLE), which estimates annual soil loss per ha as a function of rainfall erosivity (E, in MJ mm ha^{-1}h^{-1}yr^{-1}), soil erodibility (K_e, in Mg ha h ha^{-1} MJ^{-1} mm^{-1}), slope length and gradient factor (SL), land cover management factor (Co) and support practice factor (P) (Wischmeier and Smith 1965). The land cover management factor indicates the soil loss under specific soil cover conditions relative to fallow; the support practice factor indicates the erosion due to specific practices relative to erosion without those practices (i.e. terracing). The N, P, and K losses from erosion were calculated from a combination of USLE results and soil nutrient concentrations. As the incidence of soil erosion under perennial crops is negligible, it was calculated only for annual crops.

$$Soil\ loss = E \times K_e \times SL \times Co \times P \tag{6}$$

Due to lack of data on rainfall erosivity in the study area, the empirical equation developed by Hurni (1983a) that estimates the E factor from total annual rainfall (R, in mm) was used:

$$E = -8.12 + 0.562R \tag{7}$$

A value of 0.25 for K_e was applied, as estimated by Hurni (1995) for the soils of the Ethiopian highlands including the study area. The factor S and L were derived from Mitchel and Brubenzer (1980):

$$S = (0.43 + 0.3G + 0.043G^2)/6.613 \tag{8}$$

$$L = \left(\frac{d}{22.13}\right) 0{\cdot}5 \tag{9}$$

Where G is the slope gradient (%, Table 5.A3) and d is the slope length (m). Based on the presence of barriers, such as fences and hedges between fields, the slope length was visually estimated at 25 m. For Co the value of 0.15 was used, based on Adugna et al. (2015). Finally, the land management factor P was derived from Mitchel and Brubenzer (1980) as follows:

$$\mathrm{P} = 0.2 + 0.03G \tag{10}$$

5.2.4 Soil sampling and rainfall recording

Soil samples were taken from each arable field and grazing land of the 24 farms. Topsoil (0 - 15 cm) samples were taken with an auger at five points per field, two from opposite endways along the longest side (1 – 2 m from the border) and one in the middle. Per field soil samples were thoroughly mixed and a subsample was taken for analysis. The samples were oven dried at 105°C for 48 hours and passed through a 2 mm sieve prior to analysis. Total N was analysed following the Kjeldahl method (Bremner and Mulvaney 1982). Potassium and phosphorus were determined by flame emission spectrophotometry (Black et al. 1965). Texture was measured by applying the hydrometer method (Bouyoucus 1951) and soil organic carbon was determined by the wet oxidation method (Walkley and Black 1934). Soil nutrient stocks in the top 0–15 cm were calculated from soil nutrient concentrations and measured bulk densities from core samples. Dry bulk density was calculated by dividing the oven dry mass at 105°C by the volume of the core (Grossman and Reinsch 2002). Daily rainfall data from September 2014 to December 2015 was recorded from each PA with a locally constructed rain gauge (Table 5.A3). One permanent employee in each PA was hired and trained for data collection.

5.2.5 Quantifying economic performance

During the monitoring period, the quantity and price of inputs and outputs of crops and livestock activities and off-farm income were recorded (Table 5.A2). The local currency of Ethiopian birr was converted to US$ at a rate of 20 Eth. birr to one US$, the average exchange rate during the survey period (NBE 2015). Labour cost was calculated from the reported daily wage and the number of hired man days. To quantify the profitability of farms, all purchased and sold items and labour hired in and out in man days was recorded. Gross margin was the main economic performance indicator and defined as revenues minus variable costs both at farm and field level. The variable costs at farm level included mineral fertilizer, hired labour, feed, food, clothes, education and medication. The variable costs at field level included fertilizer and hired labour costs.

5.2.6 Changes in herd size and nutrient balances

The farm and field level changes in N, P and K balances and herd size between 1991 and 2015 were assessed for all 24 farms. The area of all crops and herd size in 1991 were obtained from a household survey (Mellisse et al. 2017b). The 1991 manure input to enset and coffee were calculated by using the ratio of manure to herd size applied to each crops in 2015. The 2015 rate of inorganic fertilizer input applied to different fields and outflows from all fields were kept constant for the 1991. The farm level balance was calculated on an annual basis as the difference between the aggregated amount of N, P and K in external inputs and the aggregated amount of N, P and K exported from the farm system. Finally, the nutrient balances of 1991 and 2015 were compared to examine how home garden system change influenced the nutrient balances.

5.2.7 Data analysis

A one way analysis of variance (ANOVA) was used to test the difference between the means of five crops and between home garden types in returns, gross margin, variable cost and share of different activities to returns. Descriptive statistics was used to summarise nutrient inflows, out flows, balances and stocks for the different home garden systems. Differences were deemed significant at $P < 0.05$. Analyses were performed using the Statistical Package for Social Sciences (SPSS) version 20.

5.3 Results

5.3.1 Farm structure

Most farms in the study area are smaller than one hectare. Enset is grown as major staple crop, but recently it has been supplemented with annual cereals. Khat, coffee and vegetables are grown as cash crops. Individual farms are mostly rectangular and oriented down the slope with the enset garden at the top near the dwelling followed by coffee. Khat and annual crops are commonly grown at the bottom of the slope. Vegetables are, similar to enset, cultivated on the more fertile soils near the homestead, in contrast to annual cereals which are grown at the bottom of the slope further away. When changing their cropping pattern, farmers usually first replace coffee followed by enset from the bottom of the slope upwards. Livestock is commonly kept in a small front yard and penned during the night. The front grazing land is not intentionally fertilized, but receives faeces and urine during the day. Farmers usually practice a cut and carry feeding system and only in the dry season animals are allowed to roam along road sides for grazing. Enset leaves constitute the major source of feed for livestock. Weeds grown under perennial crops and crop residues are collected and brought to livestock tied in the front yard. The front yard also serves as temporary storage site for manure.

5.3.2 Field level nutrient flows and balances

The N, P and K balances were negative for all crops (Table 5.1). For enset the N, P and K balances in Khat-based and Enset-cereal-vegetable systems were more negative than those in the other home garden types. In the former systems, the major out flow of N, P and K was with leaves and weeds (FL3 + OUT2 + FL6), constituting about 40%, 60% and 80% of the total N, P and K out flows respectively. This was mainly due to the high nutrient content of enset leaves and weeds compared to the foods *kocho* and bula (Table 5.A1). In Enset-based systems, N, P and K balances were least negative. In these systems, the major N outputs were crop produce (FL4 + OUT1a) and leaching (OUT3) whereas for P and K, crop produce (FL4 + OUT1a) and residue (FL3 + OUT2) out flows were largest. The variation in the magnitude of the major out flows among home garden systems was related to the differences in amount harvested. For coffee and khat, the negative N, P and K balances were in the same order of magnitude for all home garden systems. Crop harvest (FL4 + OUT1a) was the main output of N, P and K from coffee fields whereas from khat fields both harvest (FL4 + OUT1a), and residues (FL3 + FL6) were the main out puts of N, P and K from khat fields. For annual cereals, the balance for all nutrients was less negative in the Enset-cereal-vegetable system than in the other home garden types. For P the balance was even positive.

Table 5.1 Mean annual values of N, P and K flows and balances (kg ha^{-1}) for the different crops in the home gardens of southern Ethiopia

Crops	HT	n	In flow										Out flow													Balance		
			Inorganic fertilizer (IN1)			Manure (FL1)			Deposition (IN3)			N-fix (IN4)	Crop harvest (FL4+OUT1a)			Residue (FL3 + OUT2+FL6)			Leaching (OUT3)		Gaseous N-loss (OUT4)	Erosion (OUT5)					
			N	P	K	N	P	K	N	P	K	N	N	P	K	N	P	K	N	K	N	N	P	K	N	P	K
Enset	K-b	9	0	0	0	28	2	17	5	1	3	4	27	5	23	32	10	96	8	14	5	0	0	0	-36	-12	-112
	E-c-v	3	0	0	0	51	5	41	5	1	3	4	22	5	19	61	19	156	10	26	8	0	0	0	-42	-18	-157
	E-b	3	0	0	0	46	5	21	5	1	3	4	25	5	21	8	2	25	26	13	7	0	0	0	-12	-2	-35
	E-c	6	0	0	0	14	1	6	5	1	3	4	12	3	11	22	7	55	12	4	3	0	0	0	-27	-8	-61
	E-l	3	0	0	0	73	5	40	5	1	3	4	28	6	24	41	12	98	20	22	11	0	0	0	-19	-13	-101
Coffee	K-b	7	0	0	0	2	0.2	1	5	1	3	4	28	6	28	0	0	0	7	3	1	0	0	0	-26	-5	-27
	E-b	3	0	0	0	7	1	3	5	1	3	4	27	6	27	0	0	0	13	5	2	0	0	0	-27	-5	-26
	E-c	6	0	0	0	15	1	7	5	1	3	4	31	7	31	5	1	6	11	7	4	0	0	0	-26	-6	-34
Khat	K-b	9	80	17	0	0	0	0	5	1	3	4	32	10	35	43	10	65	13	1	12	0	0	0	-11	-3	-97
	E-c	3	53	11	0	0	0	0	5	1	3	4	20	7	22	32	7	50	12	1	8	0	0	0	-12	-2	-70
	E-l	2	67	16	0	0	0	0	5	1	3	4	22	7	24	35	9	52	15	1	10	0	0	0	-6	-1	-74
Annual cereals	K-b	7	57	18	0	0	0	0	5	1	3	4	35	17	16	19	4	40	15	1	9	32	0.2	8	-45	-2	-63
	E-c-v	2	32	11	0	0	0	0	5	1	3	4	9	5	7	4	2	6	20	1	6	29	0.2	8	-28	4	-19
	E-b	2	68	16	0	0	0	0	5	1	3	4	34	16	16	18	5	39	21	1	10	42	2	11	-49	-4	-64
	E-c	2	56	18	0	0	0	0	5	1	3	4	33	16	15	18	5	38	20	1	9	32	0.2	8	-48	-3	-59
Vegetable	E-c-v	3	29	15	0	9	3	19	5	1	3	4	22	12	17	0	0	0	37	16	3	43	0.3	11	-59	6	-22

HT home garden types; n sample size; n; K-b Khat-based; E-c-v Enset-cereal-vegetable; E-b Enset-based; E-c Enset-coffee; E-l Enset-livestock

Although losses through leaching, gaseous loss and erosion were in the same order of magnitude, the small input lead to lower out flow in crops and crop residues in this system. In vegetable fields, erosion and leaching lead to large losses of N and K. For P however, fertilizer application offset the harvested amount. Due to whole plant removal of vegetables (onion and cabbage) with crop harvest, no crop residues were left in the field.iation between crops and home garden types, N, P and K balances also varied between farms in the same type (Fig 5.2).

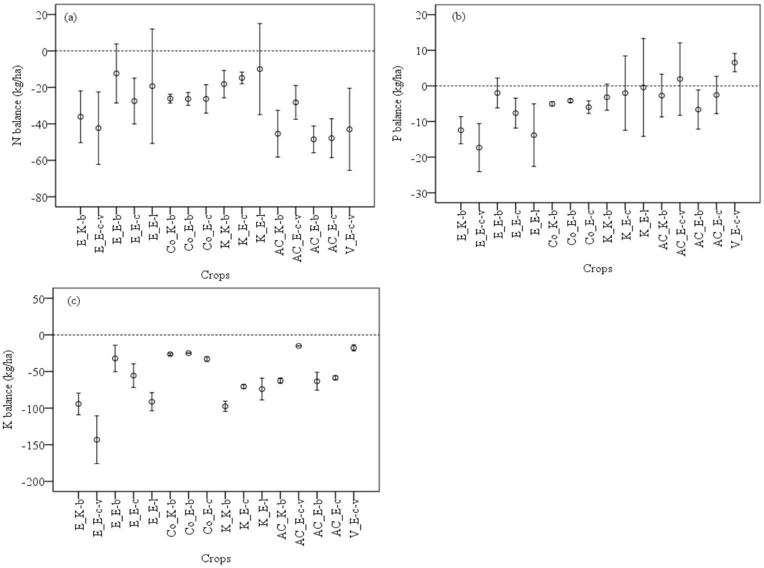


Fig. 5.2 Nitrogen (a), phosphorus (b) and potassium (c) balances for the different crops (enset, E; coffee, Co; Khat, K; annual cereals, AC and vegetables, V) in the home gardens (Khat-based, K-b; Enset-cereal-vegetable, E-c-v; Enset-based, E-b; Enset-coffee, E-c and Enset-livestock, E-l) of southern Ethiopia. Error bars indicate mean ± SE.

The N balances for enset fields of Khat-based and Enset-cereal-vegetable systems were below -20 kg ha^{-1} year^{-1} for all farms (-20 to -50 and -20 to -60), whereas they ranged from +2 to -30, -10 to -40 and +10 to -50 kg ha^{-1} year^{-1} in Enset-based, Enset-coffee and Enset-livestock systems respectively Fig.5.2). For coffee, the N balance ranged between -20 and -35 kg ha^{-1} year^{-1}. The N balances for khat ranged between +10 and -30 kg ha^{-1} year^{-1} for all farms. For annual cereals and vegetables, the N balance ranged between -20 and -60 kg ha^{-1} year^{-1}. The enset P balances were below -10 kg ha^{-1} year^{-1} for most farms in Khat-based, Enset-cereal-vegetable and Enset-livestock systems whereas they were close to equilibrium for Enset-based and Enset-coffee systems. For coffee, P balances were close to the equilibrium. For khat, annual cereals and vegetables P balances fluctuated around the equilibrium. K balances of enset fields were below -100 kg ha^{-1} year^{-1} for most farms in Khat-based and Enset-cereal-vegetable systems whereas above -100 kg ha^{-1} $year^{-1}$ for those in the traditional systems. For coffee, annual cereals and vegetable K balances ranged from -20 to -70 kg ha^{-1} whereas for khat they ranged from -70 to -120 kg ha^{-1}.

5.3.3 Farm level nutrient flows and balances

For Khat-based systems, the N and P balances were positive, mainly due to the application of inorganic fertilizer, and food purchase (Table 5.2). Enset-cereal-vegetable systems had a slightly negative balance for N and positive balance for P, again due to application of inorganic fertilizer and food purchases. In the traditional home garden systems, with a small import of N and P with inorganic fertilizer and purchased food, N and P balances were more negative due to selling of crops and leaching. For K, the balances in all systems were negative as no K was imported with mineral fertilizer. Selling crop produces removed most K from Khat-based and Enset-coffee systems, whereas leaching was the largest K loss from Enset-cereal-vegetable and Enset-livestock systems. In Enset-based systems, K export in sold crop produceand leaching were of a similar magnitude. Although N losses with erosion from annual crop fields accounted for 35% of the total out flow, at farm level it accounted for only 5% of the total out flow due to the small area devoted to annual crops.

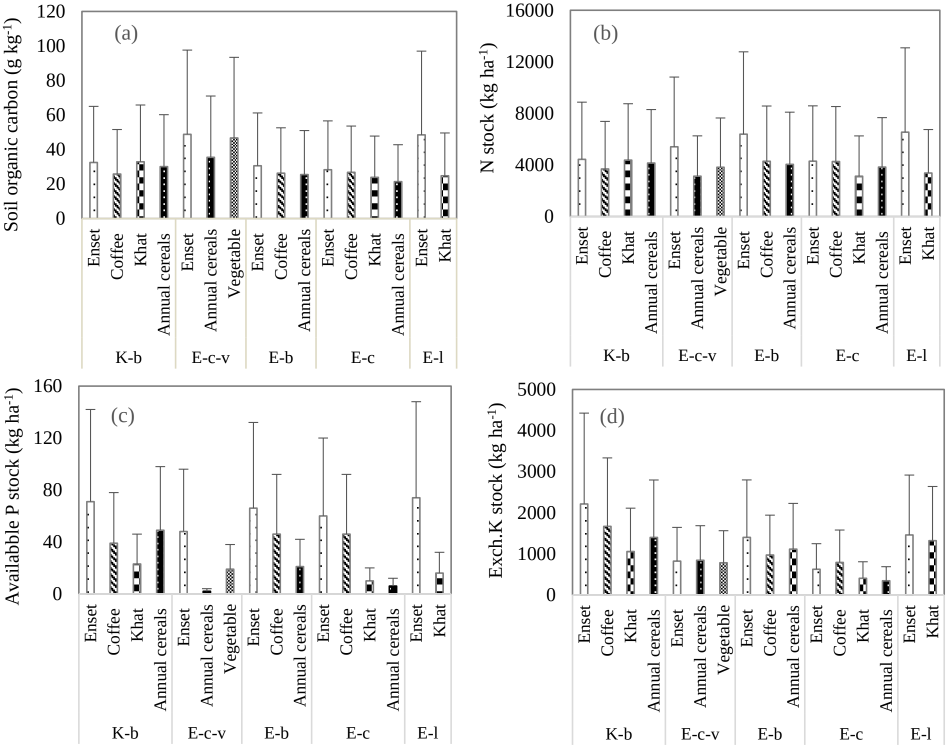
Table 5.2 Mean values of N, P and K flows and balances (kg ha^{-1}) for the different home garden types (HT) in southern Ethiopia

Nutrients	HT	n	In flow (IN)					Out flow (OUT)						
			Fertilizer (1)	Feed (2a)	Food (2b)	Deposition (3)	N-fix (4)	Crop (1a)	Livestock 1b	Residue (2)	Leaching (3)	N-loss (4)	Erosion (5)	Balance
N	K-b	9	42.6	1.4	12.3	4.4	3.6	34.5	2.0	0.8	13.3	7.4	4.6	1.4
	E-c-v	3	13.9	0.2	9.2	4.8	3.9	7.1	1.7	0.1	13.7	5.0	12.7	-8.3
	E-b	3	5.9	0.0	2.4	4.6	3.8	15.4	0.8	0.0	23.0	6.5	3.8	-32.8
	E-c	6	8.6	1.8	4.5	4.5	3.7	32.1	3.6	0.0	10.5	3.8	1.7	-28.6
	E-l	3	6.9	0.4	3.2	4.1	3.4	6.4	9.5	1.1	9.7	6.3	0	-15.0
P	K-b	9	9.8	0.4	4.0	0.7	-	11.5	0.5	0.2	0.0	-	0.1	2.6
	E-c-v	3	5.7	0.1	2.4	0.8	-	3.6	0.4	0.0	0.0	-	2.6	2.4
	E-b	3	1.4	0.0	0.9	0.8	-	3.2	0.2	0.0	0.0	-	0.2	-0.5
	E-c	6	2.4	0.6	1.4	0.7	-	7.6	1.0	0.0	0.0	-	0.0	-3.5
	E-l	3	1.7	0.2	1.2	0.7	-	1.9	2.6	0.3	0.0	-	0.0	-1.0
K	K-b	9	0.0	1.8	5.7	2.9	-	36.5	0.5	2.4	3.9	-	1.2	-34.1
	E-c-v	3	0.0	0.1	3.9	3.2	-	5.5	0.7	0.3	11.0	-	3.2	-13.5
	E-b	3	0.0	0.0	1.1	3.0	-	14.7	0.1	0	10.6	-	1.0	-22.3
	E-c	6	0.0	1.4	2.5	2.9	-	31.1	0.1	0	4.6	-	0.5	-29.5
	E-l	3	0.0	0.2	1.4	2.7	-	6.5	1.0	3.3	10.6	-	0	-17.1

- not applicable; n sample size; K-b Khat-based; E-c-v Enset-cereal-vegetable; E-b Enset-based; E-c Enset-coffee; E-l Enset-livestock

5.3.4 Soil organic carbon content and nutrient stocks

Soil organic carbon content (SOC) and nutrient stocks differed between the crops in the home garden systems (Fig 5.3). In khat-based systems all fields had a similar SOC (30-33 g kg^{-1}), except for coffee fields, where SOC was somewhat lower (26 g kg^{-1}). In Enset-cereal-vegetable systems the annual cereals had a lower SOC (36 g kg^{-1}) than the other crops (47-49 g kg^{-1}). In Enset-based systems, enset fields had a somewhat higher SOC (31 g kg^{-1}) then coffee and annual cereals (26 g kg^{-1}). In Enset-coffee systems we observed a gradient of decline in SOC in the order enset – coffee – khat - annual cereals from 28 to 21 g kg^{-1}. In Enset-livestock systems khat fields clearly had a lower SOC (25 g kg^{-1}) then enset (38 g kg^{-1}).



Error bars indicate ±SE, K-b Khat-based; E-c-v Enset-cereal-vegetable; E-b Enset-based; E-c Enset-coffee; E-l Enset-livestock

Fig. 5.3. Soil organic matter (a), N stock (b), available P (c) and exchangeable K (d) for different crops grown in home gardens of southern Ethiopi

Over all systems we observed the highest SOC in enset fields and SOC in annual cereals tended to be lowest. The high SOC in Enset-cereal-vegetable systems could be related to a somewhat higher silt and clay content in the soil compared with the soils of the other home garden systems. The same pattern was observed for the soil N-stock for all home garden types and crops, with the only difference that the N-stock in khat fields of the Enset-coffee systems was smaller than that in annual cereal fields. The soil N stock varied between 3100 kg total N per ha for annual cereals in Enset-cereal-vegetable systems and 6500 kg total N per ha for enset in Enset-livestock and Enset-based systems. The soil P-stocks where substantially higher in enset and coffee fields (39–74 kg available P ha^{-1}) than in the other fields over all systems (2-23 kg available P ha^{-1}), except for annual cereals fields in the Khat-based system (49 kg available P ha^{-1}). The soil K-stocks showed a pattern similar again to SOC and soil N-stocks, but the differences between soil K-stocks under enset and the other crops are relatively smaller than for SOC and N.

5.3.5 Change in herd size and nutrient balances between 1991 and 2015

5.3.5.1 Herd size and manure use efficiency

The herd size per household in 2015 was much smaller than in 1991 in all home garden systems except in Enset-based systems (Table 5.3). For example, shifting from the traditional systems in 1991 to Khat-based system in 2015 caused a decline in herd size by 76% (Table 5.3). Similarly shifting from Enset-livestock in 1991 to Enset-cereal-vegetable systems in 2015 led to a decline in herd size by 42%. The decline in herd size was related to the scarcity of feed, imposed by the decline in farm size and subsequent replacement of enset, a major livestock feed source. When feed scarcity became a constraint to keep their own livestock, Enset-based farmers adopted the strategy of accessing manure through feeding beef cattle for cattle traders. Farmers in the newly-evolved Khat-based and Enset-cereal-vegetable systems applied about a quarter of the manure from the manure heap to crops whereas those in the Enset-based systems applied about three quarters of the manure to crops. Farmers in Enset-coffee and Enset-livestock systems applied about half of the manure added to manure heap to crops. The newly-evolved home garden systems are less reliant on manure due to the replacement of enset and coffee by khat and vegetables or annual cereals, which receive inorganic fertilizer. In the other three home garden systems where the area share of enset and coffee remains dominant, a greater proportion of the manure was used.

Table 5.3. Herd size per household in 1991 and 2015, manure production is calculated from 2015 herd size for the different home garden types in southern Ethiopia (mean values with standard deviation in brackets)

			Manure (kg DM)			
Home garden types	Herd size (TLU)		Produced	Added to heap	Applied to crops	Proportion of manure used on crops (%)
2015	1991	2015	2015	2015	2015	
Khat-based	9.3	2.2	2689	1344	324	24
(n=9)	(9.4)	(1.2)	(1390)	(695)	(294)	(12)
Enset-cereal-	10.0	5.8	7010	3505	1001	28
vegetable (n=3)	(5.1)	(2.5)	(3048)	(1524)	(601)	(16)
Enset-based	4.6	5.7	6825	3413	2473	74
(n=3)	(0.8)	(0.7)	(802)	(401)	(913)	(31)
Enset-coffee (n=6)	7.1	3.2	3788	1894	1105	58
	(4.5)	(1.4)	(1632)	(816)	(1468)	(41)
Enset-livestock	10.3	6.8	8233	4115	1770	43
(n=3)	(12.8)	(5.2)	(6350)	(3174)	(1706)	(12)
Mean	8.4	3.9	4714	2357	1053	37
	(7.6)	(2.7)	(3214)	(1607)	(1181)	(29)

5.3.5.2 Field level changes in nutrient balances

Generally, the worsening of N, P and K balances in 2015 compared to the 1991 for enset and coffee were related to the decline in herd size and the reverse is true for the improvement of these nutrient balances (Fig 5.4 and 5.A1). For annual cereals, the worsening of N, P and K balances in 2015 were related to the shift from barley in 1991 to maize in 2015 and the reverse is true for the improvement of these nutrients. For the farms that shifted from a traditional system in 1991 to a Khat-based system in 2015, the N, P and K balances of enset fields were more negative in 2015 than in 1991 (Fig 5.4 and 5.A1). The worsening of N, P and K balances on enset fields of Khat-based systems was mainly explained by the decline in herd size and sparse manure use compared with enset and coffee fields (Table 5.3). Two out of the three farms that remained Enset-based improved the N balance of the enset field mainly due to an increase in herd size (Fig 5.4). For five out of six Enset-coffee system in 2015, a positive N balance on enset fields in 1991 was changed into a negative balance in 2015 due to the decline in herd size .

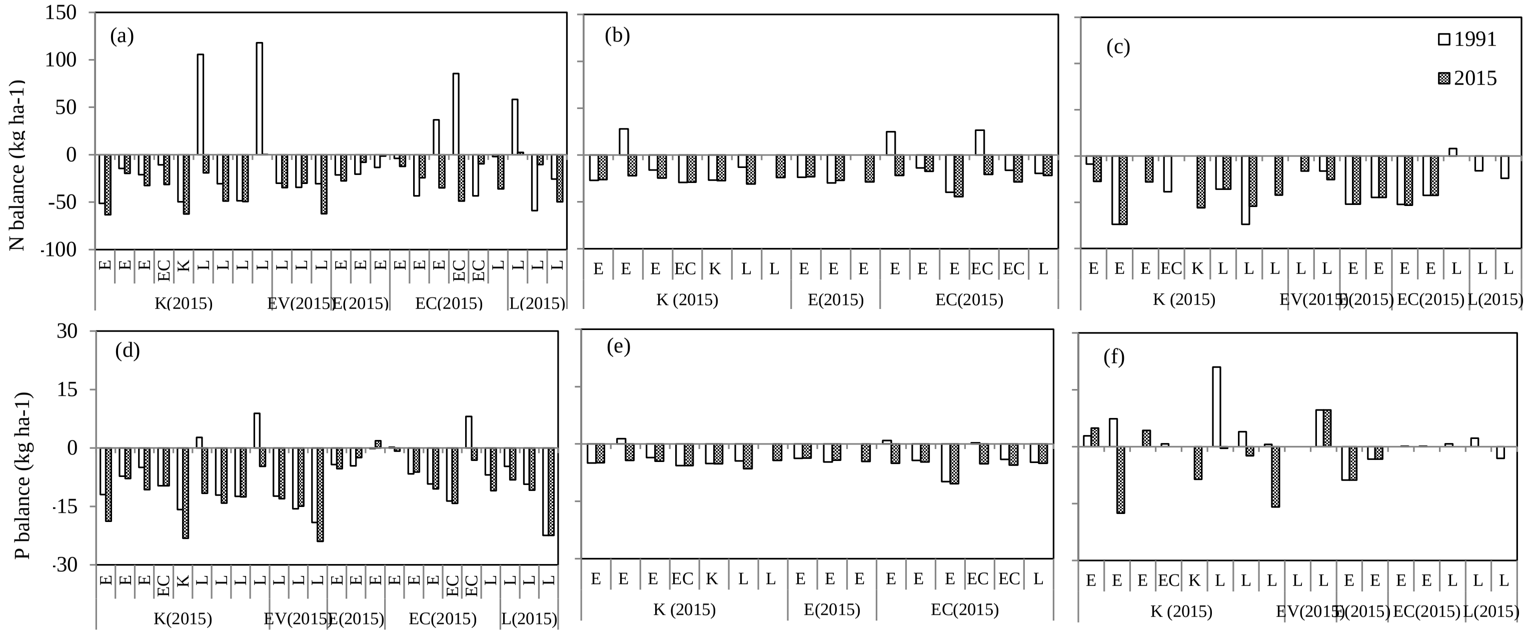


Fig. 5.4 N and P balances for enset (a, d), coffee (b, e) and annual cereals (c, f) grown in the home gardens of southern Ethiopia in 1991 and 2015. K Khat-based; EV Enset-cereal-vegetable; E Enset-based; EC Enset-coffee; L Enset-livestock; letters without year in the bracket represent the 1991 home garden systems.

5.3.5.3 Farm level changes in nutrient balances

Fig 5.5 shows the change in N, P and K balances of the home garden systems between 1991 and 2015 at farm level. For most farm households, the shift to Khat-based systems led to a more positive N and P balance, whereas those that remained Enset-based aggravated their negative balances. The need to fertilize khat with inorganic fertilizer and purchase food for the family contributed substantially to the improvement of N and P balances. K balances decreased, due to lack of K application. For most farm households, the shift to Enset-cereal-vegetable systems improved the N balances. For half of the farms in Enset-coffee systems, the negative N and K balances were improved in 2015 compared to the 1991 balances.

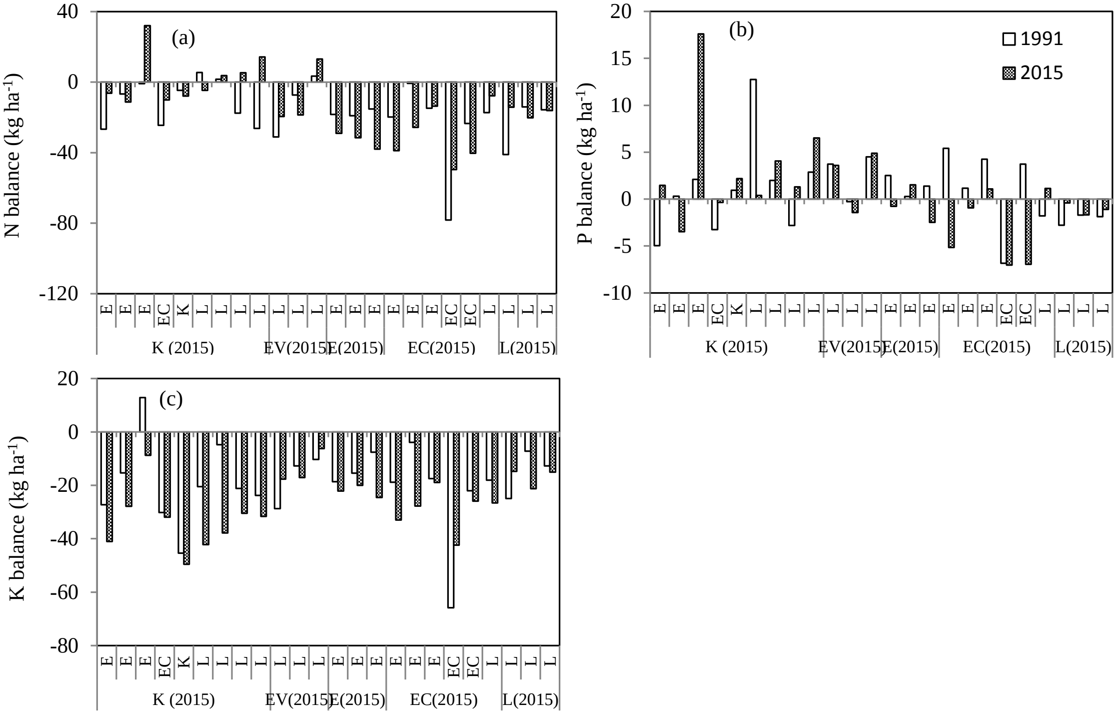


Fig. 5.5 The N (a), P (b) and K (c) balance at farm level within the different home garden systems in 1991 and 2015. K khat-based; EV Enset-cereal-vegetable; E Enset-based; EC Enset-coffee; L Enset-livestock; letters without year in the bracket represent the 1991 home garden systems.

5.3.6 Economic performance

5.3.6.1 Crop level

The gross margin of khat was significantly larger than that of other crops (Table 5.4). The high returns more than compensated the higher costs of khat cultivation. Enset and coffee did not differ significantly in terms of returns and gross margin. For the cash crops khat and vegetables, fertilization and hired labour were the major cost components, whereas for coffee it was only hired labour. For the food crops, fertilization was the most important cost component for cereals and hired labour for enset, although negligible in relation to the returns

Table 5.4 Economic performance of crops grown in home gardens of southern Ethiopia on an annual basis (mean values with standard deviation in brackets; row values with no letter in common are significantly different).

	Cash crops			Food crops	
	Khat (n = 14)	Vegetable (n = 3)	Coffee (n = 16)	Enset (n = 24)	Annual cereals (n = 13)
Gross margin (US$ ha^{-1})	11721 (4917)a	6378 (801)b	2481 (1051)c	2176 (1382)c	694 (270)d
Returns (US$ ha^{-1})	12101 (4994)a	6502 (866)b	2516 (1077)c	2184 (1374)c	793 (277)d
Variable cost (US$ ha^{-1})	379 (173)a	123 (110)bc	37 (36)dc	8 (18)d	98 (33)c
Fertilizer (US$ ha^{-1})	155 (59)a	78 (41)b	0	0	98 (33)b
Hired labour (US$ ha^{-1})	224 (135)a	45 (41)b	37 (36)b	8 (18)b	0

5.3.6.2 Farm level

The gross margin in Khat-based systems was significantly larger than in the other home garden systems (Table 5.5). In Enset-based systems most income was derived from food crops, but the large off-farm income illustrates the inadequacy of farming activities meeting household needs. For all home garden systems except Khat-based, the daily family earnings from agricultural activities was below the poverty line of 1.9 US$ a day per person (World Bank 2015). In contrast, the daily family earnings of Khat-based farmers was two times more than the poverty line and the daily wage for unskilled labour (1.5 US$ day^{-1}) in southern Ethiopia. The daily family earnings from agriculture activities in Enset-cereal-vegetable and Enset-coffee systems were equal to the daily wages for unskilled labour in southern Ethiopia. Livestock contribution to returns was almost equal to that of cash crops in the Enset-livestock systems. Food purchase was the major variable cost in Khat-based systems, unlike in the other systems which were largely food self-sufficient.

Table 5.5 Economic performance of different home garden systems in southern Ethiopia on an annual basis (mean values with standard deviation in brackets; row values with no letter in common are significantly different)

	Khat-based (n=9)	Enset-cereal-vegetable (n=3)	Enset-based (n=3)	Enset-coffee (n=6)	Enset-livestock (n=3)
Gross margin (US$ farm^{-1})	7089 (4128)a	1647 (1056)b	1935 (1030)b	3035 (2124)b	2943 (1953)b
Return (US$ farm^{-1})	8115 (4564)a	2077 (1144)b	2209 (1070)b	3391 (2186)b	3422 (2236)b
Variable cost (US$ farm^{-1})^{a}	1025 (554)a	430 (97)b	274 (84)b	570 (364)b	479 (405)b
Fertilizer (US$ farm^{-1})	94 (62)a	47 (46)ab	14 (12)b	23 (31)b	32 (42)ab
Hired labour (US$ farm^{-1})	120 (104)a	8 (7)b	1 (1.2)c	58 (65)b	64 (79)ab
Food (US$ farm^{-1})	535 (275)a	270 (36)ab	180 (97)b	343 (232)ab	190 (130)b
Off farm income (US$ farm^{-1})	41 (61)a	84 (75)a	197 (61)a	104 (188)a	87 (150)a
Cash crops (% of returns)	87 (4)a	33 (7)c	16 (12)c	63 (15)b	26 (34)c
Livestock (% of returns)	5 (5)b	20 (19)a	1 (1)b	8 (10)ab	19 (10)a
Food crops (% of returns)	8 (3)d	47 (15)bc	83 (11)a	29 (11)c	55 (43)ba
Family earnings (US$ ae^{-1} day^{-1})^{b}	3.6 (2.3)a	1.2 (0.8)b	0.83 (0.2)b	1.3 (0.8)b	1.8 (1.2)ab

[a] hired labour, fertilizer, food purchase, other; [b] return minus cost of fertilizer and hired labour; ae is adult equivalent

5.4 Discussion

5.4.1 Nutrient balances and ecological sustainability of home garden systems

The long-term existence of enset-coffee home gardens in densely populated regions of southern Ethiopia is commonly attributed to the strong interaction in terms of nutrient flows among the enset/coffee and livestock components of the system (Kippie 2002; Amede and Diro 2005; Abebe 2005). However, as population density doubled over the last two decades and per capita land holding fell below 0.25 ha (Mellisse et al. resubmitted), the area allocated to enset strongly declined. Feed scarcity imposed by shortage of enset leaves has led to the decline in herd size from an average 8.4 TLU in 1991 to 3.9 TLU in 2013 (Table 5.3). Consequently, manure availability for enset and coffee reduced (Table 5.1), leading to more negative N, P, K balances of enset in 2015 compared with 1991 (Fig 5.4, 5.A1). Especially in Khat-based and Enset-cereal-vegetable systems, the nutrient balances of the enset fields were strongly negative. This implies nutrient depletion over time in response to the decline in herd size and manure availability and could over time result in decreased yields (Mellisse et al. resubmitted). When farmers are unable to harvest enough enset biomass or generate sufficient income from coffee, they tend to shift towards the high value cash crop khat or to annual cereals and vegetables and become entirely dependent on external input for its fertilization (Table 5.1).

In Khat-based systems where inorganic fertilizer was applied, the farm level N and P balances were positive, whereas balances were negative on farms where the import of inorganic fertilizer was small (Table 5.2). Hence, considering nutrient balances at farm level as indicators of sustainability, Khat-based systems seem the most sustainable. However, considering the nutrient balances of individual fields within the system challenges this view. Farmers applied more N and P to khat than enset and coffee, which led to more negative balances on enset and coffee fields (Table 5.1). Thus, analysing the nutrient balances at different levels, in this case field and farm level, gives a better understanding of the input distribution strategy of smallholders, favouring specific fields (Haileslassie et al. 2006). The same effect as for Khat-based systems was observed for Annual-cereals-and-vegetable systems, but due to the lower inorganic N input the farm level N balance remained slightly negative. However, the less negative N and P balances on khat fields compared to enset fields (Table 5.1), did not correspond to larger nutrient stocks in khat fields than in enset and coffee fields (Fig 5.3). Soils planted with annual cereals and vegetables also had smaller N, P and K stocks than soils planted with enset or coffee. As farmers usually replace enset and coffee with khat or annual cereals from the bottom fields upwards, the difference in nutrient stocks could be explained on the one hand by the variation in soil fertility along a gradient from the homestead to the bottom fields. Strong gradients of decreasing soil fertility with increasing distance from the homestead within smallholder African farms have been reported elsewhere (Tittonell et al. 2005; Zingore et al. 2007). On the other hand, it could be explained in terms of the changes in management such as the switch in input use from manure to inorganic fertilizer and removal of all residues, which resulted in a decline in soil organic carbon (Fig 5.3a). Similarly, a recent study reported a decline in soil organic carbon by more than 15% following the conversion of enset and coffee to khat or sugarcane (Kim et al. 2016). As soil organic carbon is simultaneously a source and sink for nutrients and plays a vital role in soil fertility maintenance, its decline leads to decreasing soil fertility (Bationo et al. 2007) with direct repercussions on crop productivity if no additional fertilizer is applied. In an earlier study, Mellisse et al. (resubmitted) reported a significantly positive relationship between soil organic carbon and enset biomass. Soil organic carbon is also considered as an indicator for sustainable land management and it is critical in determining the response to N and P fertilization (Tittonell and Giller 2013). Given the fact that soil organic carbon plays a role in supplying plant nutrients, enhancing cation exchange capacity, improving soil aggregation and water retention and supporting biological activity (Tiessen et al. 1992; Lehmann et al. 2007) its deterioration could have negative implications for the sustainability of crop production. Therefore, the process of shifting to khat and annual cereals with the application of only N and P could threaten sustainable production unless strategies to enhance soil organic carbon can be identified.

5.4.2 Profitability and economic viability of home gardens

The economic viability of home gardens is commonly attributed to the low cost of production and the possibility to harvest multiple products and generate income from multiple sources (Kumar and Nair 2004). Among the five home garden types of the study area, enormous variations were observed in the sources from which income is derived (Table 5.5). Farmers in Enset-cereal-vegetable and Enset-livestock systems earn a significant amount of their income from a wide range of sources whereas those in Khat-based and Enset-based systems mainly from a single source. Enset-coffee systems are somewhere in between. In rural areas of sub-Saharan African countries, diversification of income sources is a strategy smallholder farmers often use to minimize the risks of income variability (Abdulai and CroleRees 2001; Agyeman et al. 2014). Especially, in areas where farming is entirely dependent on a variable climate and there is limited access to insurance, farmers are often willing to accept a lower income for greater security (Ellis 2000; Wanyama et al. 2010). In terms of dependency on external inputs, there is a considerable difference between Khat-based and Enset-oriented systems. Farmers in Enset-based and Enset-coffee systems are less dependent on external input, resulting in decreased vulnerability to limited input supply and price fluctuations than those in the Khat-based systems. Khat-based systems are highly dependent on external input, both inorganic fertilizer and food, so an increase in input prices could increase farmers’ vulnerability to both economic and household food security risks. In countries like Ethiopia, where smallholder farmers have no access to insurance, being mainly dependent on a single source of income could also aggravate the vulnerability to economic risks and threaten the long term sustainability of farming. Similarly, other studies reported the incapability of small commercialized farms to generate sufficient income to support a sustainable livelihood following a decline in output prices (Wiggins et al. 2011).

Despite being vulnerable to price fluctuation, Khat-based farms were highly profitable. The economic performance of Khat-based farms, in terms of gross margin was significantly superior (Table 5.5). The daily per capita earnings of Khat-based farmers were more than double those of other systems. In densely populated regions of the study area where the per capita farm size falls below 0.25 ha and the rural unemployment rate steadily increases (Bezu and Holden 2014), agricultural systems like the Khat-based systems, which can provide higher per capita earnings, are much more attractive for the farmers. Growing of khat was 17, 5, 5 and 2 times more profitable than annual cereals, enset, coffee and vegetables respectively (Table 5.4). Thus it is not surprising that enset and coffee, keystone components of traditional home gardens are being replaced, particularly in such densely populated regions.

5.4.3 Future sustainable management of home garden systems

Given the possibility of generating significantly higher income from khat, its cultivation seems a viable means of utilizing the scarce land. However, the increasing dependency of Khat-based farmers on the income from one crop could induce risks associated to harvest failure and price fluctuations. As N and P are currently the only nutrient inputs to khat and the decrease in soil organic carbon content could threaten long term production and exacerbate the vulnerability to risks. Hence, there is an urgent need to identify and develop adapted interventions to maintain ecological and economic sustainability of the system. One promising option is to intensify production systems through intercropping khat with annual crops such as cereals and legumes. Khat is the main crop receiving inorganic fertilizer, which would also benefit the intercropped food crops, thus contributing to food self-sufficiency and reducing the risk of entirely relying on the market for food. At the same time the crop residues that are produced could provide a welcome fodder source for livestock and ease the pressure on harvest of enset leaves for fodder. As enset leaves decompose easily (Nurfeta 2008) and contain large amounts of K, their application to khat fields as mulch could be a good source of K. In such a way, it would be possible to establish strong interdependencies that facilitate nutrient flows between the enset, khat and livestock components of the system. For the other newly evolving Enset-cereal-vegetable systems, reducing N export through erosion, which accounts for more than 50% of total N out flows, could contribute to enhance soil fertility and long term productivity of cereals and vegetables. For enset, as major field-level out flows of N, P and K were caused by the use of enset leaves as fodder, growing forage species such as *Leucaena leucocephala* and *Pennisetum purpureum* (Zarate 1987; Franzel et al. 2003; Wambugu et al. 2011) could ease the pressure and reduce negative balances. Besides, as farms in the newly evolved systems applied only a quarter of the available manure (Table 5.3), the strongly negative N, P and K balances on enset fields could be alleviated by improving recycling of manure to the fields. This is especially true for Enset-coffee and Enset-livestock systems where farmers only applied about half the available manure.

For Enset-based systems where leaching contributed about 30% of N loss from enset and coffee fields, negative nutrient balances on these fields could be improved by applying strategies that can help to reduce nitrate leaching. As farmers apply manure only two times a year, nitrate leaching could be reduced by increasing the frequency of manure application to four or more times and growing cover crops such as sweet potato (Dinnes et al. 2002). Besides, given the possibility of intercropping enset with coffee, introducing improved coffee varieties is another option that could enhance the profitability of traditional systems. Such new varieties suited to the highland and mid-altitude agroecology can yield up to 2750 to 3250 kg ha^{-1} respectively under management similar to farmer's practices (Belete et al. 2014).

5.5 Conclusion

Our study reveals major challenges posed by increasing population pressure and resulting land fragmentation on herd size and manure availability in the densely-populated highlands of southern Ethiopia. The decline in herd size and resulting difficulty of fertilizing enset and coffee with manure forced smallholders to shift from traditional Enset-coffee, Enset-based and Enset-livestock systems to Khat-based and Enset-cereal-vegetable systems, which has led to a shift from manure to inorganic fertilizer use. Whereas shifting to cultivation of khat and vegetables enhances profitability, it comes at the expense of declining soil fertility. The shift to annual cereals was neither profitable nor ecologically sustainable in terms of soil fertility maintenance. Highly profitable Khat-based farmers generated almost all of their income from the cash crop compared to the least profitable Enset-based farmers who generated almost all of their income from food crops. While traditional systems seem more sustainable than Khat-based systems in terms of maintaining soil fertility, low reliance on external input, and generating income from multiple sources, the capacity of satisfying the family's food demand is challenged by scarcity of farm lands. Sustainable intensification options for the current home garden systems include intercropping khat with food crops, integrated soil fertility management comprising efficient manure use and handling, and improved crop varieties. As home gardens have evolved to comprise a large variability in structure and functioning, these options need to be tailored to the specificity of each home garden type.

Acknowledgements

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CHAPTER SIX

6. General discussion

6.1 Introduction

The main objective of this study is to assess the influences of rising rural population pressure and market developments in southern Ethiopia upon the dynamics of home garden systems and to bring out the implications for the socio-economic and ecological sustainability of these systems. Evaluating home garden systems in terms of socio-economic and ecological sustainability helps to explore sustainable development options which could support the livelihoods of the rising population without burdening the environment. We consider productivity, profitability, food security and dietary diversity as indicators of socio-economic sustainability, and plant species diversity, nutrient balances and soil nutrient stocks as indicators of ecological sustainability. As rising rural population pressure and the development of markets are typical features of developing countries, where home garden systems are predominantly practiced, the lessons we learn from this study can be applied beyond the study region. A farming systems analysis is applied that does justice to the fact that smallholder systems are characterized by a large heterogeneity (Tittonell et al. 2010), and that trade-offs exist between multiple dimensions of sustainability, imposing constraints on the adoption of technology options (Descheemaeker et al. 2016).

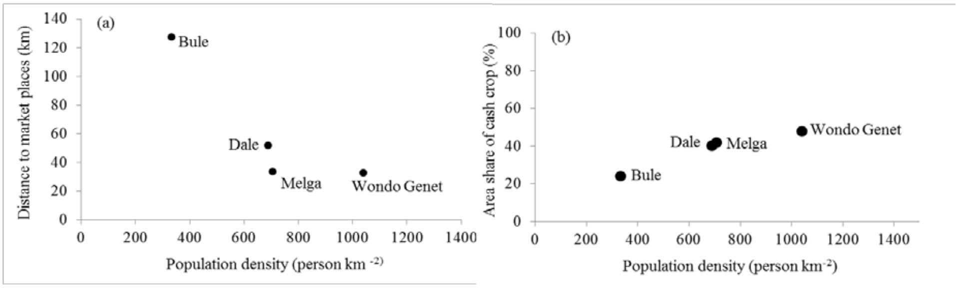

Fig.6.1. The relationship between population density and the distance from market places (a) and the area share of cash crops (b) for the four districts in the study region

6.2 Implications of population pressure and market access for the dynamics of home garden system in southern Ethiopia

In southern Ethiopia, the change from traditional Enset-based, Enset-coffee and Enset-livestock systems to commercial Khat-based systems was not only driven by increasing population pressure, as postulated by Boserup (1965), but also by market developments (see Chapter 2). To unravel these effects, the developments in four districts, with differing population pressure and degrees of market access, were studied. The positive relation between population density and the area share of cash crops illustrates the substantial influence of population pressure on the process of commercialization (Fig. 6.1b). Similar responses to socio-economic pressures have been reported from Kerala, India, where a shift occurred from traditional home gardens to commercial to rubber-based systems (Peyre et al. 2006), and in Java, Indonesia, and Sudan, where a shift to vegetable-based farming was observed (Abdoellah et al. 2006; Wiggins et al. 2011). Although population density and distance to the market are closely related (Fig. 6.1a), the variation in these driving factors between different localities pushed home garden change in the study area in different directions (see Chapter 2). In the densely populated and market-proximate Wondo Genet district more than half of the households replaced traditional home garden systems with Khat-based systems (see Fig. 2.6 and 2.7 in Chapter 2). In contrast, in the less densely populated and less accessible Bule district, khat was not observed at all. Instead of turning to Khat-based systems, farmers in the Bule district modified traditional systems through the incorporation of annual cereals and vegetables, which resulted in the development of Enset-cereal-vegetable systems. Although the Melga and Dale districts support an almost equal population density, the prevalence of Khat-based systems was only noticed in the Melga district, which is better connected to the market than Dale (see Fig. 6.1a). This can be explained by the rapid perishability of khat with a maximum shelf-life of four days after picking (Distefano 1983).

This implies that it will be unlikely that farmers in the Bule district will respond to increasing population pressure by adopting Khat-based systems, unless the region will be better connected to market places. In the moderately accessible Dale district, where about 3% of the surveyed farmers have already adopted Khat-based systems (see Fig. 2.6 in Chapter 2), khat expansion will be feasible, particularly when the highway which is under construction between Dale and Hawassa will be completed. As farmers commonly first replace coffee with khat, khat expansion to Dale will lead to the replacement of the locally known sidama coffee, the main coffee ecotype grown in these district. If we assume the farm area to be allocated to khat will increase by 1.2% each year in Dale, as was the case in the moderately populated Melga district, coffee, which currently occupies about 25% of the farm area in Dale (see Fig. 4 in Chapter 2), will be completely replaced by 2040, which will lead to the disappearance of sidama coffee from the market.

6.3 Sustainability of home garden systems

This section reviews various claims about the sustainability of home garden systems, in the light of the findings of this study.

6.3.1 Socio-economic sustainability

The possibility of producing multiple products on small plots of land (Kumar and Nair 2004; Wiersum 2004), allowing year-round harvesting (Christanty et al. 1986; Krishna 2006), is often claimed to be an explanation for the capacity of home garden systems to support a very dense population. However, it is not at all clear whether the multiple products obtained from traditional home gardens are sufficient to cover the food and cash demands of households (see Chapter 4). Earlier studies have focused mainly on an evaluation of standing biomass (Negash 2013). However, as the food security of smallholders depends on cash resources as well as on the annual production of food, we incorporated both of these aspects in this study (see Chapter 4). In southern Ethiopia, where the contribution of off-farm activities is negligible (see Table 5.5 in Chapter 5), household food security is largely determined by farm size (see Fig. 4.10 in Chapter 4). When land is subdivided among heirs, farms are fragmented into small plots, which directly impacts food security. As food security requires a reliable access to a sufficient quantity of affordable and nutritious food, which can be achieved by either by producing food on the farm or by purchasing food from the market, we assessed productivity in three ways, based on annually harvested biomass, energy value and revenue (see Chapter 4). None of the five home gardens systems was superior in terms of all three productivity indicators (see Table 4.1 in Chapter 4). Most farmers in Khat-based systems who maximize their income through khat cultivation and those in Enset-cereal-vegetable systems who enhanced crop yield through incorporating annual cereals and vegetables were food-secure, while most that remained practicing the traditional Enset-based, Enset-coffee and Enset-livestock systems were not (see Fig. 4.7a and Chapter 4). Food security is commonly used as an indicator of human well-being

(Regassa and Stoecker 2011); we consider it to be an essential criterion for the socio-economic sustainability of these systems.

A second widespread claim made about home gardens, is that the possibility of year-round harvesting of diverse products from home gardens systems contributes to food security, especially during ‘lean seasons’ (Christanty et al. 1986; Krishna 2006). However, this was not clearly observed in the home garden systems of southern Ethiopia, as the households found it difficult to satisfy their energy requirement at the beginning of *tseday*, during the entire *bega*, and at the end of the *kiremt* seasons of the year (see Fig. 4.7b in Chapter 4). Also, the claim that the home garden systems warrant a diverse diet was not substantiated, as the studied households consumed products from less than 6 food groups (see Fig. 4.8b in Chapter 4). This illustrates the inability of traditional home garden systems to accommodate the increasing population. However, it seems possible to ensure food security through modifying traditional systems (see Fig. 6.2a). In particular, replacing coffee, which is harvested only once a year and needs a relatively long establishment period, with khat, which has the added advantage of multiple harvests, has significantly improved the income per unit of land (see Table 5.4 in Chapter 5). Consequently, land-constrained farmers who introduced khat were able to satisfy their family’s food requirements (see Fig. 6.2a).

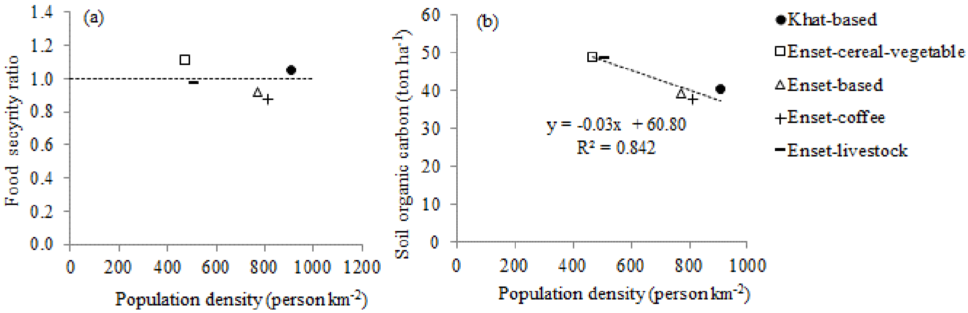

Fig. 6.2 Relationship between population density and food security ratio (a) and soil organic carbon (b) for the five home garden systems of southern Ethiopia, based on data from 2013. The dotted horizontal line in (a) indicates the threshold value for the food security ratio.

The third claim often made about the presumed socio-economic sustainability of home gardens is that they allow the generating of income from multiple sources (Kumar and Nair 2004), thus minimizing the risks of income variability (Abdulai and CroleRees 2001; Agyeman et al. 2014). However, this claim was not substantiated in this study, as it appeared that farmers in the traditional Enset-based and Enset-coffee systems earned about 83% and 63% of their income mainly from the food crop enset and cash crop coffee respectively, which is almost similar to the farmers in the newly-evolved Khat-based systems, who earned about 87% of their income from the cash crop khat (see Chapter 5). In contrast, farmers in the newly-evolved Enset-cereal-vegetable and in the traditional Enset-livestock systems earn a significant part of their income from a wide range of sources. Particularly for farmers depending on few crops, or crops with fluctuating prices, the development of insurance schemes is a priority.

The fourth claim made about the socio-economic sustainability of home gardens concerns the low dependency on external inputs (Abebe 2005), which is supposed to protect farmers from input supply limitations and price fluctuations. It is certainly true that farmers in all traditional home garden systems are less dependent on external inputs, such as inorganic fertilizer, than those in Khat-based and Enset-cereal-vegetable systems (see Chapter 5). Thus especially for farmers in Khat-based systems, which are highly dependent on external inputs of both inorganic fertilizer and food, the risk of rising input prices constitutes a potential threat to both economic security and household food security.

Another quality of home garden systems claimed to contribute to socio-economic sustainability is the strong interaction between the components of the systems, which allows the recycling of organic matter and positively influences crop productivity (Abebe 2005). The development of new home garden systems has resulted in a change in the recycling of organic matter (including manure) between the components of the system (see Chapter 4 and 5). The decrease of the area of enset per farm in response to khat expansion had a direct impact on the herd size, as enset leaves are the major livestock feed source in the area (see Chapter 2). The decline in herd size in response to feed scarcity (enset leaves) in turn led to a shortage of manure to fertilize enset and coffee, which affected the productivity of these crops negatively (see Chapter 4). The decline in herd size is also expected to influence the nutritional quality of human diets, as the enset diet is nutritionally poor (Brandt et al. 1997; Tsegaye and Struik 2001) and as farmers tend to buy mainly cereals on the market. Thus, although the newly-evolved Khat-based and Enset-cereal-vegetable systems are better performing in terms of profitability, productivity and food security for now, their long-term sustainability is not guaranteed due to the weakened interaction between the crop-livestock and livestock-household components of the system.

6.3.2 Ecological sustainability

The presence of several crops and trees with a diverse canopy structure in home garden systems is believed to ensure a continual organic matter supply to the soil in the form of litter fall (Torquebiau 1992). It is also believed to allow an optimal utilization of light, water and nutrient resources (Soemarwoto 1987; Niñez 1987), which is often considered to be a factor contributing to the productivity of home garden systems. However, this study shows that in the home gardens of southern Ethiopia the presence of diverse plant species did neither guarantee high crop productivity nor soil fertility (see Chapter 4 and Fig. 6.2b), as we found an inverse relation between plant species richness and crop productivity (see Fig. 4.6 in Chapter 4). Instead, our study points to the crucial role of livestock in maintaining soil fertility through the input of manure (see Chapters 4 and 5). Given the fact that livestock contribute to soil organic carbon, the negative relation between population density and soil organic carbon (see Fig. 6.2b) can be (partly) explained by the decline in herd size in response to increasing population pressure and resulting farmland constraints (see Chapters 2 and 5). Thus, with the herd sizes on the decline, it is difficult to get enough manure to maintain soil fertility. In this situation crop productivity could be improved through applying inorganic fertilizer, but this may not be a sustainable option, given the observed decline in soil organic carbon and N, P and K stocks on the fields which received only inorganic fertilizer (see Chapter 5). The decline of soil organic carbon, given its critical role in soil fertility maintenance (Bationo et al. 2007), and determining the response to N and P fertilization (Tittonell and Giller 2013), could negatively impact crop productivity. For high productivity and maintenance of soil fertility a combination of organic and inorganic fertilizer might be best.

The second widespread claim made about the ecological sustainability of home gardens is that only a limited amount of nutrients are exported from the system (Abebe et al. 2006), as only a limited number of enset plants and only the berries of coffee are harvested annually. In this study we observed more negative N, P and K balances on enset fields in Khat-based and Enset-cereal-vegetable systems than in other systems (see Chapter 5). This implies a difference in input use on enset, with farmers in the newly-evolved systems prioritising other crops, leading to more negative balances on enset fields (see Table 5.1 in Chapter 5). However, despite the variation in magnitude, the N, P and K balances were negative for all crops in all home garden systems (see Table 5.1 in Chapter 5), which implies a widespread nutrient depletion which could over time result in decreased yields. Thus, the harvesting of a limited number of enset plants or coffee berries does not guarantee ecological sustainability.

6.4 Home garden system change and sustainable development options

6.4.1 Options for the newly-evolved Khat-based systems

For land-constrained farmers in densely populated areas who want to increase both income and food security, the cultivation of khat might seem a viable strategy. However, their increasing dependency on the income from one crop makes them more vulnerable to the risks of harvest failure and price fluctuations (see Table 5.5 in Chapter 5). This risk is higher for low resource endowed Khat-based households, as they spend a larger proportion of their earnings on food than those in other home garden types and better endowed farmers. Although khat is commonly grown as a monocrop, we did a khat-maize and khat-haricot bean intercropping trial on 20 farms, 10 in the lower altitude area of Wondo Genet (1680 m a.s.l.) and 10 in the higher altitude area of Melga (2200 m a.s.l.). The objective of the trial was to understand whether khat can be combined with food crops and to quantify the effect of intercropping on the productivity of both companion crops. The trial set-up, methods of monitoring and analysis as well as the yield and land equivalent ratio (LER) results are detailed in Appendix 6A.

Based on the average maize yield obtained from this trial, we calculated how the food self-sufficiency of three different resource endowed types of Khat-based farmers would be improved by intercropping khat with maize. Intercropping three quarters of the khat field with maize would make the low resource endowed farmers food self-sufficient, whereas only one fourth of the khat field would be needed for high- and medium-endowed farmers (Fig. 6.3). Thus, intensification of khat cultivation through intercropping with annual crops such as maize would be a viable development pathway for Khat-based farmers. Khat is the main crop receiving inorganic fertilizer, which also benefits the intercropped food crops (Table 6.A1). Intercropping of beans with khat could also be a good means to produce a nutritious diet, given the low protein content of the staple food crop enset. At the same time, the crop residues that are produced could provide a welcome fodder source for livestock and ease the pressure on enset leaves. Thus, more animals could he kept, and the problem of low soil organic carbon in khat fields could be solved by applying manure (Chapter 5). In such a way, it would be possible to establish a strong positive interaction that facilitates nutrient flows between the enset, khat and livestock components of the system.

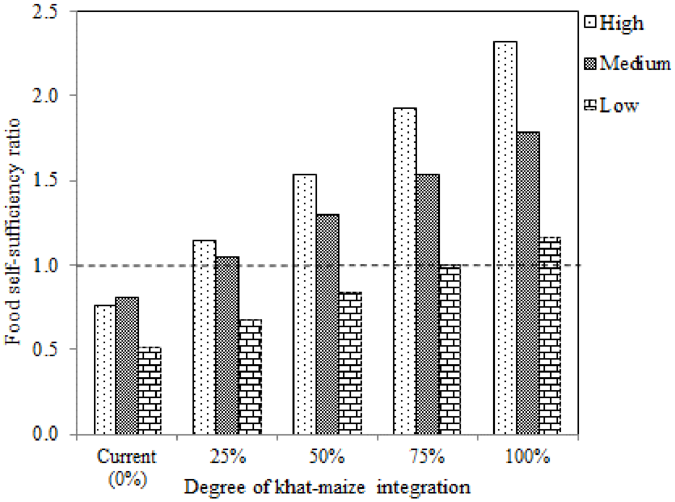

Fig. 6.3 Food self-sufficiency through intercropping different percentages of the khat area with maize for three resource endowment classes. The broken horizontal line indicates food self-sufficiency.

As the expansion of khat at the expense of the food crop enset has led to a reduction in women's opportunities in agriculture (see Chapter 4), intercropping of food crops such as maize and beans with khat could further women's participation in agriculture, as food crops are mainly cultivated by women in the study area. Given the traditional gender norms that assign women with the responsibility of feeding the family, the involvement of women in agriculture could have positive implications for food availability, dietary diversity and the nutritional security of the households.

However, the agronomic aspects of intercropping, such as spacing, and the implications for both khat and the intercrop yield need further investigation.

6.4.2 Options for the newly-evolved Enset-cereal-vegetable systems

The other newly-evolved system, that of Enset-cereal-vegetable, so far came off better than the other systems in terms of both socio-economic and ecological sustainability (see Fig. 6.2 a and b; Chapter 4 and 5). However, the loss of nutrients through erosion in response to the introduction of annual cereals such as barley and vegetables (see Chapter 5) could impair soil fertility and the long-term productivity of these crops. As only part of the manure is used, the major outflows of nutrients through the use of enset leaves as fodder could negatively influence soil fertility and the long-term productivity of enset, endangering the long-term socio-economic and ecological performance of the system. The loss of nutrients through erosion from the fields of annual crops could be reduced by applying soil conservation schemes such as terracing and ridging, which are being widely advocated in Ethiopia (FDRE 2011 and 2016). Growing forage species such as *Leucaena leucocephala* and *Pennisetum purpureum* (Zarate 1987; Franzel et al. 2003; Wambugu et al. 2011) could ease the pressure on fodder sources and reduce negative nutrient balances (Chapter 5). Also, as farmers in these systems apply only a quarter of the available manure, they can enhance N and P input through applying manure, for example to barley fields (see Table 4.2 in Chapter 4 and Table 5.3 in Chapter 5). Although the farm-level crop productivity in Enset-cereal-vegetable systems was the highest, also here, the low resource endowed farmers with less than 0.4 ha of land were neither food secure nor had diverse diets (see Fig. 4.7a and 4.8a in Chapter 4). The food self-sufficiency of low resource endowed farmers in particular could be enhanced by improving the barley yield, which is about three times smaller than the average barley yield obtained in Khat-based systems (see Chapter 4). Barley productivity improvement could be achieved by increasing the N and P application rate, which is currently three times lower than the recommended blanket rate.

6.4.3 Options for traditional home garden systems

Increasing population pressure and the subdivision of farm lands threaten the socio-economic and ecological sustainability of traditional home gardens, in particular in Enset-based and Enset-coffee systems (Fig. 6.2a and b). Although the Enset-based system is characterized by the highest energy productivity, farmers in this system are neither food secure nor have a diverse diet (see Table 4.1 and Fig. 4.7a and 4.8a in Chapter 4). This is explained by the use of food crops as cash sources for miscellaneous expenses, as farmers in Enset-based systems generate hardly any revenue from cash crops (see Fig. 4.4b in Chapter 4 and Table 5.5 in Chapter 5). Being situated in high-altitude locations and far from markets is a major impediment for generating income by growing cash crops such as coffee. However, according to the farmers living at high altitude, they have recently started growing coffee, profiting from the increasing temperature due to climate change (focus group discussion). The adaptation of coffee to higher altitudes and its potential for productivity improvement need further investigation. Also, the recently adopted practices of feeding cattle for cattle traders in order to alleviate manure shortage and generate income could help to ameliorate soil organic carbon content and partially satisfy the urgent cash need of the farmers. Thus, given the fact that most Enset-based farmers are food-self-sufficient (see Fig.4.9 in Chapter 4), enhancing their capacity of generating income from other activities to avoid enset sales could improve the sustainability of the system.

For Enset-coffee and Enset-livestock systems, characterized by lower total crop and energy productivity (see Table 4.1 in Chapter 4), improving the productivity of crops is vital. As farmers in these systems only apply about half the available manure, it would be possible to increase the productivity of enset by applying more manure (see Fig. 4.5c in Chapter 4 and Table 5.3 in Chapter 5). Earlier studies have reported that an increase in N application from 90 to 140 kg ha^{-1} per year not only increased *kocho* biomass from 26 to 32 ton ha^{-1} but also shortened the maturing time of enset by about two months (Ayalew 2015). However, all farmers except two in these systems applied less than 80 kg N ha^{-1} to enset (Fig. 4.5c in Chapter 4). Increasing manure input would not only benefit crop productivity, but also increase soil organic carbon content, thus enabling a more sustainable production of crops. Besides, given the possibility of intercropping enset with coffee, introducing improved coffee varieties adapted to the local environment is another option that could be tested. Varieties suited to highland and mid-altitude agro-ecology can yield more than two times the average yield observed in this study (Belete et al. 2014).

6.5 The role of considering system heterogeneity and the multiple dimensions of sustainability in the development of sustainable options

The degree to which farm households adopt new technologies depends on their socio-economic characteristics (Feder and Umali 1993). Thus the challenge for policy makers and planners, particularly in the study region where population density and access to markets vary between localities, is to identify technologies that are best suited for a particular area. By categorizing farms in groups on the basis of resource bases, enterprise patterns, household livelihoods and constraints, it is possible to develop technologies tailored to these groups (Giller et al. 2011; Descheemaeker et al. 2016). In this study, the categorization of farm households into five different systems based on crop allocation, has helped to understand the variation in production orientation and goals among them. We have seen that the responses of smallholder farmers to the prevailing constraints and opportunities vary between the five systems; therefore it is also to be expected that they will respond differently to new technological options. Therefore, before recommending technologies, their influence on the overall sustainability of the systems needs to be understood in various dimensions. As such, by using multiple criteria we have been able to understand the impact of khat introduction on the socio-economic and ecological sustainability of home garden systems in southern Ethiopia. While khat introduction enhanced food security, it led to decline in soil organic carbon content, thus negatively impacting the ecological sustainability of the systems. This shows the trade-offs between the different dimensions of sustainability. Thus, taking into account both farming system heterogeneity and multiple sustainability criteria, is necessary in order to develop options that can enhance socio-economic sustainability without jeopardizing ecological sustainability.

For farmers, ecological objectives are often secondary in relation to socio-economic objectives. Farmers may change their input use from manure to inorganic fertilizer or their agricultural practice from diverse systems to monoculture systems without thinking of the negatively impact on soil organic carbon content and plant species diversity respectively. Thus, even if a particular system currently performs well both socio-economically and ecologically, its performance may change over time in response to increasing population pressure and resulting farmland constraints. For example, in 1991, when the population density in the study region was less than 600 persons per km^2, almost all households were practicing traditional home garden systems, characterized by manure usage and a large species diversity. At that time, these system could sustain the population in an ecologically sound way. But in 2013, in areas where population density exceeded 700 person per km^2, about 24% of the households replaced the traditional systems with Khat-based systems (see Chapter 2). Consequently, soil organic carbon contents declined. Besides, the replacement of enset and coffee, key components of traditional systems with annual crops, led to soil loss through erosion. Hence, recent improvements have ameliorated various socio-economic indicators of home garden systems, but at the cost of ecological sustainability, which means that in time the socio-economic performance may be impaired as well.

6.6 Conclusions

The main conclusions from this thesis can be summarized as follows:

- Increasing population pressure, resulting farmland constraints and market developments have led to the replacement of traditional Enset-based, Enset-livestock and Enset-coffee systems in the study area by (1) cash crop-oriented Khat-based systems in densely populated market-proximate areas, and (2) combined food-and-cash-crop-oriented Enset-cereal-vegetable systems in less populated and less accessible areas. Variation in these drivers has led to diversity in home garden systems.

- The application of multiple criteria sustainability analysis provides insight into the trade-offs between sustainability indicators;
- Although the newly-evolved systems are performing well in terms of productivity and food security, the decline in ecological sustainability in terms of lower soil organic carbon content and soil loss through erosion could threaten the long term socio-economic sustainability of these systems, unless mechanisms for soil fertility enhancement are implemented.
- Although the presence of diverse perennial crops and trees in home garden systems are widely claimed to be major contributors of organic matter to the soil in the forms of litter fall, the quantitative analysis in our study does not support this claim. Instead, it appears that livestock makes a crucial contribution to soil organic carbon through manure input.

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APPENDIX

Appendix 4A

Supplementary information for Chapter 4:Are traditional home gardens in southern Ethiopia heading for extinction? Implications for productivity, plant species richness and food security

To understand the relationship between farmer reported fam size and crop yields were regressed the measured value against the reported value of each variables. The result in Fig 4.A1 indicate a systematic underestimation of crop yields. For all crops, farmer reported yields were smaller than the measured. Unlike the crop yields, farmer reported field size was not always smaller than the GPS measured (4.A2).

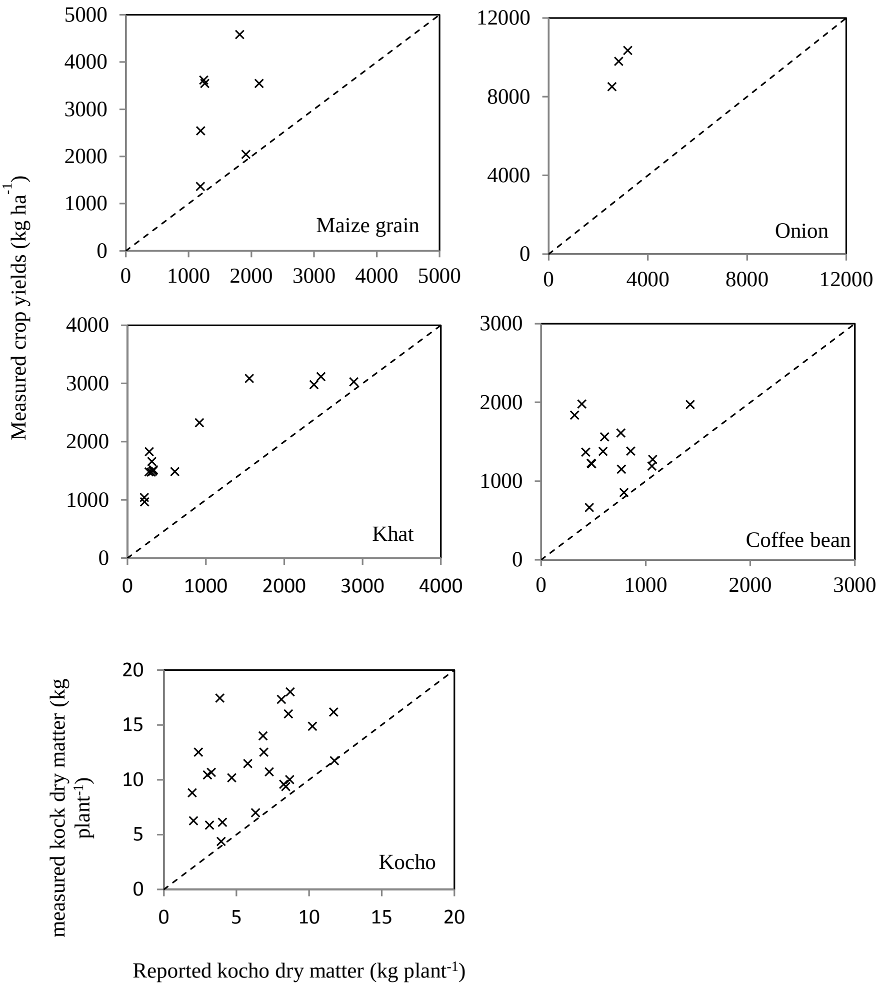

Fig 4.A1: Scatterplots of measured against reported crop yields. The dotted diagonal line is the 1:1 line.

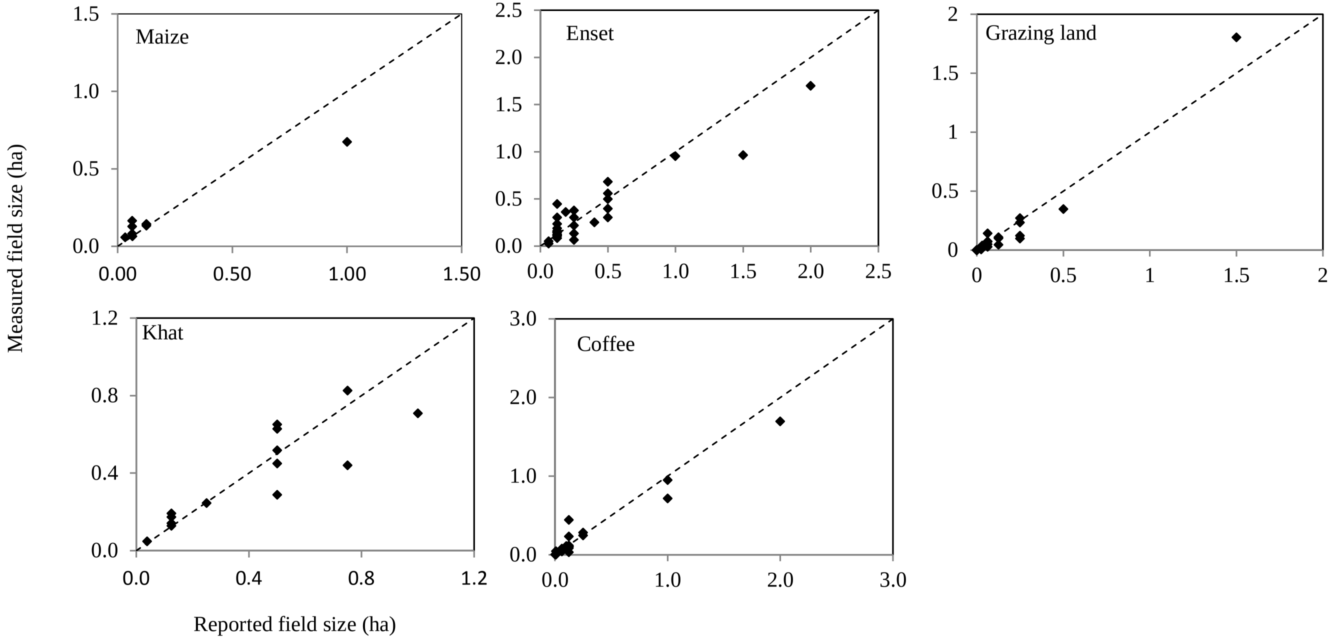

Fig 4.A2: Scatterplots of measured against reported field size. The dotted diagonal line is the 1:1 line.

Appendix 5A

Supplementary information for Chapter 5: Implication of agricultural transformation on ecological and economic sustainability of home garden systems in southern Ethiopia

Table 5.A1 shows the nutrient composition of materials required for nutrient flow analysis in Chapter 5. The price of different items used for calculating the profitability both at crop and system level was indicated in Table 5.A2 whereas in Table 5.A3 the average annual rainfall recorded from different home garden systems and other parameters used for calculating the soil loss through erosion were included. The K balances for the 1991 and 2015 for crops grown in the different home garden systems of southern Ethiopia were indicated in Fig. 5.A.

Table 5.A1. Nutrient composition (% dry weight) of materials required for nutrient flow analysis. Figures in parenthesis refer to standard deviation. n is number of samples.

Material		n	N	P	K	Source
Harvested products	*Kocho*	5	0.7 (0.2)	0.2 (0.1)	0.6 (0.3)	Analysed
	Bula	3	0.3 (0.2)	0.3 (0.1)	0.5 (0.1)	Analysed
	Coffee	1	2.2	0.5	2.2	Analysed
	Khat leave &twigs	4	1.4 (0.2)	0.5 (0.1)	1.6 (0.4)	Analysed
	Maize	1	1.1	0.5	0.5	Analysed
	Teff	-	1.8	0.5	0.6	Elias et al. (1998)
	H.bean	2	3.8 (0.1)	0.9 (0.1)	2.1 (0.4)	Analysed
	Barley	2	1.3 (0.1)	0.7 (0.1)	0.9 (0.1)	Analysed
	Onion	1	0.2	0.1	0.2	Analysed
Livestock products	Milk	-	3.6	0.1	0.2	Myburgh et al. (2012)
	Meat	-	3.9	0.6	0.3	Myburgh et al. (2012)
	Egg	-	0.2	0.2	0.2	Roe et al. (2012)
Crop residue	Enset leaves	5	1.5 (0.3)	0.5 (0.1)	4.6 (0.4)	Analysed
	Maize	1	0.7	0.2	1.4	Analysed
	Barley	2	0.6 (0.1)	0.3 (0.1)	0.3 (0.1)	Analysed
	Khat branch & stems	1	0.5	0.1	0.7	Anteneh et al. (2015)
	Grass	15	1.6 (0.5)	0.5 (0.2)	2.0 (0.6)	Analysed
	Compost	23	2.0 (1.0)	0.2 (0.1)	1.1 (0.6)	Analysed

Table 5.A2 average price for different items from the monitoring data (mean values with standard deviation in brackets).

Material		Sample size	Unit	Selling Price (US $)	Buying price (US $)
Food crops	*Kocho*	24	kg	0.3 (0.03)	0.3 (0.1)
	Bula	24	kg	0.5 (0.1)	-
	Maize	9	kg	0.3 (0.02)	0.3 (0.1)
	Barley	3	kg	0.4 (0.02)	-
	Teff	6	kg	-	1.0 (0.5)
	Haricot bean	16	kg	-	0.7 (0.2)
Cash crops	Coffee	16	kg	1.8 (0.9)	-
	Khat	14	kg	2.0 (0.6)	-
	Onion	3	kg	0.2 (0.03)	-
	Cabbage	3	kg	0.07 (0.02)	-
Livestock products	Milk	10	Litre	0.4 (0.1)	-
	Butter	10	kg	3.6 (1.9)	-
	Meat	22	kg	-	5.3 (1.0)
	Egg	14	No	0.1 (0.01)	-
Feed	Enset leave	9	No	0.07 (0.02)	-
	Concentrate	14	kg	-	0.3 (0.05)
	Sugar cane top	5	kg	-	0.1 (0.05)
Fertilizer	DAP	17	kg	-	0.7 (0.04)
	Urea	17	kg	-	0.5 (0.2)
Others	Oil	23	Litre	-	1.7 (0.4)
	Salt	24	kg	-	0.3 (0.02)
	Pepper	24	kg	-	3.4 (0.8)
	Sugar	24	kg	-	1.2 (0.2)
Labour		11	Man days	1.5 (0.8)	

Table 5.A3 Parameters used to calculate soil erosion.

Parameters	Home garden types				
	K-b	E-c-v	E-b	E-c	E-l
Rainfall (mm)	843	1210	1087	915	687
Erosivity factor (E, in MJ mm $ha^{-1}h^{-1}yr^{-1}$)	466	672	603	506	-
Erodibility (K, in Mg ha h $ha^{-1}MJ^{-1}$ mm^{-1})	0.25	0.25	0.25	0.25	-
Slope gradient (G, in%)	11.2	10.1	11.3	10.0	-
Slope length (L, m)	25	25	25	25	-
Slope length factor (L)	1.1	1.1	1.1	1.1	-
Slope gradient factor (S)	1.4	1.2	1.4	1.3	-
Land cover management factor (Co)	0.15	0.15	0.15	0.15	-
Supporting practice factor (P)	0.5	0.5	0.5	0.5	-
Eroded soil (kg ha^{-1} $year^{-1}$)	2181	6191	2414	2208	-

No annual crops; K-b Khat-based; E-c-v Enset-cereal-vegetable; E-b Enset-based; E-c Enset-coffee; E-l Enset-coffee

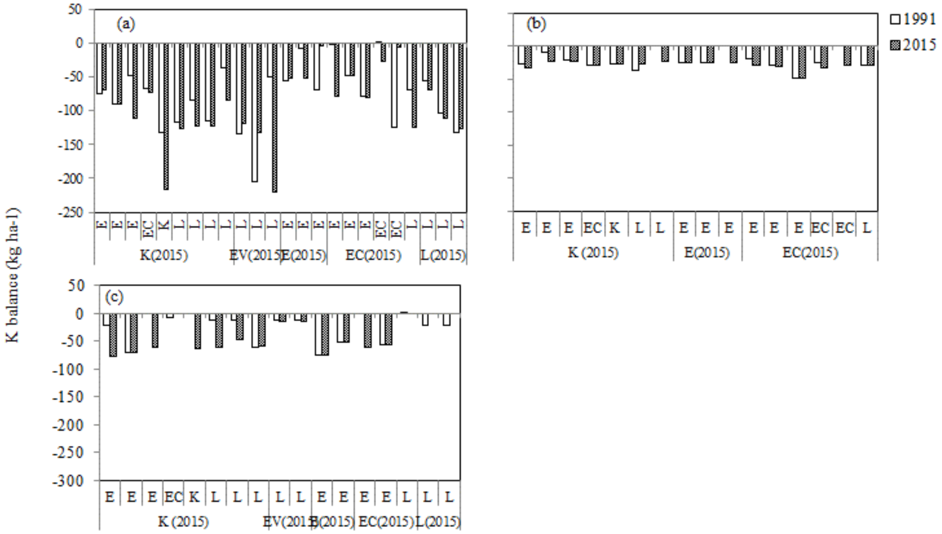

Fig. 5.A1. K balances for enset (a), coffee (b) and annual cereals (c) grown in the home gardens of southern Ethiopia for the 1991 and 2015. K Khat-based; EV Enset-cereal-vegetable; E Enset-based; EC Enset-coffee; L Enset-livestock; letters without year in the bracket represent the 1991 home garden systems.

Appendix 6A

Supplementary information for general discussion: Intercropping trial description

A khat-maize and khat-haricot bean intercropping trial was conducted on 20 farms, 10 in the lower altitude area of Wondo Genet (1680 m a.s.l) and 10 in the higher altitude of Melga (2200 m.a.s.l). The intercropping was of an additive type where the two components are combined with their full sole crop population. A hybrid maize, BH540 variety and red haricot bean variety (Awassa Dumme) were planted on farmers' fields in the 2015 cropping season Maize was planted with 80 cm inter-row and 40 cm intra-row spacing whereas beans with inter-row and intra-row spacing of 40 cm and 15 cm respectively. The plots were 4.8 m x 3.2 m with a spacing of 0.5 m between them. Intercropping of the annuals with the perennial crop khat was applied on existing khat fields with the same plant density and spacing considered for sole maize and sole bean cropping systems. The variation in khat plant density in lower and higher elevation ranged from 11719 to 40365 and 13020 to 44271 plants per ha respectively. Blanket fertilization was applied at a rate of 100 kg per ha DAP at planting. Urea was applied at a rate of 100 kg per ha four weeks after emergence except in khat-bean and sole bean plots. All the agronomic practices were kept uniform for all the treatments. General linear model analysis of variance (ANOVA) was used to analyse the data on grain yield and khat yield and the difference between the means of cropping systems and experimental sites were deemed to be significant when $P<0.05$ according to the Least Significant Difference (LSD) test. In the mixed culture, the intercrop yield of each crop was divided by the control (sole) yield of each crop and the resulting ratios for the two crops were added to obtain the land equivalent ratio (LER), which was used to evaluate the performance of cropping systems (Grookston and D.S 1979).

The maize yield obtained from khat-maize intercropping system was significantly higher than from the sole-maize plots. The maize grain yield obtained at the lower altitude in Wondo Genet was significantly higher than at the higher altitude in Melga. Contrary to maize, no significant difference between bean yield obtained from sole-bean and Khat-bean intercropping was observed. However, bean yield obtained in Wondo Genet was significantly larger than in Melga. Intercropping of maize and bean with khat significantly influenced khat biomass yield. Intercropping of maize with khat reduced the khat biomass yield by 20 and 40% in Wondo Genet and Melga respectively and by 25% and 30% for bean intercropping (Fig 3). However, the LERs were greater than one for all intercropping systems (Fig 3). Among cropping systems Khat-maize was superior in both study sites compared to Khat-bean.

Table 6.A1. Maize and bean yield and khat dry matter yield (kg ha^{-1}) for different cropping systems in Wondo Genet and Melga districts in Sidama zone (n = 20); the figures in parentheses indicate the standard deviation. Values with different letters within a row are significantly different between districts and values with different letters within a column are significantly different between cropping systems at $P< 0.05$.

Cropping systems	Wondo Genet (1680 m.a.s.l)	Melga (2200 m.a.s.l)	Mean
Maize			
Sole-maize	3808 (714)	3087 (784)	3447 (819)b
Khat-maize	4882 (887)	3258 (927)	4069 (1214)a
Mean	4344 (958)a	3172 (840)b	
Bean			
Sole-bean	4204 (683)	2190 (375)	3198 (1164)a
Khat-bean	2973 (1266)	2047 (544)	2510 (1060)a
Mean	3589 (1174)a	2119 (640)b	
Khat			
Sole khat	1866 (630)	1332 (671)	1599 (690)a
Khat-maize	1525 (645)	819 (256)	1171 (601)b
Khat-bean	1364 (503)	901 (242)	1133 (452)b
Mean	1586 (614)a	1017 (480)b	

SUMMARY

In southern Ethiopia the home garden systems are under a huge strain, as a result of increasing population pressure. Farm sizes are decreasing, while food demand is expanding. Challenged to provide enough food and cash for their families in these circumstances, farmers tend to replace enset and coffee, key components of traditional home gardens, with the high-value cash crop khat, a perennial, or annual crops such as cereals and vegetables. This process is fuelled by market opportunities. In order to understand how home garden systems change and how they vary both within and between different localities of the study area, variables like resource endowment (e.g. land ownership) and the proximity to market places need to be taken into account. Farming system analysis provides a framework for bringing into view the diversity in farming systems. It integrates biophysical and socio-economic factors, distinguishes farm components and interactions between them, and quantifies inputs and outputs both at the component and the system level. Farm components include crops, livestock, trees and the household. Crop remains, such as enset leaves, are fed to animals, manure is applied to the crops, and both crops and animal products are consumed and sold by the household. The output per unit area depends on the amount and type of input used and on farm management practices, factors that in turn depend on the socio-economic characteristics of the household.

In Chapter 2 farming system analysis was applied in order to understand the diversity of farm types and to explain the spatial patterns of change in home gardens. Also, the dynamics of farm components such as the cropping pattern and livestock population over the past two decades was assessed. We constructed a farm typology based on the 2013 crop allocation data from a survey of 240 farm households. Accordingly, farms were grouped into five types: Khat-based, Enset-cereal-vegetable, Enset-based, Enset-coffee and Enset-livestock. Threshold values of area shares were used to classify each farm in consecutive periods going back to 1991. This revealed a shift away from the traditional Enset-based, Enset-livestock and Enset-coffee systems to (1) cash crop-oriented Khat-based systems in densely populated, market-proximate areas, and (2) combined food and cash crop-oriented Enset-cereal-vegetable systems in less populated and less accessible areas. The change in cropping pattern over the last two decades shows an expansion of khat, from 6% to 35% of the farm area in densely populated market-proximate areas, and a decrease in the area devoted to enset and coffee (taken together) from 45% to 25%. The cattle herd size fell from 5.8 TLU to 3.9 TLU per household in the same period. Meanwhile, in medium-populated, less accessible areas, enset and coffee together

maintained a share of over 45% per farm, which implies that there the combined production of food and cash crops has remained the rule.

Changes in the components of home garden systems can be expected to influence the system's performance and to have consequences for the socio-economic and ecological sustainability of these systems. In this study, productivity, profitability, food security and dietary diversity are used as indicators of socio-economic sustainability, while plant species diversity, nutrient balances and soil nutrient stocks are used as indicators of ecological sustainability.

In the quantification of the productivity of the perennial crops enset and khat, allometric relations are required, in order to prevent destruction of the production base, the perennial plants. In Chapter 3 we developed models for estimating the edible and commercial yield of enset and khat plants respectively, based on the data collected from 20 enset and 100 khat plants. In the case of enset, humans eat *kocho*, the processed corm, and part of the leaf sheets (laminas), while the leaves are fed to the livestock. For khat the tender twigs and leaves are harvested two to three times a year.

Chapter 4 describes the socio-economic sustainability and the species diversity, related to ecological sustainability, of home garden systems. On the basis of surveys among the heads of 63 households, we quantified crop productivity and herd size (the latter influencing manure input). The information supplied by the farmers was complemented by the measuring of actual soil fertility and crop yields, and by the monitoring of inputs and outputs for a subsample of 24 households. As the home gardens produce several crops with distinct advantages (e.g. food, feed, cash generation), the farm level productivity was expressed in three ways, in terms of annual crop yield, human edible energy yield and revenue. It appeared that farmers in the newly-evolved Enset-cereal-vegetable systems had significantly more *kocho* standing biomass (21366 kg ha^{-1}) than those in traditional Enset-coffee (14697 kg ha^{-1} systems. Similarly, significantly larger khat (2160 kg ha^{-1}) and barley (1281 kg ha^{-1}) yields were obtained in the newly-evolved Khat-based systems than in other systems, whereas the barley yield in Enset-cereal-vegetable (436 kg ha^{-1}) systems was the smallest. Maize and coffee yields did not significantly differ between the home garden systems. The N application with compost explained 30% of the variability in *kocho* standing biomass, whereas the N application in inorganic fertilizer explained 43% and 25% of the variability in khat and barley yields respectively. The significantly lower barley yield obtained in Enset-cereal-vegetable systems was related to the low N (25 kg ha^{-1}) and P (8 kg ha^{-1}) application, which was about three times lower than the recommended blanket N and P application. At farm level the total revenue was the highest in the Khat-based systems, whereas the total crop yield was the largest in the Enset-cereal-vegetable systems. In the traditional Enset-based systems, the energy productivity of food crops was the highest. However, farmers in the newly-evolved home garden systems were more food-secure during the whole year, compared to those in the traditional systems – mainly because they had a higher income, allowing them to purchase food. Farmers in the newly-evolved systems were better off in terms of accessing a diverse diet than those in the other systems. Nevertheless, the low-resource-endowed farmers within each system type, with less than 0.4 ha, were not food-secure. The widespread claim that species diversity contributes to productivity, was not confirmed, as species diversity correlated negatively with all three productivity indicators, except for the total annual revenue in Enset-oriented systems. Also the hypothesis that commercialisation leads to loss in agro-biodiversity does not tally with our findings, as the introduction of khat did not lead to the expected decline in plant species richness. Although the changes in home garden systems had positive effects on some indicators of socio-economic sustainability, the shift from manure input to inorganic fertilizer in response to the introduction of khat and annual crops could negatively influence soil organic carbon levels, which may compromise future crop yields.

In Chapter 5 we assessed the nutrient balances and stocks, representing the soil-resources part of ecological sustainability, and the economic sustainability of the different home harden systems in terms of gross margin. The N, P and K balances at both crop and farm level were assessed. Soil fertility was quantified in terms of the soil organic carbon and N, P and K stocks. Gross margin was assessed both at crop and at farm level. In Khat-based and Enset-cereal-vegetable systems, the nutrient balances of the enset fields, which received only manure, were more strongly negative than in the other systems, which was explained by the decline in herd size. However, in Khat-based systems, where more inorganic fertilizer and food were obtained on the market, the farm-level N and P balances were positive, whereas balances were negative where access to inorganic fertilizer and food was limited. The application of N and P fertilizers to khat and not to enset and coffee in the Khat-based system, led to more negative balances for the latter crops. However, this was not reflected in larger nutrient stocks in khat fields compared to enset and coffee fields. Soils planted with annual cereals and vegetables also had smaller N, P and K stocks than soils planted with enset or coffee. The shift away from enset and coffee, which received only organic fertilizer, to khat, which received solely inorganic fertilizer, led to a decline in N, P and K stocks by 20%, 70%, 30% respectively. However, khat cultivation was 17, 5, 5 and 2 times more profitable on a per-hectare basis than annual cereals, enset, coffee and vegetables respectively. Consequently, the farm gross margin attained in

Khat-based systems was 4, 4, 2, and 2 times larger than the Enset-cereal-vegetable, Enset-based, Enset-coffee and Enset-livestock systems respectively. This shows a trade-off between the economic performance and the ecological sustainability, expressed in the nutrient balances and stocks of these systems.

The market dependency of Khat-based systems constitutes a risk, given the price fluctuations of khat. A way to increase food self-sufficiency is to intercrop khat with maize or beans. On the basis of an intercropping field trial, we showed that if low-resource-endowed Khat-based farmers intercropped three quarters of their khat fields with maize they would be self-sufficient in food. This would be at the expense of about 300 kg of khat, provided they apply the recommended fertilizer rates. For the better-endowed farmers the intercropped area required for food self-sufficiency can be reduced to one quarter of the khat field.

There are opportunities for the development of the Enset-cereal-vegetable system, such as soil conservation to counteract the erosion related to annual crops and the cultivation of fodder crops for livestock. Specifically for the low-resource-endowed farmers, improving crop yields, in particular barley, is a promising option.

In order to sustain a growing population, the traditional home gardens farmers should focus on improving crop productivity by growing improved crop varieties (e.g. for coffee), by improving the recycling of manure for use on enset and coffee, and by increasing fertilizer rates.

We recommend more detailed research to assess the contribution these options can make to farm system performance.

From the results of this study, it can be concluded that:

- Increasing population pressure and resulting farm-level land constraints combined with market developments were major drivers of home garden system change towards commercial Khat-based systems;
- The introduction of cash crops and annual food crops in traditional systems enhances the food security of smallholders farmers, which has a positive influence on the socio-economic sustainability of these systems;
- Introduction of cash crops and annual food crops in traditional systems does not negatively influence species richness;
- The development of Khat-based and Enset-cereal-vegetable systems has weakened crop-livestock interactions, which can have negative consequences for the long-term ecological and economical sustainability of these systems.

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LIST OF PUBLICATIONS

PEER-REVIEWED PUBLICATIONS

1. **Beyene Teklu Mellisse**, Katrien Descheemaeker, Ken E. Giller, Tesfaye Abebe, Gerrie W.J. van de Ven. 2017d. Agriculture, Ecosystems and Environment . https://doi.org/10.1016/j.agee.2017.09.026
2. **Mellisse, B.T**., van de Ven, G.W.J., Giller, K., Descheemaeker, K., 2017c. Home garden system dynamics in southern Ethiopia. Agroforestry. Systems. doi: 10.1007/s10457-017-0106-5
3. **Mellisse, B.T.,** Descheemaeker, K., Mourik , J.M., van de Ven, G.W.J., 2017b. Allometric equations for yield predictions of enset (*Ensete ventricosum*) and khat (*Catha edulis*) grown in home gardens of Southern Ethiopia. **Annals of Applied. Biology** 171, 95-102 doi:10.1111/aab.12350
4. Abera Titalhun, **Beyene Teklu** and Dana Hoag 2017a. Challenges and conteributions of crop production in agro-pastoral systems of Borana Plateau, Ethiopia. Pastoralism: Research, Policy and Practice 7, 2-8. DOI 10.1186/s13570-016-0074-9
5. **Teklu, B**., Negesse, T. and Angassa, A. 2011. Effect of farming systems on livestock feed resources and feeding systems in Benishangul-Gumuz region, western Ethiopia. International Research Journal of Agricultural Science 1, 020-028
6. **Teklu B**., Negesse T., and Angassa A. 2010. Effects of farming systems on floristic composition, yield and nutrient content of forages at the natural pasture of Assosa zone (western Ethiopia) Tropical and Subtropical Agroecosystems, 12, 583 -592.

CONFERENCE PROCEEDINGS

1. **Beyene Teklu Mellisse**, Gerrie Van de Ven1, Ken Giller, Abebe Tesfaye, Katrien Descheemaeker. Population Increase and Market Development as a Peril for Traditional Home Gardens and a Promise for Khat in Southern Ethiopia. In: Solidarity in a competing world —fair use of resources. Proceedings of the Tropentag, September 18-21, 2016, Vienna, Austria
2. **Beyene Teklu**, Yibeltal Tebikew, Dana Hoag, and Solomon Desta. Implications of Constrained Mobility on Livestock Production and Pastoral Livelihoods of Borana Plateau, Southern Ethiopia. In: Marco-trends and future opportunities, October 27-30, Nairobi, Kenya
3. **Beyene Teklu**, Tegene Negesse and Ayana Angassa. Assessment of feed resource and feeding systems in Western Ethiopia: The case of Assosa Zone, Benishangul-Gumuz

Region. In: Climate change, livestock and people: Challenges, opportunities, and the way forward. Proceedings of the 17th annual conference of the Ethiopian Society of Animal Production held in Addis Ababa, Ethiopia, September 24-26, 2009.

PE&RC Training and Education Statement

With the training and education activities listed below the PhD candidate has complied with the requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (4.5 ECTS)

- The dynamics of home garden systems in southern Ethiopia

Writing of project proposal (4.5 ECTS)

- Trends and prospects for the productivity and sustainability of home garden systems in Southern Ethiopia

Post-graduate courses (6.1 ECTS)

- Tropical farming system with livestock; WASS (2013)
- Farming system and rural livelihood course in Ethiopia; PE&RC (2013)
- Introduction to R; PE&RC (2017)

Deficiency, refresh, brush-up courses (13.5 ECTS)

- Quantitative land use analysis (QUALUS); PPS
- Quantitative analysis of cropping and grassland systems; PPS
- MonQi Farm monitoring basic training in Ethiopia; CASCAPE project (2014)

Competence strengthening / skills courses (1.9 ECTS)

- Information literacy for PhD including EndNote introduction; WUR (2016)
- Scientific publishing; WGS (2017)
- Organization of the course farming system and rural livelihood in Ethiopia; PE&RC (2013)

PE&RC Annual meetings, seminars and the PE&RC weekend (1.8 ECTS)

- PE&RC Weekend first year (2013)
- PE&RC Weekend final year (2016)
- Wageningen PhD symposium: diversity in science (2016)

Discussion groups / local seminars / other scientific meetings (4.6 ECTS)

- Research review meeting on agroforestry systems; Wondo Genet, Ethiopia (2013)
- Discussion meeting about project initiation on sustainability of east African farming systems; Addis Ababa, Ethiopia (2014)
- Discussion meeting with different scholars on possibility of scaling out promising agroforestry technologies; Addis Ababa, Ethiopia (2014)
- Discussion meeting about research results on adapting livestock systems to climate change; ILRI, Addis Ababa, Ethiopia (2014)
- Discussion meeting with farmers, development workers and regional experts on sustainable intensification options; this include demonstration of on-farm trial (2015)
- Sustainable intensification discussion group meeting; Wageningen (2017)

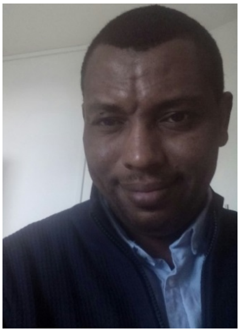
International symposia, workshops and conferences (4.4 ECTS)

- The 6th all African conference on animal agriculture; poster presentation; Nairobi (2014)
- Tropentag; oral presentation; Vienna, Austria (2016)

Supervision of a MSc student (3 ECTS)

- What comes out must go in: macronutrient balance assessment of transitioning home garden systems in southern Ethiopia (2015-2016)

ABOUT THE AUTHOR



Beyene Teklu Mellisse was born on the 17th of December 1982 in Ginchi, West Shoa, Ethiopia. He completed his secondary school at Kokebe Tsebah in Addis Ababa and started studying Animal and Range Sciences at Makelle University in 2000 and graduated in 2004. Beyene wrote a BSc thesis about poultry production systems and flock dynamics in South Eastern Tigray region, Ethiopia. After his graduation, he was employed in the Ethiopian Institute of Agricultural Research and worked as Forage agronomist at Assosa Research Centre. Beyene proceeded his studies with a MSc in Animal Production at Hawassa University in 2007. He wrote a MSc thesis on livestock feed resources, feeding systems and rangeland condition in Benishangul-Gumuz region, Western Ethiopia. In his thesis he looked at the effect of different farming systems on livestock feeding systems and rangeland condition. After his study, he was employed at Wondo Genet College of Forestry and Natural Resources, Hawassa University as a lecturer in 2009.

In December 2012 he started the PhD research described in this thesis at the Plant Production Systems Group of Wageningen University with financial support by the government of the Netherlands in the project Capacity Building for Scaling up of Evidence-based Best Practices in Agricultural Production in Ethiopia (CASCAPE).

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