Exploring opportunities for rural livelihoods and food security in Central Mozambique

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Abstract

Growing awareness of widespread hunger and poverty in many countries in the SSA is spurring a focus on productivity increase in smallholder farming systems. The rationale is that with current production systems many SSA countries are not keeping pace with population growth and changing of peoples' lifestyles. To respond to this challenge the Government of Mozambique developed its Strategic Plan for Agricultural Development (PEDSA) aiming to improve agricultural productivity of the majority of smallholder farmers who depend on agriculture for their livelihoods. Smallholder farmers are diverse in terms of resources and aspirations. The main objectives of this study are first to understand the diversity among maize-based smallholder farms and their current constraints in improving agricultural productivity in the Manica Plateau, Central Mozambique, and second, building on that understanding to explore options for biomass production either for food, cash or biofuel at farm level and contributions to maize availability in the region. The study was conducted in the Dombe and Zembe Administrative Posts. Farmers in the two posts cultivate both food and cash crops using the same resources, however, distances to the urban market differ, with Zembe close and Dombe far away from the markets. In addition, the agroecological conditions for crop production are more favourable in Dombe compared with Zembe. Using farm surveys, direct observations and on-farm measurements, followed by Principal Components Analysis (PCA) I identified land and labour as the variables that can best explain the variability found among smallholder farms (Chapter 2). Based on these variables I categorised farms into four Farm Types (FT): FT1. Large farms (4.4 ha in Dombe and 2.2 ha in Zembe), hiring in labour; FT2. Intermediate sized farms (1.9-1.2 ha), hiring in and out labour; FT3a. Small farms (1.1-0.9 ha), sharing labour; and FT3b. Small farms (1.0-0.7 ha), hiring out labour. The maize yield and maize labour productivities were higher on large farms (2.3 t ha^{-1} in Dombe and 2.0 t ha^{-1} in Zembe; 2.5×10^{-3} t h^{-1} in Dombe and 2.6 ×10^{-3} t h^{-1} in Zembe) compared with small farms (1.5 t ha^{-1} in Dombe and 1.1 t ha^{-1} in Zembe; 1.4×10^{-3} t h^{-1} in Dombe and 0.9×10^{-3} t h^{-1} in Zembe). The hiring in labour from small farms allowed large farms to timely weed their fields. Small farms were resource constrained and

hired out labour (*mutrakita*) for cash or food to the detriment of weeding their own fields, resulting in poor crop yields. Excessive alcohol consumption by small farms also raised concerns on labour quality. Chapter 3 explored options aiming at addressing farmers' objectives of being maize self-sufficient and increased gross margin and the contribution to national objective of producing food. A bio-economic farm model was used to investigate two pathways to increase agricultural production: (i) extensification, expanding the current cultivated area; and (ii) intensification, increasing input use and output per unit of land.

In the extensification pathway I considered the use of animal traction, herbicides and cultivators to save labour, whereas in the intensification pathway I explored the use improved varieties of maize, sesame, sunflower, pigeonpea and fertilizers. I focused on the large farms and the small farms hiring out labour as they represent both sides of the spectrum. The simulated results showed that combining labour and labour saving technologies substantially increased both gross margin and maize yields of large and small farms in both posts. Minor trade-offs is observed on large farms between the two goals whereas for small farms we see synergies between the goals. We concluded that prospects for increasing gross margin and food production are much better for large farms in Dombe compared with other farms. In Dombe, the maximum gross margin of large farms was 7530 \$ y^{-1} per farm and maximum maize sales of 30.4 t y^{-1} per farm. In Zembe, the maximum gross margin of large farms (2410 \$ y^{-1} per farm) and maximum maize sales (9.5 t y^{-1} per farm) were comparable to small farms in Dombe. I further assessed the impact of two biofuel investments (jatropha plantation and sunflower outgrower schemes) on farm level food security (food availability, access to food, stability of food, utilization of food). The results showed positive impact on small farms from employment on a jatropha plantation by increasing access to food and no impacts on intermediate and large farms. Impacts on food security from the sunflower outgrower scheme were minor which may be explained by the poor yields.

The need to link smallholder farmers to markets has been increasingly recognized as important strategy to promote rural development and poverty reduction. I developed an analytical framework, the Windmill Approach that looked at decision making at farm level to grow certain crops and at transaction strategies (Chapter 5). Through this framework I showed that a farmer decision to participate in a particular (new) value chain is determined

by (a) the suitability of the new crop in the farm system (including the adaptability of the current farm system), and (b) the farmer's experience with selling in various value chains. This has major policy implications as it highlights that to support smallholder farmers access to markets a holistic approach is needed that combines farming systems analysis and transaction cost theory.

In order to explore the opportunities for smallholder development there is need to understand the diversity of farms and farmers' social and economic context. For large farms, in Central Mozambique farms with on average 2-4 ha of land, opportunities to improve their livelihoods through crop production can follow two pathways: intensification and extensification. Smallholders continue to produce staple food crops even when working on a plantation or participating in outgrower schemes. For small farms, off-farm opportunities such as those in a biofuel plantation are the best options to improve their livelihoods.

Keywords: Smallholder farmers farm types, bio-economic models, alcohol, biofuel, sales arrangements

Contents

Chapter 1

General Introduction

1. Global demand for biomass and challenges for smallholder farmers in sub-Saharan Africa

By 2050, worldwide demand for crop biomass will double (FAO, 2009) The key drivers are population growth (Godfray *et al.*, 2010; Koning and Van Ittersum, 2009), income rises in developing countries that might shift human diets towards more animal based foods (Delgado, 2003), and bioenergy initiatives related to energy security and climate change (von Braun, 2008; IPCC, 2007; Cohen *et al.*, 2008; Koning and Mol, 2009).

Stretching the demand for biomass has also increased uncertainty over achieving the Sustainable Development Goals (SDGs) aiming at ending poverty and hunger by 2030 (United Nations, 2015). The uncertainty is most problematic in the developing countries where about 1.2 billion people still live on less than $1.25 a day and 57 % of them are located in the sub-Saharan Africa.

Increase in agricultural productivity of smallholder farmers in sub-Saharan Africa (SSA) is vital to lift millions of people out of poverty, achieve food and nutrition security and stimulate sustainable growth (World Bank, 2008). Large scale agricultural investments such as those in biomass for biofuel, are seen as a vehicle for poverty reduction in SSA through creation of employment, new opportunities for contract farmers and access to clean energy in rural areas (FAO, 2008). On the other hand, land deals, especially those for biofuels, are contested, as they deprive smallholder farms of their lands, threaten local food security in favour of large companies. Cotula (2012) and De Schutter (2011) refer to such deals as *land grabbing* as they can deprive smallholders of their land, threaten local food security and large companies take the profit.

Farming systems in sub-Saharan Africa consist of a wide diversity of smallholder farms (Bidogeza *et al.*, 2009; Zingore *et al.*, 2009). Their heterogeneity is driven by biophysical factors such as climate, soils and water, and socio-economic factors such as farm resources (labour, land), assets (e.g. farm chart, ploughs, cattle, goats, chickens), and degree of market orientation (home consumption, producing for market or both) (Giller *et al.*, 2011). The livelihood strategies pursued and long term aspirations thus differ among farmers. For instance, under good economic conditions (high market dynamics) and high agricultural potential, poor farmers tend to maintain their livelihoods or current activities (*hanging in*), while better-resourced farmers will invest to expand their activitives (*stepping up*) or accumlate assets that enable them to move out of agriculture (*stepping out*) (Dorward *et al.*, 2009).

Overall, the biophysical productivity of smallholder farmers in SSA is poor due to a wide array of factors including soil-fertility depletion (Sanchez *et al.*, 1997; Stoorvogel *et al.*, 1993), dependence on erratic rainfall, lack of access to agricultural inputs, and lack of capital to invest in soil fertility (Tittonell and Giller, 2012). These are some of the key constraints holding back agricultural development in SSA, a region that has spare land to contribute to increased demand of biomass for food (Koning and van Ittersum, 2009), and/ or for energy supply (Smeets *et al.*, 2007; German and Schoneveld, 2012).

Erenstein (2006) describes two models to increase agricultural production. First, land use extensification, which means increasing the area under cultivation, without increasing inputs per unit area. Second, land use intensification, which means increasing inputs per unit area. However, in many SSA countries, e.g. Rwanda and Kenya the available area of land per capita is very small (Hengsdijk *et al.*, 2014) which limits the pathway of extensification. Mozambique is in contrast to many SSA countries, land abundant offering unique opportunities for developing both the extensification and intensification pathway of smallholder farming systems, which ever best fits farmers' preferences and local conditions.

1.1. Agricultural development in Mozambique

Despite the rapid economic growth of 7.6 percent of the GDP (2005-2009), and the per capita income increase of 5 percent a year (Moçambique, 2011), Mozambique is one of the world's poorest countries ranking 184 out of 187 in the Human Development Index (UNDP, 2011). Achieving inclusive economic growth by directing efforts towards increased production and productivity in the agriculture and fisheries sectors, generating employment and fostering human social development are the main objectives of Mozambican Government (Moçambique, 2011).

Mozambique has a potential to achieve inclusive growth through agriculture by creating incentives to increase productivity of smallholder farmers, a "pro-poor" growth approach (Moçambique, 2011). The total arable land in the country is estimated at nearly 38 million hectares, of which 5.6 million hectares are cultivated (INE, 2011a). About 70 % of the Mozambican population depends on agriculture for their livelihoods. Despite the abundance of land, the average size of smallholder farms is 1.4 ha similar to that in other SSA countries (Hengsdijk *et al.*, 2014). Extensification could be a preferred strategy to increase crop production (Baudron *et al.*, 2012), yet the farms are constrained by lack of labour, animal traction and mechanisation (Woodhouse, 2010). Intensification options, on the other hand, are limited by the lack of capital to buy inputs such as fertilizers, pesticides, herbicides and agricultural equipment (FAO, 2013). In addition, smallholder farmers are resource constrained, for example shortage of labour and capital (Udo *et al.*, 2011; Naudin *et al.*, 2012). Those constraints are exacerbated when farmers engage in activities that compete for the same resources within the farm (Giller *et al.*, 2006) resulting in trade-offs. For example, Tittonell *et al.* (2007) reports that investments in hiring labour for weeding and planting is prioritized by smallholder farms in Kenya over fertilizer purchase to obtain high yields. Van Wijk *et al.* (2009) analysed the interactions in labour allocation between crop and animal production in African smallholder farming systems. They show that when labour use for cropping activities is favoured over labour for the collection of animal feed, more feed has to be purchased. The above examples show how farmers face trade-offs when they decide to allocate their scarce resources for different activities that compose their livelihood strategies. Smallholder farmers are also expected to contribute to national objectives such as producing food and biofuel potentially conflicting with food and cash needs at farm level (Giller et al., 2008).

The relative land abundance, good biophysical conditions and ample water availability for crop production, and the strategic location to the ocean, place Mozambique in a favourable position for biomass production for biofuel (Batidzirai *et al.*, 2006; Arndt *et al.*, 2008). In 2009 the government published its Biofuel Policy and Strategy aiming to contribute to energy security, job creation and promote socio-economic development especially in rural areas (Moçambique, 2009). This policy includes several measures to ensure that biomass production for biofuel does not jeopardize the national objective of being food self-sufficient. Some of these measures are land zoning (MINAG, 2008c) and the development of a national framework for sustainable biofuel production, which was launched in 2012 (Schut *et al.*, 2014). The zoning aims to avoid competition for land between food and other biomass uses, including biofuel. The framework aims to promote transparency and a secure investment environment for companies involving in biofuel production in Mozambique.

1.2. "Pro-poor" growth and market access

The biophysical potential coupled to a pro-market approach of Government of Mozambique attracted foreign investments in biomass production for both food and biofuel (WorldBank, 2011; Cotula, 2012). The pro-market approach can contribute to the improvement of smallholder farmers' livelihoods and reduce poverty ("pro-poor" growth) if these farmers are involved. However, physical limitations such as a remote location, high transport costs and low populations densities in rural areas lead to high transaction costs (IFAD, 2003).

Poulton *et al.* (2010) point to the disadvantages faced by smallholder farmers compared with large commercial farmers due to their small scale that leads to high unit transaction costs in accessing capital, technical information, inputs and outputs markets. The value chains for new cash crops differ from those of staple crops and traditional cash crops. For instance, cash crops are often associated with product compliance, especially in modern supply chains. Staple crops, on the other hand, are marketed on a spot market. Risk aversion plays an important role in smallholder farmers' decisions on allocation of their resources, e.g. land and labour. Cultivation of biomass for biofuel or other cash crops may pose risks to smallholder farmers such as dependency upon biofuel chains and market uncertainty of agricultural commodities (Koning and Mol, 2009). Risk also depends on the type of crops involved, annual versus perennial crops. Smallholder farmers have more flexibility with annual crops compared with perennial crops that in general require relatively high initial investments. Therefore, reaping the benefits from emerging food, biofuel and cash crop markets by smallholders is not automatic. It depends on their ability to enter and compete in the market.

The question is how agricultural development based on smallholder farmers can be achieved in Mozambique while improving their livelihoods. This question forms the basis of my research. One important aspect is allocation of available resources between food and cash crops, including biofuel crops at farm level. Furthermore it is important to evaluate the impact of farm level decisions on the national goals and vice versa.

1.3. Rationale of the study

The scope for agricultural development based on smallholder farmers lies in understanding their productive resources, constraints and opportunities. Yet, the Mozambican Strategic Plan for Agricultural Development is based on the biophysical potential for crop production (MINAG 2011), which likely overestimates the true opportunities for smallholder farms. In Mozambique, a farm falls in the category of small farms if it cultivates an area below 10 ha (INE, 2011a). In Mozambique, land and labour are the main productive resources of the farmers. In this context, assessing the performance of the diversity of farms in terms of land and labour use, provides a solid base for further exploration of new production activities aimed at improving livelihoods. Bio-economic models are useful tools to explore *what if* questions related to increasing agricultural productivity (Van Ittersum *et al.*, 1998). The results can be assessed in terms of socio-economic costs-benefits for each farm type. For instance, a bio-economic model was used to assess the trade-offs between economic and environmental dairy and arable farmers (Van de Ven and Van Keulen, 2007). By optimizing one objective under restriction of the other objective it is possible to establish trade-offs or synergies between different objectives (Giller *et al.*, 2008; NEPAD, 2003a).

Linking smallholder farmers in sub-Saharan Africa to agricultural markets is widely recognized as a key pathway to improve their livelihoods and reduce poverty (Shiferaw *et al.*, 2008; Janvry *et al.*, 1991; Kydd and Dorward, 2004). Yet, the economic and physical conditions that lead to high transaction costs need to be addressed so that farmers can benefit from marketing participation. Transaction costs are the costs related to finding the transacting party, costs of information and costs for contract enforcement mechanisms (North, 1990). Farming systems analysis, seeks to understand how farmers structure their production activities and it focuses at the farm as the key level at which decisions are made in relation to allocation of available resources to production activities (Giller, 2013). It recognises that smallholder farmers face widely different sets of opportunities and constraints.

This study attempts to draw a route towards smallholder agricultural development in Mozambique. It focuses on feasible options that can be realized in present farming systems and how biomass for food and cash can be produced, while safeguarding the livelihoods of smallholder farmers. We looked at factors that are key in sustainably linking smallholder farmers to agricultural markets. In this study, it is acknowledged that decisions at farm level maybe shaped by decisions at national level (Giller *et al.*, 2008) such as the production of biomass for biofuel. In addition, the routes may differ among farmers. For some farmers development opportunities will lie in farming on their own farm, while for others a regular wage job in or outside farming is a valuable option (Jones and Tarp, 2012).

1.4. Hypothesis and objectives

The main hypothesis of this thesis is that opportunities for production of biomass to meet farm level objectives (food and cash) and national level objectives (food and biofuel) differ according to the bio-physical and socio-economic conditions of the farmers. Therefore, insight in these conditions is required to identify feasible technology options addressing the diversity of farmers.

The general objective of the study is twofold. First, to understand the diversity among smallholder farms and their constraints and explore the opportunities for biomass production either for food, or biofuel or cash. Second, to explore opportunities for development of the smallholder farming systems of central Mozambique. The focus of the study is at the farm level with links to regional level.

The specific objectives were:

a) To assess the agro-ecological and socio-economic factors that determine the productivity of smallholder farmers.
b) To explore the consequences of cultivating biomass for food, for biofuel and for cash on smallholder farmers' livelihoods.
c) To assess the impact of biofuel developments on farm level food security.
d) To understand the rationale of various marketing arrangements engaged in by smallholder farmers.

1.5. Study setting and justification

The study was conducted in two Administrative Posts, Zembe and Dombe, in the Manica Plateau, Manica Province (Figure 1). Zembe and Dombe are also the names of the two main villages in the Administrative Posts. The Plateau is characterized by good agro-ecological conditions for crop production. We selected the posts based on (a) good agricultural potential (Maria and Yost, 2006), (b) expected competition for resources between food, biofuel and cash crops (Schut *et al.*, 2011), and (c) different distances to urban markets. Zembe is located in Gondola district at 19.295^{o} S and 33.354^{o} E and Dombe is located in Sussudenga district at 19.971^{o} S and 33.398^{o} E. Predominant soils in Zembe are Ferric Acrisols and Haplic Lixisols and in Dombe they are Eutric Fluvisols and Albic Arenosols (FAO-UNESCO, 1988). The terrain in Dombe is relatively flat compared with the undulating terrain of Zembe. The two posts are characterized by unimodal pattern of rainfall that allows one main cropping season per year. The average annual rainfall is 880 mm in Zembe and 930 mm in Dombe (USGS/FEWSNET, 2011). Crop production is the dominated by maize often found growing in the same fields with sunflower, sesame, assorted plants of pumpkins or cowpea. Maize is sold locally to outside buyers. In terms of livestock most farmers own poultry that forage freely and are fed on scraps. Village poultry has low local demand. Farmers often sell chickens when travelling to Chimoio city to buy household commodities. Some farms with ample land also keep cattle.

Both posts are located within target areas of foreign investments for large scale production of biomass for biofuel and other cash crops, such as sesame and sunflower, but they are also in target areas for increasing food production. This could lead to synergies or competition between those objectives. The distance to the market is considered important because it offers different off-farm labour opportunities and markets for farmers.

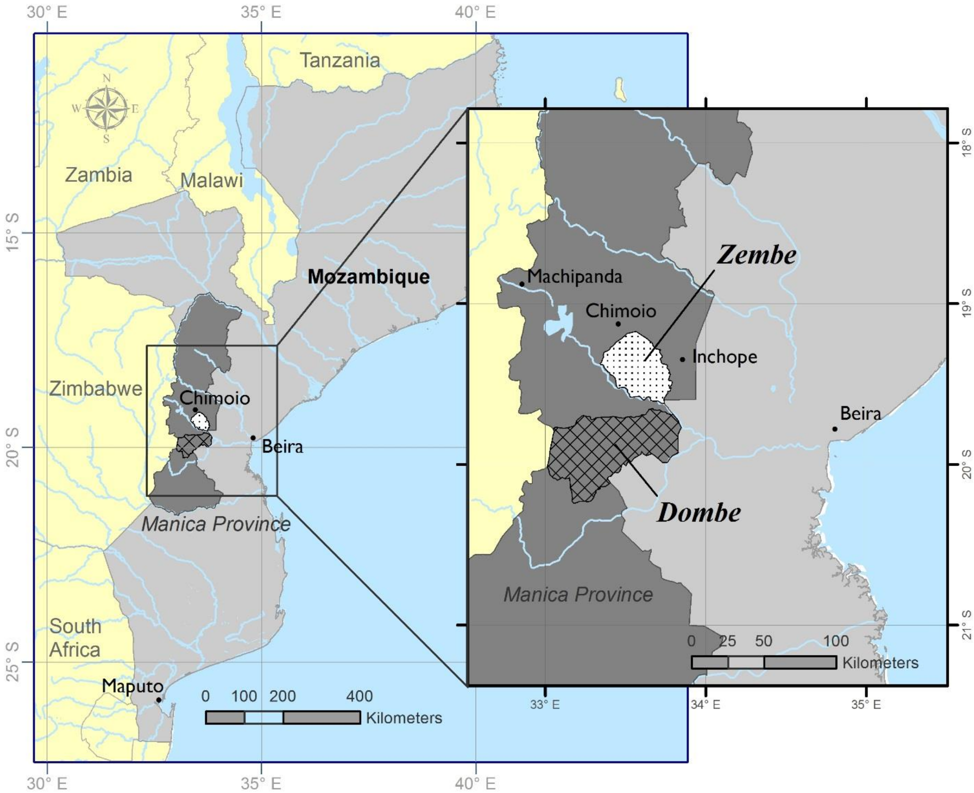


Fig. 1.1 Dombe and Zembe Administrative Posts, in Manica Province, Mozambique

1.6. Methodological approach and thesis outline

Using farming systems analysis I applied the DEED participatory cycle (Giller *et al.*, 2008) to *Describe, Explain, Explore* and *Design* new farming systems. To *describe* the current situation, I firstly conducted a farming systems characterization, based on semi-structured questionnaires, interviews and group discussions to identify biophysical and socio-economics factors that determine the diversity and productivity of the current farming systems. Secondly, I conducted on-farm measurements to *explain* current productivity and its determinants focusing on farm level food security and market orientation. To *explore* pathways for improvement of the livelihood of smallholders, I established on-farm trials to assess achievable yields of maize and soybean and used the results in a bio-economic model.

For both current and alternative crops, I considered labour savings technologies (animal traction and herbicides) and land saving technologies (fertilizers and legumes crops). I used the model outputs to *design* new production systems for smallholder farmers in Zembe and Dombe taking account the gross margin at farm level and maize production contributing to regional food availability.

I looked at how food security, expressed as food availability, food access, food stability and food utilization, of smallholder farmers was impacted by participating in biomass production for biofuel organized at regional level. I explicitly accounted for two types of involvement by smallholders in biofuel production, an outgrower scheme and a wage job at plantation.

Finally, to sustainably link smallholder farmers to agricultural markets, I combined Transaction Cost Economics (TCE) and Farming Systems Analysis to understand the choice of particular marketing arrangements by smallholder farmers. As part of co-learning process, I discussed the results of the four phases of the DEED participatory cycle with farmers.

The outline of the thesis is presented in the Figure 2. **In Chapter 2**, I describe the diversity in the maize-based smallholder farming systems of Sussundenga and Gondola districts, in the Manica Plateau. Subsequently I explain how labour dynamics between different farm types shape the variability of land and labour productivities of smallholder farmers and impacts on food self-sufficiency.

In **Chapter 3,** I assess the synergies and trade-offs between alternatives to increase the gross margin of smallholder farmers in the Manica Plateau and their contribution to regional food security. By means of a bio-economic model I explored five scenarios for improvement of current farming systems using data of land and labour productivities presented in the Chapter 2, interviews, on-farm trials and available.

In **Chapter 4**, I assess how two modes of participation in the production of biomass for biofuel, i.e. full time employment and outgrower schemes, affect the food security in terms of food availability, access to food, food stability and utilization of food of diverse groups of smallholder farmers.

In **Chapter 5,** I highlight the importance of an holistic approach with a farmer as the centre of decision making process for linking smallholder farmers to markets. The combination of farming systems analysis and transaction cost theory, integrated in a holistic approach, allows understanding the farmer decision to participate in a particular value chain.

In **Chapter 6** I discuss the findings from previous chapters, and places these matters into the broader context of smallholder farming systems in southern Africa. The opportunities, limitations and risks associated with biomass production for food, for biofuel and for cash are discussed. I end with the overall conclusions from this study, including limitations of the study as well as the policy implications for interventions aiming at development of smallholder farming systems in Mozambique.

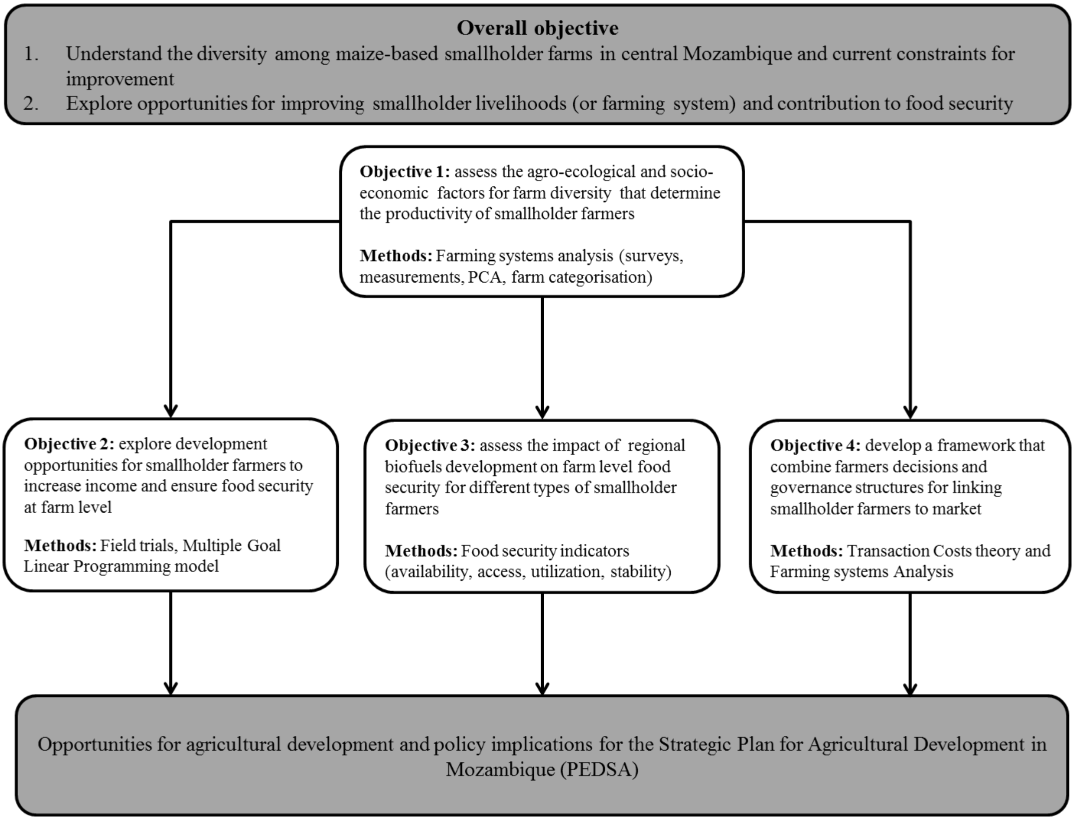


Fig. 1.2. Schematic outline of the thesis with oval indicating the objectives and the rounded rectangle the methodology used in chapter. The arrows indicate the links between chapters.

Chapter 2

Labour not land constrains agricultural production and food self-sufficiency in maize-based smallholder farming systems in Mozambique

This chapter is modified from:
Wilson J. Leonardo, Gerrie W. J. van de Ven, Henk Udo, Argyris Kanellopoulos, Almeida Sitoe, Ken E. Giller (2015). Labour not land constrains agricultural production and food self-sufficiency in maize-based smallholder farming systems in Mozambique. Food Sec. 7, 857-874.

Abstract

Despite abundant land and favourable climatic conditions, Mozambique remains food insecure. We investigated the diversity, constraints and opportunities to increase smallholder productivity and achieve food self-sufficiency in maize-based farming systems in two Posts in central Mozambique. We identified four farm types in each post based on cultivated area and labour. Farm type 1 cultivated relatively large areas, owned cattle and hired in labour. Farm type 2 cultivated moderate areas and both hired in and hired out labour. Farms of type 3a and 3b cultivated the smallest areas. Farm type 3a shared labour while Farm type 3b only hired out labour. For each farm type, we calculated land and labour productivities of maize, sunflower and sesame and assessed maize self-sufficiency. Access to labour during weeding was the main constraint. The hiring out of labour by small farms caused severe reductions in both land and labour productivity. Yield reductions on these farms were due to delayed weeding in own fields. In one Post, Farm type 3b was not maize self-sufficient. Labour quality was probably impaired by excess alcohol consumption among the poorer farmers (both men and women). Our results showed that production can be increased based on current agricultural practices. Farmers did not cultivate all of their land, suggesting that lack of labour constrained intensification by smallholder farmers.

Key words: Farm types, Labour use, Productivity, Alcohol consumption, Weeding

Labour not land constrains agricultural production and food self-sufficiency in maize-based smallholder farming systems in Mozambique

1. Introduction

Mozambique has abundant land and favourable agro-climatic conditions for agriculture (Batidzirai *et al.*, 2006; MINAG, 2008a). Yet it remains one of the poorest countries in world, ranking 184 out of 187 in the 2011 UN Human Development Index (UNDP, 2011). To tackle this poverty, the Poverty Reduction Action Plan (PARP) identified increasing agricultural production by the smallholder farming sector as one of its main objectives (Moçambique, 2011). Agriculture is the main source of food and income for nearly 70 % of the Mozambican population who live in rural areas. Smallholdings account for 96 % of the 5.6 million hectares of the total cultivated area and their farmers are responsible for 95 % and 76 % of the area allocated to food and cash crops, respectively (MINAG, 2008b). The smallholder farming systems are capital extensive and use few inputs (WorldBank, 2006). Only 4 % of smallholder farmers apply fertilizers, 2 % use animal traction (the other 98 % relying on hand-hoeing) and 5 % use irrigation. Thus the key resources available to farmers for agriculture are their land and labour.

Maize (Zea mays L.) is the staple food crop and occupies about 44 % of the area allocated to basic food crops (INE, 2011a). Consequently, it has been used to assess the food self-sufficiency of smallholders (SETSAN, 2010; Schut et al. 2011; Milgroom and Giller, 2013) and is the main component of food aid interventions (Tschirley *et al.*, 2006).

The Strategic Plan for Development of the Agricultural Sector (PEDSA) emphasises the need for increasing smallholder productivity in order to achieve food security and increase farmers' income (MINAG, 2011). PEDSA prioritises regions with relatively high agricultural potential. Understanding the diversity of farmers and their access to and allocation of productive resources is essential in order to target farmers with improved technologies (Giller et al. 2011; Senthilkumar *et al.*, 2009; Shepherd and Soule, 1998).

Our objectives were to understand the diversity, constraints and opportunities in the maize-based smallholder farming systems of central Mozambique to identify options for increasing smallholder productivity and achieving food self-sufficiency. Given that smallholder farmers in Mozambique use few external inputs we focused on land and labour as the key resources for agriculture. The study was conducted on the Manica plateau in Manica province, a target area for increasing smallholder food production (MINAG, 2011).

2. Materials and methods

2.1. Sites

Manica province is situated in an agroecological zone with relatively good potential for agriculture. We selected two Administrative Posts (Zembe and Dombe) based on expected competition for resources between food and cash crops and different distances to urban markets. Zembe Post is located at 19.295° S and 33.354° E whereas Dombe Post lies at 19.971° S and 33.398° E. There are two main seasons: the hot and wet season (November-March) and the cool and dry season (April-October). The region has a unimodal rainfall pattern that allows one main cropping season per year. Average annual rainfall over the last 15 years was 880 mm in Zembe and 930 mm in Dombe (USGS/FEWSNET, 2011). The predominant soils in Zembe are Ferric Acrisols and Haplic Lixisols and in Dombe they are Eutric Fluvisols and Albic Arenosols (FAO-UNESCO, 1988). In Dombe the terrain is relatively flat compared with the undulating terrain of Zembe. Chimoio city, the main urban market in the province is situated 25 km and 145 km from Zembe and Dombe, respectively. The two Posts are 120 km apart. Based on the objectives of the thesis and the available time and resources we opted for case-studies.

2.2. Rapid survey

A rapid farm survey was carried out in Zembe and Dombe during the cropping season 2009-2010 as an entry point for characterizing farming systems. In Zembe we selected Catize and Charonga villages whereas in Dombe we selected Mabaia and Magalo villages. Based on discussions with agricultural officers, these villages are representative of smallholder farming systems in each administrative post. Prior to systematic data collection, exploratory visits were made to each of the selected villages. From the visits we learnt that there was one main road crossing each village, which is characteristic of many villages in Mozambique. Starting from one of the entrances of the village we selected one out of every three households on both sides along the main road. In both posts, footpaths branch from the main roads with a length of 100-1000 m. We continued along the footpaths following the same pattern of selecting one out of every three households. Where the selected household was not available for interviews, the immediate next household was selected. A total of 52 of

3,844 farmers in Zembe and 72 of 9,837 farmers in Dombe (INE, 2011b) were interviewed using a semi-structured questionnaire. The sample size determines the sampling error (Webster 2001) not the representativeness. The detailed characterisations of the households that were conducted required repeated contact with the households, which precluded a large sample size. A one-off questionnaire could not have provide the same level of insight (role of alcohol) and quality data (labour input). Table 2.1 summarizes the main biophysical and socio-economic characteristics of the two Posts. Table S2.1 shows that attributes of the households in the study area were similar to those from the national agricultural household survey (TIA) (MINAG 2008b). So, though the sample size is relatively small our sampling procedure allowed us to have representative samples, in agreement with our objectives, and the findings of this study are applicable to a wide range of smallholder farmers in the region.

Three focus group discussions per village were organized with farmers for cross-checking data. We also interviewed three key informants per site together with a local extension officer to cross-check data from the survey and the focus group discussions. The semi-structured questionnaires covered three topics a) demographics and crop production, b) livestock systems, c) off-farm activities, and d) markets. For demographics and crop production we looked at household and labour size, labour availability and distribution over agricultural activities, cropping systems, previous cropping history, cultivated crops, geometric patterns, field types, input used, production objectives (e.g. consumption or profit). For livestock systems we looked at type of animals owned by a household, feeding systems (e.g. communal land, crop residues), production objectives, crop - livestock interactions through manure, use of animal traction and crop residues. Off-farm activities investigated were: wage labour in town, self-employment and petty-trade, and income from temporal migration. With respect to the markets we covered the type of buyers, distances to markets and prices. During the group discussions composed of 6-8 people (50 % male and 50 % female) we focused on understanding how land and labour limited production. We discussed the peak period of labour demand, inter-household labour exchange and hiring out labour as well as the impacts on crop production, the use of animal traction in agriculture and the costs of labour. The interviews and focus group discussions were conducted in local languages (Chiute in Zembe and Ndau in Dombe) with the help of a local interpreter and each took 40 to 60 minutes.

Table 2.1. The main biophysical, socio-economic and production characteristics in Zembe and Dombe. Sources: (INE, 2011b; FAO, 1988; SDAE-Gondola, 2012; SDAE-Sussundenga, 2011).

	Units	Zembe	Dombe
Biophysical characteristics			
Area of administrative Post	km²	1475	2041
Precipitation	Mm	880	930
Topography		Moderately undulating (Slopes 0-8%)	Relatively flat (Slopes 0-2%)
Predominant soil types		Ferric Acrisols, Haplic lixisols	Eutic fluvisols, Arenosols
Organic matter	%	0.5-6.0	0.5-5.0
Socio-economic indicators			
Average cultivated area	ha/farm	1.7	2.1
Population density	inhab.km^{-2}	12.8	24.2
Distance to Chimoio city	Km	25	145
Biofuel investments		Jatropha	Sugarcane
Main production activities			
Food crops		Maize, sorghum, cowpeas	Maize, sorghum, cowpeas
Cash crops		Sunflower	Sesame and maize
Livestock		Village poultry, goats, cattle	Village poultry, goats, cattle

2.3. Farm typology

The information from the rapid survey was first explored by principal components analysis (PCA), using Canoco for Windows version 4.5 (Jongman *et al.*, 1995). Twenty five variables were included (Table 2.2). The PCA was used with the objective of exploring relationships within the complex array of variables. PCA can help in the understanding of which variables can best be used to explain the largest part of the variability found in the data. PCA results were combined with participant observations on the main activities (cultivating crops), information on the tools used and use of external inputs. This resulted in the definition of four farm types. Next, the farm typology was validated in group discussions with farmers in both Posts and checked using independent variables collected during the rapid survey. Statistical differences between Posts were tested using t-tests while differences among farm types were tested using one-way ANOVA. Two nonparametric tests were used: the Kruskal-Wallis test was used to determine differences between farm types for variables which were not normally distributed such as the number of household labourers, the number of cattle, and the number of goats and chickens. The Chi-Square test ($\chi 2$) was used to determine farm type differences for the categorical variables such as gender of household head. To assess the differences between pairs of farm types, we used two multiple post-hoc tests, Tukey HSD and the Mann-Whitney Test. The first was used for those variables that meet the assumption of homogeneity of variances and the latter for variables that did not meet this assumption. All statistical comparisons were made at α=0.05 significance level using SPSS for Windows 10.0.

Table 2.2. Household characteristics used as variables in the principal components analysis (PCA).

Input variable	Unit	Abbreviation used in Figure 2.5.
Gender of head of household	Dummy	Gender
Household members providing full time labour for agricultural activities	#	hh labour
Household size	#	hh size
Households that hire labour to assist with cropping activities	-	hire labour
Households cultivating improved sesame variety	Dummy	I_variety
Total land area cultivated by the household	Ha	Area
Land labour ratio (area over the hh labour)	ha person^{-1}	LLR
Households that obtained the current cultivated land through heritage system	-	Inherited land
Households that obtained the current cultivated land from relatives	-	relatives_land
Households that obtained the current cultivated land from traditional leader (regulo)	-	regulo_land
Households acquiring capital goods on top of the land that sustain it and obtain the right to use the land.	-	bought land
Household that only hire labour and do not hire out labour	Dummy	only hire labour
Number of chickens owned	#	# chickens
Number of cattle owned	#	# cattle
Total number of fields owned	#	# fields
Number of goats owned	#	# goats
Households with permanent jobs outside agriculture	Dummy	full off-farm
Households with temporal jobs outside agriculture	Dummy	temporal off-farm
Self-employment and petty trade	Dummy	other enterprises

Hiring out labour	Dummy	sale labour
Growing cash crops (maize not included).	Dummy	cash crop
Tools to prepare the land	-	Tools
Crop exclusively cultivated for market	-	Cash crop
The first preferred market used by the households for sale of sunflower	-	MKT1
The second preferred market used by the households for sale of sunflower	-	MKT2

2.4. Detailed survey

For each village, three farms per farm type were selected for more detailed analysis of the farming system. These farms were chosen to represent the range of cultivated area and the common soil types in each village. The detailed data collection focused on crop yields, labour input and on data related to food self-sufficiency. The information on labour input per activity and the timelines per activity were combined to produce a crop labour calendar. Data from the detailed survey were cross-checked by discussing preliminary results with the farmers.

2.5. Performance indicators

2.5.1. Yield and labour productivity at field level

Maize and sesame crop yields (t ha^{-1}) were based on on-farm yield measurements and are expressed at 12 % and 18 % moisture, respectively. Before the yield measurements were taken, we walked with each farmer to the centre of the field. Four samples for yield measurements were taken from plots of 7 m × 7 m, one plot located at the centre of a “Y frame” and the other three plots at half distance to the end of each of the arms (Tittonell, 2008). The yields were taken at farm level and dried in the sun for two days prior to weighing. For sunflower, yields were expressed as t ha^{-1}. Total crop production and revenue (US$) per hectare were calculated for maize, sunflower and sesame in sole crop and in relay-intercropping systems. An exchange rate of 1 Metical (MT: Mozambican currency) to 0.035 US$ was used (www.oanda.com; August 9, 2013).
Crop labour productivity (t h^{-1}) was defined as the crop production per hour of both own and hired labour. In both Posts, children between 10 and 12 years of age performed some of the farming activities. Based on focus group discussions with farmers, we estimated the child labour contribution as equivalent to 1/4 of adult labour. Data on labour input per activity

was provided for the total crop area. Given that the hours worked per day differed among farm types, man-days were converted into man-hours for the comparisons. Labour input per ha was calculated by dividing the time spent by the area of the crop.

During the surveys we observed that a large proportion of household members in both Posts had consumed alcohol even early in the morning and during the busy periods when labour demands for planting and weeding were heavy. Also during the focus group discussions it was mentioned that farmers hiring out labour tended to consume excessive amounts of alcohol. Our calculations of labour input for farm operations did not indicate a great shortage of labour – which implies that the quality of the labour was poor, perhaps due to the influence of alcohol. Therefore, it was decided to collect information on alcohol consumption, which could be used to infer the quality of labour. Using the list of households from the rapid survey, we first collected data on breath alcohol content in 124 households (52 in Zembe and 72 in Dombe), including the 12 case study farmers. During making the measurements, many of the neighbouring farmers showed interest in participating; therefore we collected data from an additional 32 and 20 farmers from Zembe and Dombe, respectively. Measurements were taken each day during a period of two weeks for an equal number of farmers per farm type. The measurements were made between the growing season and next rains for the following two reasons. First the farmers (both wealthier and the poorer farmers who worked as labourers) were busy during the growing season. Secondly, measurements made around harvest time could be influenced by the extra money available from sale of produce and therefore not representative. Only the head of each household participated. The data were collected between 9.00 and 11.00 hrs using a Daisy Al 7000 alcohol digital breathalyzer (http://www.digitalbreathalysers.co.uk/al7000-breathalyser.html) and weekends were avoided. A threshold value of 0.6 ‰ was used to judge whether alcohol consumption was likely to affect labour quality. This threshold is the blood alcohol content limit above which it is illegal to drive in Mozambique.

2.5.2. Maize self-sufficiency at farm level

Maize self-sufficiency is a clear objective of all farmers. The food self-sufficiency ratio for maize (FSS) was calculated as the annual on-farm maize production divided by the household's annual needs. A value of FSS greater than or equal to one indicates maize self-sufficiency. A value below one indicates a maize deficit. The household need was based on detailed interviews with women at the homestead. They estimated the average quantity of shelled maize consumed by all household members over a month. This quantity was multiplied by 12 to calculate the consumption per year assuming the same quantity consumed in each month. Using an annual time period allows us to have a general understanding of the likely maize consumption within a household. Seasonality was not accounted for, even though it might help to better understand the variability of maize consumption across months. We collected data around two months after harvesting which may be a better indication of the amount that farmers would like to consume compared with other periods. For instance, in the lean season the amount of maize available and therefore consumed may be less than desired as reducing the number of meals is a coping strategy. Annual maize consumption was cross-checked with available data from other regions in the country where maize is also a staple food (Lukanu *et al.*, 2007; Tschirley *et al.*, 2006) and was found to be within the same range. No data on post-harvest losses due to the main pest, the large maize borer (Sitophilus zeamais), was available in either Posts.

2.5.3. Gross margin and labour productivity at farm level

The crop yields from on-farm measurements were converted into monetary value (US$) by multiplying the total yield per farm with the farm gate price. Price data collected by the Agricultural Marketing System of Mozambique (SIMA) neither include sesame and sunflower nor cover Zembe and Dombe Posts. Thus, we interviewed farmers, farmers associations and itinerant buyers to obtain farm gate prices. Maize was sold in local units (gallon or 20 litre tin) and was converted into SI units. Sesame and sunflower were sold per kg. Maize prices varied over the year. The amount of maize used for home consumption was valued at the price at harvest. To value the maize surplus we used three farm gate prices: the price at harvest (April to July), during the middle period (August to November) and during the lean period (December to March). Surplus sold for each of the three prices was estimated. The prices of sunflower and sesame were fixed.

Crop revenues were calculated as the crop yield multiplied by the farm gate price of the product and expressed in US$ per ha. Gross margin at farm scale was calculated as:

$$FarmLevel\ Gross\ margin = (FarmRevenue - FarmVariablecosts)\quad (US\$) \qquad \text{Equation (1)}$$

where *FarmRevenue* is the total revenue of all cropping activities on the farm.

$$FarmRevenue = \sum_{c=1}^{n} Y_c \times p_c \times A_c \quad (US\$) \qquad \text{(Equation 2)}$$

where *FarmVariablecosts* are the total variable costs of the farm:

$$FarmVariablecosts = \sum_{c=1}^{n} Variablecosts_c \times A_c \quad (US\$) \qquad \text{(Equation 3)}$$

and where Y_c is the average yield of crop c in t per ha, p_c is the farm-gate price of the crop c in US$ per t, A_c is the area occupied by crop c on the farm in ha, n is number of crops. All current farming systems are extensive and hired labour is the main variable cost. Farmers use saved seed from the previous harvest, even for the improved sesame variety.

Labour productivity at farm scale was calculated as the farm level revenues minus the farm level variable costs divided by the total number of hours spent on the farm, including both own and hired labour (Equation 2):

$$FarmLevelLabour\ productivity = (FarmRevenue - FarmVariable\ costs)/\sum_{c=1}^{n} h_c \quad (US\$\ h^{-1})$$

(Equation 4)

where h_c is the time (including hired labour) in hours spent on crop *c*.

We compared the farm level labour productivity with the minimum wage in the farming sector in Mozambique which was calculated from the monthly wage of 81.3 US$, based on national minimum wage (Moçambique, 2012), divided by 22 working days in a month, resulting in 3.7 US$ per day (with 8 hours per day this is 0.47 US$ h^{-1}). To compare with data in the Third National Poverty Assessments (Alfani *et al.*, 2012) we expressed the farm level labour productivity per full time equivalent household member per year. A third comparison made was with the Manica Province poverty line, which is expressed in US$ per capita per day and amounts to 0.68 US$.

3. Results and Discussion

3.1. The farming system

The rapid and detailed surveys confirmed that rain-fed maize was the major crop, grown in more than 90 % of the cropped fields in both posts. An exception was the larger farmers in Dombe where one quarter of the cultivated area was occupied by sesame. Sunflower, sesame and sorghum were grown as relay-intercrops with maize, on only part of the cultivated area. For sesame, an improved variety was cultivated as sole main crop. Sunflower, sesame and sorghum were planted in holes between the maize rows as relay crops. The resulting pattern for maize-sunflower, maize-sesame and maize-sorghum was 1:1. Seeds of pumpkins and cowpeas were mixed with maize at planting on the remaining part of the cultivated area. In Dombe, maize was cultivated for food and cash by all farmers. In Zembe, only 17 % of the farmers grew maize for food and cash. Some farmers in Zembe grew vegetables (mainly kale and onion) in fields alongside river banks that they sold in Chimoio market. Only 25-30 % of the farmers who have such fields cultivated them every season. The vegetable season starts after the second weeding of maize at the end of the rainy season.

In Dombe there is a huge demand for maize from buyers from southern and central Mozambique, in particular the main maize milling company in central Manica (Empresa Nacional Desenvolvimento e Comercializaçao Agrícola - DECA). Although Dombe is about 1000 km north of Maputo, it is the region closest to Maputo where maize can be sourced. By contrast, farmers in Zembe rely on itinerant buyers from Chimoio or alternatively they transport their produce about 25 km by bicycle for sale in Chimoio. The proximity of Zembe to Chimoio offers more opportunities for non-agricultural related earnings. Barrett et al. (2001) and Lanjouw et al. (2001) found the proximity to urban areas to be a major factor influencing smallholder farmers to diversify into non-agricultural activities.

Figure 2.1 shows the timeline of the main agricultural activities and crop sequence for maize, sunflower, sesame, sorghum and vegetables in Zembe and Dombe from the rapid survey.

In both posts weeding was consistently said to be the most important and most labour demanding activity by the farmers. Farmers from both sites relied on hand-hoeing and none of them used herbicides. While the rapid survey showed that 35 % and 38 % of farmers used animal traction in Zembe and Dombe, respectively, the interactions between crops and livestock were limited to land preparation and transport of harvested products. The farmers reported that lack of animal-drawn weeding tools hampered the use of animal traction for weeding. The larger farms hired additional labour during the first weeding of maize. During interviews with individual farmers and key informant farmers in Zembe we learnt that when animal traction was used to prepare the land for maize, there was no need for a second weeding in contrast to land preparation by hand. While animal traction was also used in Dombe the farmers still weeded their maize fields twice. In both posts, relay-intercropping was said to be a strategy that allowed the farmers to avoid using labour to open new land.

The majority of farmers cultivated less than 2.5 ha in both posts, but the areas cultivated in Zembe were smaller (<3.5 ha) compared with Dombe where several farmers cultivated 5 to 8 ha. According to the Mozambican land system, the land is the property of the State. Two land tenure arrangements predominated in the two posts: Inheritance and through traditional leader (*regulo*). The regulo has the right to allocate land to someone who asks for it. We learnt that if a piece of land is not used for more than five to six years, the regulo can allocate it to someone else. The cultivated area was not the same as farm size, as all farmers leave roughly 25 % of their land fallow. The rapid survey showed that 55 % and 60 % of the farmers left land fallow for 1-5 years in Zembe and 1-6 years in Dombe. The fallow system and the retention of crop residues of maize and sorghum in the field were used to maintain soil fertility and avoid soil erosion. Soil chemical analysis (Table 2.3) suggested that the most limiting nutrient for crop production is nitrogen in both posts, but that phosphorus was limiting only in one soil type in Zembe. The potassium concentration was relatively high.

Free range chickens were the most abundant livestock in both posts. Farmers indicated that chickens were kept primarily as a source of cash for daily expenditures such as milling grains, buying household necessities such as soap, and school fees.

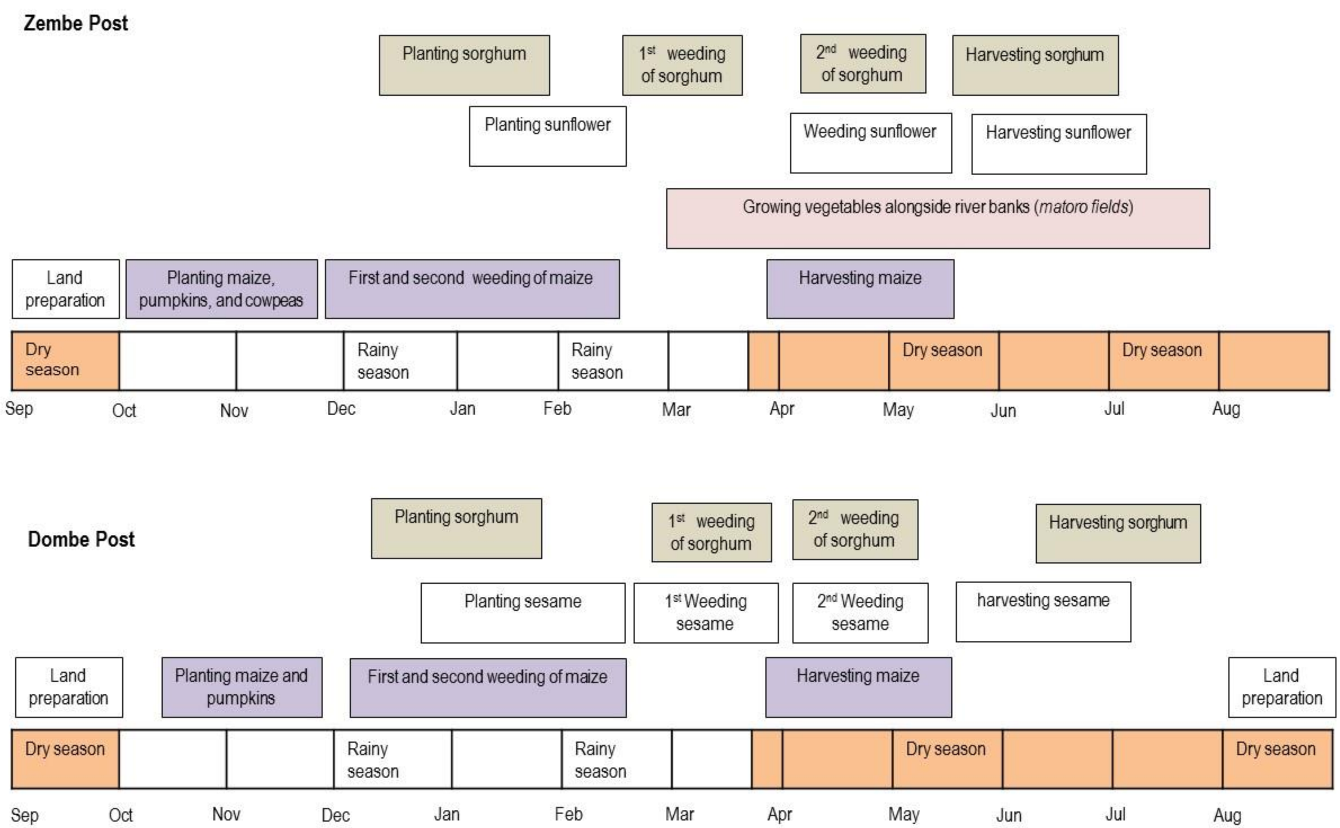


Fig. 2.1. Cropping seasons and timeline of the main agricultural activities for the main cultivated crops including vegetables cultivated on river banks in Zembe and Dombe

Goats were next in abundance followed by cattle. More households in Dombe (57 %) kept goats than in Zembe (39 %). Only 14% of households in Zembe and 11 % in Dombe kept cattle. The cattle were grazed extensively. Cattle herding was done by one child in the household after they had participated in crop production. Cattle were sometimes herded together with those of neighbours. Therefore, overall we assumed that there was no substantial competition between labour used to care for cattle and that used for cropping practices. None of the farmers in either village applied animal manure to arable fields.

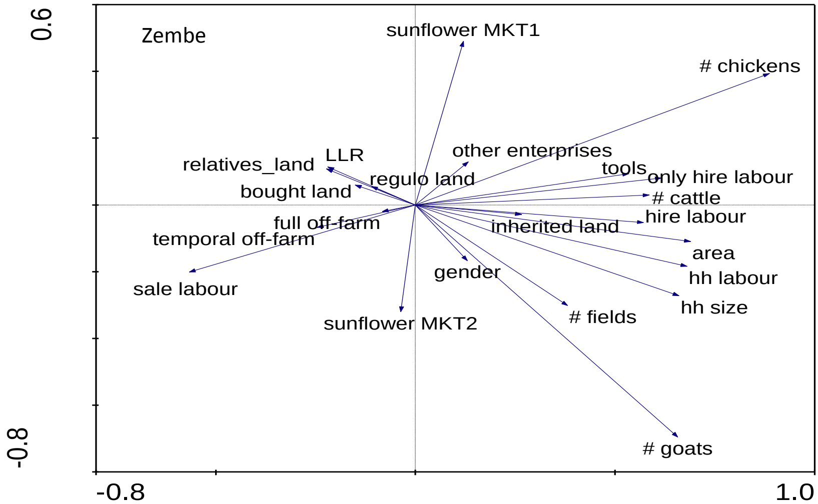
Table 2.3. Soil properties for four different soil types as found in Dombe and Zembe administrative posts.

	Zembe		Dombe	
	Soil type 1	Soil type 2	Soil type 1	Soil type 2
N (%)	0.07	0.13	0.12	0.1
SOC (%)	1.4	1.4	1.6	1.4
pH (H_2O)	5.8	5.9	5.6	5.7
Olsen P (mg kg^{-1})	25.4	2.5	46.2	18.4
Exchangeable K (cmol$_c$ kg^{-1})	0.8	0.9	0.6	0.6
Clay (%)	24	26	24	21
Silt (%)	12	12	33	15
Soil type	Sandy clay loam	Sandy clay loam	Loam	Sandy clay loam
Soil local name	Tchica + Djetcha	Tchica	Djiho + Djetcha	Djiho

3.2. Farm typology

3.2.1. Farm categorisation

The PCAs highlighted the similarities between the farming systems in the two posts (Fig. 2.2). The first two principal components together captured 56.3 % of the variability of household characteristics in Zembe and 59.6 % in Dombe. Table 2.4 shows the loadings for the correlation matrix for 20 and 21 household characteristics in Zembe and Dombe, respectively. The loading values indicate that variables related to land and labour, the principal resources available to the farmers, could be used to categorize farms as key variables. Although the PCA highlighted the strong contribution of the numbers of goats and chickens to the first two principal components, these variables can fluctuate wildly and were not considered useful for characterization. Based on results of the PCA (Fig. 2.2), focus group discussions and participant observation, four cases of labour dynamics were identified: (1) households only hiring labour (9 in Zembe and 17 in Dombe); (2) households hiring in and out labour (23 in Zembe and 22 in Dombe); (3) households who shared labour (8 in Zembe and 22 in Dombe); (4) households only hiring out labour (12 in Zembe and 11 in Dombe).



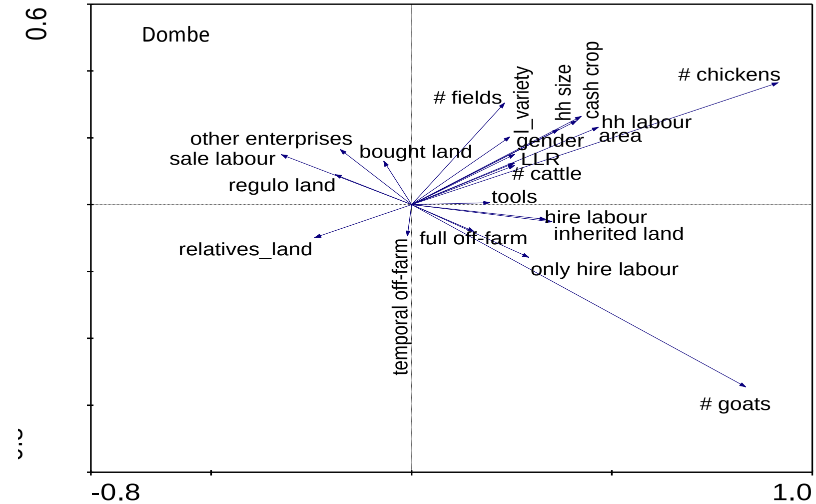


Fig. 2.2. Vectors showing the contribution of variables to the first two principal components in Zembe and Dombe from a principal componentanalysis. Abbreviations are given inTable 2.2.

When farms were grouped based on these criteria for labour dynamics, the area of land cultivated was found to differ strongly between the groups (Fig. 2.3). Thus we used these two criteria, labour dynamics and cultivated area to group the farms into farm types. In Zembe, 8 out of 9 households that cultivated more than 1.8 ha were those that only hired in labour. In Dombe, the cut off between these groups was 2.5 ha. These two values (1.8 ha and 2.5 ha) were used as the lower limit to identify Farm type 1: only hiring in labour. The same approach was used to distinguish households only selling labour (*mutrakita* – Farm type 3), resulting in upper limits for the cultivated area of 0.9 ha in Zembe and 1.4 ha in Dombe. More than half of the households fell into the 'hiring in and out' category of Farm type 2 in both posts. Further analysis showed those households with cultivated area equal or less than 0.9 ha in Zembe and 1.4 ha in Dombe, did not hire but shared labour (exchanging labour with neighbours) locally called *gúmuè*. To capture this diversity within the group, households that shared labour were named Farm type 3a. Six and fourteen households in Zembe and Dombe, respectively, fell into the "neither hiring in or out" category. These households were grouped into different farm types according to the size of their cultivated area. For instance, if a household in Dombe that neither hired in or out labour and had a cultivated area of 1.6 ha, we placed them in Farm type 2, and so on. The cultivated area was significantly different between Farm types 1 to 3 (Table 2.5). Farm types 3a and 3b cultivated similar areas of land.

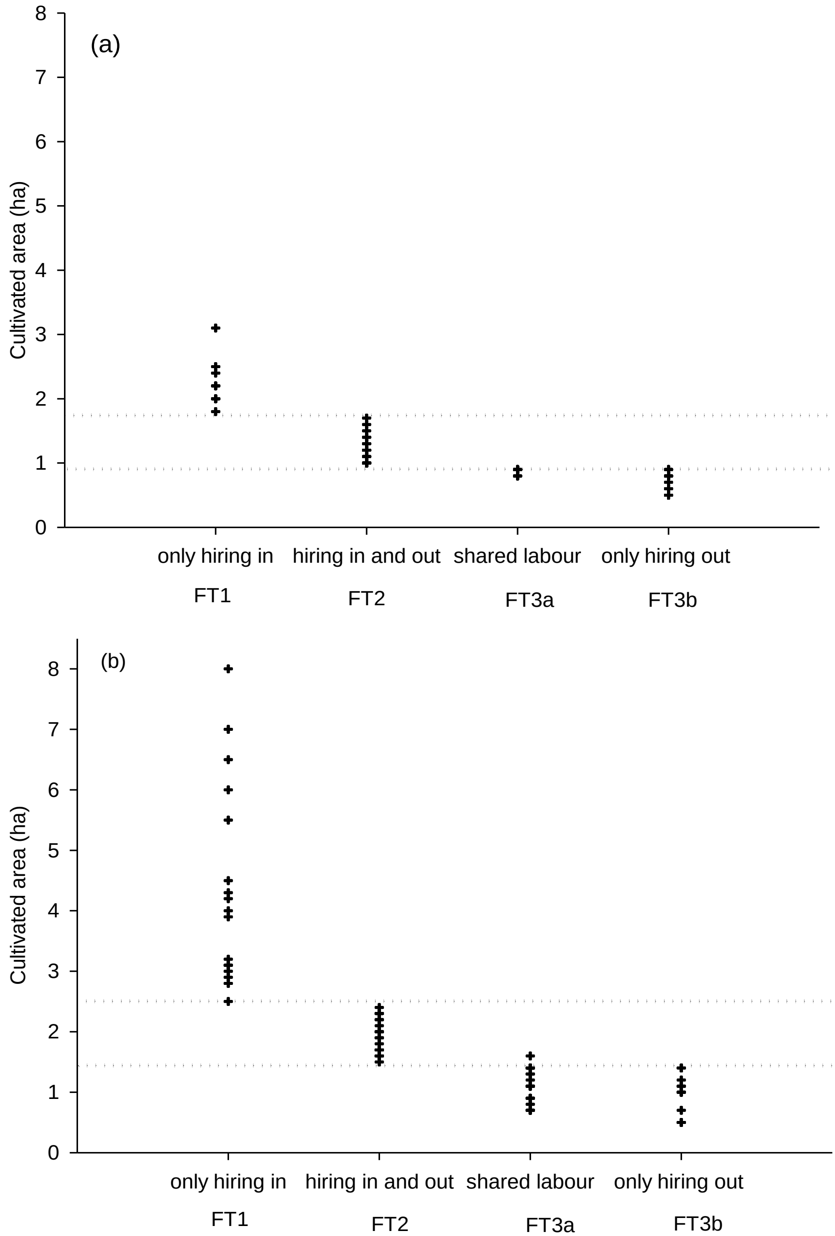


Fig. 2.3. Cultivated area of all farms related to four types of labourdynamics in (a) Zembe (n=52) and (b) Dombe (n=72) and the classificationinfarmtypes.

Table 2.4. Loading values for the correlation matrix for 22 and 21 household characteristics in Zembe (A) and Dombe (B). The variables are ranked in importance to the first principal component.

	Principal Components			
Variables	1	2	3	4
A) Zembe				
# chickens	0.879	0.410	-0.231	0.027
hh labour	0.714	-0.198	0.487	-0.139
area	0.682	-0.104	0.375	-0.031
hh size	0.676	-0.287	0.502	-0.165
# goats	0.657	-0.680	-0.298	0.025
only hire labour	0.619	0.078	0.305	-0.425
# cattle	0.596	0.016	0.587	0.412
hire labour	0.568	-0.047	0.069	-0.382
sale labour	-0.567	-0.201	-0.188	0.474
Tools	0.543	0.079	0.610	0.405
# fields	0.393	-0.313	0.379	0.124
inherited land	0.262	-0.023	0.003	0.545
temporal off-farm	-0.252	-0.062	-0.137	0.189
LLR	-0.246	0.131	-0.339	0.130
relatives_land	-0.216	0.094	0.302	-0.155
bought land	-0.154	0.066	-0.305	-0.232
gender	0.132	-0.169	0.111	-0.359
full off-farm	0.128	0.133	-0.056	0.271
sunflower MKT 1	0.118	0.485	0.252	-0.226
regulo land	-0.113	0.055	0.025	-0.271
other enterprises	-0.081	-0.021	-0.094	-0.493
sunflower MKT 2	-0.040	-0.312	-0.194	-0.211
B) Dombe				
# chickens	-0.700	0.342	0.090	0.056
area	-0.649	-0.097	-0.043	0.568
hire labour	-0.585	-0.334	-0.016	-0.213
cash crop	-0.572	0.042	-0.227	-0.496
hh labour	-0.556	0.491	-0.270	0.298
sale labour	0.541	0.406	-0.300	0.081
only hire labour	-0.505	-0.617	0.087	-0.215
hh size	-0.496	0.393	-0.249	0.329
LLR	-0.469	-0.346	0.107	0.430
relatives_land	0.416	-0.227	0.306	0.186
# goats	-0.407	0.107	0.391	-0.129
gender	-0.386	0.144	-0.139	0.166
# fields	-0.370	0.310	-0.176	-0.151
I_variety	-0.355	0.080	-0.258	-0.674
# cattle	-0.330	-0.169	0.262	0.256
full off-farm	-0.322	-0.195	0.416	-0.157
inherited land	-0.170	0.662	0.479	-0.206
other enterprises	0.137	0.043	-0.667	0.052
temporal off-farm	0.131	0.263	0.283	0.237
regulo land	-0.116	-0.531	-0.621	0.140
bought land	0.062	0.128	-0.254	-0.119

3.2.2. Farm characterisation

The Posts significantly differed in average cultivated area (2.1 vs. 1.2 ha), in mean number of people per household (7.4 vs. 5.5 persons) and, in mean land to labour ratio (LLR, 0.5 vs. 0.4 ha per person) with Dombe having the larger farms and households and more people below 12 years of age (Table 2.5). We did not observe any significant difference in number of female headed households between the Posts (16 in Zembe and 15 in Dombe). The farm types in both Posts were similar in terms of farm size pattern and labour dynamics, but the absolute values of the variables differed somewhat. The larger farms had significantly more household members (P=0.002) in both Posts (Table 2.5). The number of labourers in the four types did not differ between the two Posts although these were significantly greater in Farm Type 1. The land to labour ratio (LRR) was significantly higher in Farm type 1 (0.8 ha person^{-1} in Dombe) and (0.6 ha person^{-1} in Zembe) than in the other farm types. In both sites, Farm types 3a and 3b tended to have the most female-headed households, whereas households of Farm type 1 were mainly male-headed households. In Zembe Farm type 1 was exclusively comprised of male-headed households. A study in Sussundenga district (Sousa, 1999), where Zembe is located, showed that female-headed households were the poorest with severe constraints to the improvement of their livelihoods due to inequality in asset ownership. In our case-studies, the female-headed households were mostly divorced or widowed. They often suffered from social exclusion as they were perceived to be connected with witchcraft or prostitution.

The number of chickens owned by Farm type 3b was significantly smaller in both Posts and in 3a in in Dombe (Table 2.5). The number of goats differed significantly between the farm types only in Dombe (P=0.039). In Dombe only Farm type 1 owned cattle, whereas in Zembe Farm types 1 and 3a and 3b had cattle. Thus Farm type 1 contained the relatively wealthier farmers in the two Posts. They had more land, better access to labour, more livestock and were more market oriented. The use of animal traction on Farm type 1 was limited to land preparation, as none of the farmers own cultivators, which led to labour constraints during the weeding phase, which they overcame by hiring labour.

Table 2.5. Distribution of households over farm types and household characteristics per site (S) and per farm type (FT) for Zembe and Dombe based on the rapid farm survey.

Sites (S)		Zembe (*n*=52)						Dombe (*n*=72)							
		Farm types (FT)						Farm types (FT)						P-values^{y}	
Variables	Unit	1	2	3a	3b	Mean	P(FT)^{w}	1	2	3a	3b	Mean	P (FT)^{w}	S	FT
Distribution of households	%	17	44	15	23			24	31	31	15				
Cultivated area	Ha	2.2^{a}	1.2^{b}	0.9^{c}	0.7^{c}	1.2	0.000	4.4^{a}	1.9^{b}	1.1^{c}	1.0^{c}	2.1	0.000	<0.000	<0.000
Household size	# hh^{-1}	8.1^{a}	5.4^{b}	4.9^{b}	4^{b}	5.5	0.002	9.8^{a}	7.3^{ab}	6.8^{b}	5.2^{b}	7.4	0.002	0.001	<0.000
Household labourers^{u}	# hh^{-1}	3.8^{a}	3.7^{b}	3.1^{b}	2.6^{b}	3.3	0.005	4.2^{a}	3.8^{b}	3.8^{b}	3.2^{b}	3.9	0.002	0.051	0.000
Land:labour ratio (LLR)^{v}	ha $person^{-1}$	0.6^{a}	0.4^{b}	0.3^{b}	0.3^{b}	0.4	0.001	0.8^{a}	0.5^{b}	0.3^{c}	0.4^{bc}	0.5	0.000	0.003	<0.000
Female headed households	%	0^{a}	17^{b}	50^{b}	58^{b}	-	0.008	12^{a}	17^{a}	27^{a}	27^{a}	-	0.621	0.304	0.025^{z}
Chickens^{u}	# hh^{-1}	26.0^{a}	14.0^{a}	13.0^{a}	5.0^{b}	13.8	0.007	27.0^{a}	18.0^{ab}	12.0^{b}	10.0^{b}	16.9	0.039	0.330	<0.008
Cattle^{u}	# hh^{-1}	2.4^{a}	0.3^{b}	0^{b}	0^{b}	0.6	0.000	2.2^{a}	0^{b}	0.5^{b}	0.3^{b}	0.7	0.004	0.731	0.000
Goats^{u}	# hh^{-1}	4.7^{a}	1.6^{ab}	1.5^{a}	0.3^{b}	1.8	0.067	5.9^{a}	6.0^{ab}	2.3^{bc}	1.3^{c}	4.2	0.039	0.009	0.005

[a,b,c] Means followed by the same superscript letter in a row do not differ significantly by Tukey HSD and the Mann-Whitney Test
[u] Calculated based on rank using Kruskal-Wallis test.
[v] LLR is calculated as the cultivated area over household labour, taking into account children < 12 year as 1/4 labourer and excluding hired labour.
[w] p (FT) is the probability for farm types in each site.
[y] Probability value for the site and farm type comparison.
[z] Probability value for farm type comparison only.

3.2.3. Labour demand and availability during the growing season

There was a strong seasonality in labour required for cropping activities (Figs. 2.1 and 2.4). Peak demand for labour occurred in December and January-February during the 1st and 2nd weeding and in April during the harvest of maize and weeding of sunflower and sesame. The maximum availability of labour in the farm, indicated by the dashed line (Fig.2.4), comprises both adult and child labour with long days due to time pressure. Land preparation was exclusively done by adults and was spread over a long period before the rainy season started. Children worked in the fields only during sowing, weeding and harvesting. Farm type 1 was constrained by farm labour availability during weeding of maize, when they hired in labour. Labour was always hired from people living in the vicinity from Farm types 2 and/or 3b. On average, Farm type 1 hired in 120 h in Zembe and 170 h in Dombe (Table 2.6). There were periods of slack labour demand during the cropping season, and especially during the dry season from May to August (Fig. 2.4). Some of this labour was used to grow other crops, and some for non-agricultural related activities (Fig. 2.5). Fewer than 25 % of all households had no additional activities. In Dombe, 80 % of the farmers engaged in only one additional activity. In Zembe, with the exception of Farm type 1, all the other farm households engaged in more than one non-agricultural related activity, such as charcoal production or firewood collection from uncultivated land.

For cattle keeping households, one family household member (most often a child) spent approximately 7 h per day herding cattle. Goats were tethered in fallow land close to the homestead during the cropping season and demanded negligible labour (c. 10 min for tethering each day). During the off-season period the goats grazed freely on crop residues, and no labour was required as the animals returned to the homestead at end of the day. Farmers did not keep goats in kraals.

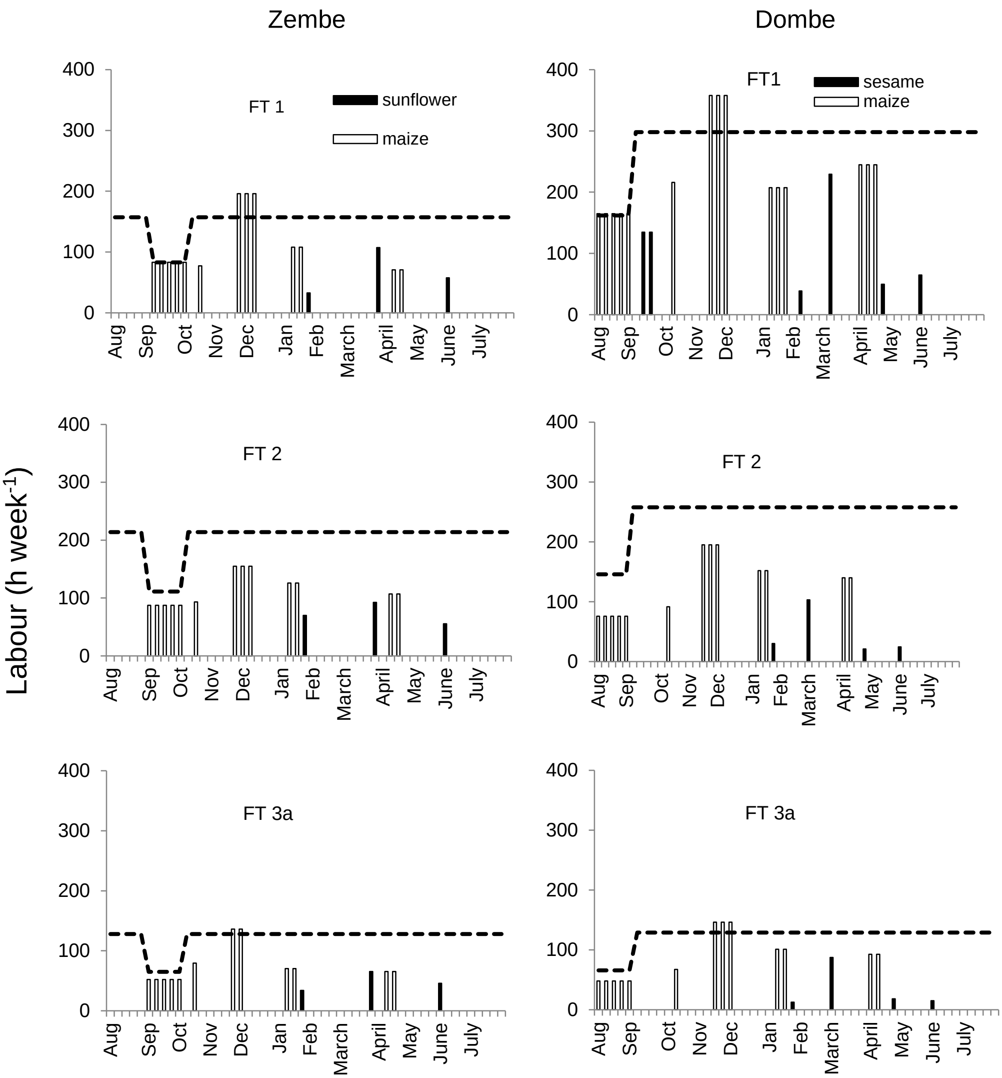


Fig. 2.4. Crop labour calendars for the cultivation of maize, sunflower and sesame for different farm types (FT) in Zembe and Dombe. The dashed line indicates the total available labour in the whole farm based on both adult and children's input with long days due to time pressure on activities. The lower available labour corresponding to labour used during land preparation excludes children because they do not participate in land preparation.

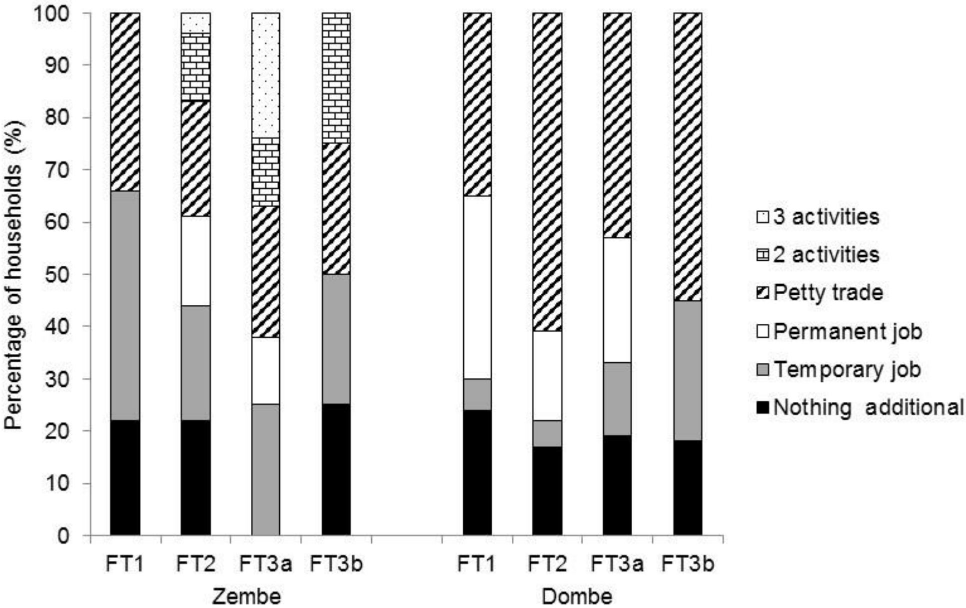


Fig. 2.5. Percentage of households without an additional source of income; with one source of income from a temporary job or permanent job or petty trade; and with two or three sources of income simultaneously.

In general the maize grain yields per ha were greater in Dombe than in Zembe (Table 2.6A). The smallest maize yield in Dombe (1.5 t ha^{-1}, Farm type 3b) was comparable to the second largest maize yield in Zembe (1.7 t ha^{-1}, Farm type 2). The difference in maize yield between the Posts was much wider for Farm types 3a (0.7 t ha^{-1}) and for Farm type 3b (0.4 t ha^{-1}). For Farm type 1 the difference was (0.3 t ha^{-1}) and for Farm types 2 it was only (0.2 t ha^{-1}). Farm type 1 had better maize yields in both Posts (Table 2.7), which can mainly be attributed to timely weeding, achieved by hiring labour. Farm types 3a and 3b in Zembe had very poor maize yields and labour productivity was poor compared with the other farm types. The larger maize yields in Farm type 1 in Dombe than in Zembe are due to the combination of better soils (Table 2.3) and better crop management. The maize labour productivity for Farm type 1, however, was similar in Zembe and Dombe, due to lower labour inputs in Zembe. For the other farm types the crop labour productivity was higher in Dombe than in Zembe. Sunflower yields were similar across all farm types (including Farm type 1), except for Farm type 3a where yields were lower (Table 2.6B). Crop labour productivity tended to be highest in Farm type 1. The yield of improved sesame (Farm type 1) was slightly larger but the labour input almost twice that of traditional varieties (Farm types 2, 3a and 3b) (Table 2.6B). This was because the improved sesame varieties were grown as sole crops, demanding labour for land preparation, whereas the traditional varieties were relay-intercropped into the maize fields. No labour was hired for cultivation of cash crops.

The hiring-out of labour from Farm type 3b caused severe reductions in both yield per ha and labour productivity as weeding of their own fields was delayed. Thus although the early cropping season offers the greatest opportunity in the year to find work (paid in kind or cash), a strong trade-off exists between hiring-out labour and focusing on cropping in their own fields.

Table 2.6. Cultivated area, labour use per hectare, crop yields and crop labour productivities, total labour input and hired labour at farm level for maize (A), sunflower and sesame (B) for different farm types based on the detailed survey (n=2 for Farm type 1 and n=3 for other farm types).

Sites		Zembe (Farm types)				Dombe (Farm types)			
Variables	Unit	1	2	3a	3b	1	2	3a	3b
(A)		Maize				Maize			
Cultivated area	Ha	2.1	1.5	0.8	0.8	3.4	1.9	1.3	1.3
Total labour	h ha^{-1}	750	990	980	1270	930	880	870	1140
Maize yield	t ha^{-1}	2.0	1.7	1.1	1.1	2.3	1.9	1.8	1.5
Maize labour productivity (10^{-3})	t h^{-1}	2.6	1.7	1.2	0.9	2.5	2.1	2.0	1.4
Total labour[a]	h farm^{-1}	1530	1460	880	960	3160	1640	1130	1490
Hired labour	h farm^{-1}	140	25	0	0	130	10	0	0
(B)		Sunflower				Sesame			
Cultivated area	Ha	1.4	1.0	0.4	0.4	1.0	0.6	0.4	0.4
Total labour	h ha^{-1}	150	230	330	330	640	320	330	340
Crop yield	t ha^{-1}	0.3	0.3	0.2	0.3	1.3	1.0	0.9	0.9
Crop labour productivity (10^{-3})	t h^{-1}	1.7	1.1	0.5	0.8	2.0	3.2	2.7	2.6
Yield	t farm^{-1}	0.3	0.2	0.1	0.1	1.5	0.7	0.4	0.4
Total labour[a]	h farm^{-1}	200	230	130	120	640	180	130	130
Hired labour	h farm^{-1}	0	0	0	0	0	0	0	0

[a] Includes household and hired in labour.

In Dombe the crop revenue , expressed in US$ per ha (Table 2.7), was larger for maize-sesame relay-intercropping with traditional varieties in Farm types 2-3b, than for maize and sesame as sole crops in Farm type 1. Farm type 2 had only slightly greater crop revenue than 3a and b. For maize-sunflower the crop revenue was greater in Farm types 1 and 2 than in Farm types 3a and b.

Maize yields of all farm types in both Posts were above the estimated provincial and national averages of 0.5 and 0.6 t ha^{-1}, respectively. Yet they were far below the attainable yields of 6.0 t ha^{-1} obtained with the use of fertilizers at a nearby research station (Geurts and Van den Berg, 1998) indicating a large yield gap. In general, sunflower yields were small (Table 2.6B) compared with the average yields in Manica province of 0.6 t ha^{-1} which can be explained by the sparse plant density (15870 plants ha^{-1} measured in relay-intercropping compared with the recommended density of about 50000 plants ha^{-1} in monoculture), as well as lack of fertilizer use. In Dombe, the yield of sesame in all farm types was larger than the average yield of 0.4t ha^{-1} estimated for Manica province. The crop revenues (Table 2.7), showed that growing maize and sesame in relay-intercropping earned 50-70 % more than growing sole crops of maize and the improved sesame variety under current management. This was also reflected in the crop labour productivity (Table 2.6), as sesame as a sole crop requires more labour, particularly for land preparation. Our results on time spent on the agricultural activities are in agreement with other studies in the region. For instance, Howard *et al.* (1998) found that households in East and Central Manica spent 620 to 990 man-hours ha^{-1} cultivating maize. Values of the same magnitude were also reported by Uaiene (2004).

Table 2.7. Yields of maize, sesame sunflower in sole cropping and relay-intercropping systems and revenues per ha in Zembe and Dombe posts, based on farm gate prices at harvesting time. Maize: 0.18 US$ kg^{-1} in Zembe and 0.12 US$ kg^{-1} in Dombe; sunflower 0.28 US$ kg^{-1} and sesame 0.88 US$ kg^{-1}.

		Zembe (Farm types)				Dombe (Farm types)			
Variables	Unit	1[a]	2[a]	3a[a]	3b[a]	1[b]	2[c]	3a[c]	3b[c]
Maize yield	t ha^{-1}	2.0	1.7	1.1	1.1	2.3	1.9	1.8	1.7
Sesame yield	t ha^{-1}	-	-	-	-	1.3	1.0	0.9	0.9
Sunflower yield	t ha^{-1}	0.3	0.3	0.2	0.3	-	-	-	-
Land Crop revenue	US$ ha^{-1}	413.7	373.2	250	267.6	698.2	1122.9	997.2	990.5

[a] Maize and sunflower in relay-intercropping.
[b] Maize and sesame both as sole crops in a rotation, crop revenue is the average of a ha of maize and sesame.
[c] Maize and sesame in relay- intercropping system.

3.2.4. Maize self-sufficiency at farm level

The food self-sufficiency ratio based on maize as proxy indicator showed that all farm types produced enough maize to satisfy household consumption needs year-round, except Farm type 3b in Zembe (Table 2.8). Farm type 3b in Zembe was not self-sufficient due to low maize yields in combination with the small area cultivated. Although Farm type 3a cultivated the same area as Farm type 3b, the sharing of labour during the weeding phase (*gúmuè*) seemed to improve the maize yield sufficiently to enable Farm type 3a to achieve self-sufficiency. The average income from hiring out labour for Farm type 3b was 21 US$ y^{-1}, which is enough to buy 100 kg of grain maize in the local market. When this amount of maize was added to the total maize production, Farm type 3b was just self-sufficient as was Farm type 3a. Farm type 3b could become maize self-sufficient by working on their own farms, but this would prevent them from earning food and cash through selling their mutrakita labour during a critical period when their own food stocks are exhausted.

Surpluses were sold at the market or used for paying labour in kind. Farm type 1 in Zembe and all farm types in Dombe produced maize for sale in the market. Farm type 2 in Zembe only sold maize when there was sufficient surplus. The results do not take into account harvest losses nor post-harvest losses as it was not possible to verify these. So, we may have overestimated the food self-sufficiency of the various farm households. According to the agricultural census (TIA) 16 % of households in Manica reported post-harvest losses, 61 % of which reported insect pests as the major problem. Post-harvest losses due to the larger grain borer (LGB) are severe in the neighbouring province of Gaza (Milgroom and Giller, 2013).

Table 2.8. Maize food self-sufficiency ratio per farm type in Zembe and Dombe based on the detailed survey (n=2 for Farm type 1 and n=3 for other farm types).

Sites		Zembe (Farm types)				Dombe (Farm types)			
Variables	Unit	1	2	3a	3b	1	2	3a	3b
Household size	#	5	7	7	6	10	7	5	6
Household need	t yr^{-1}	0.9	1.1	1.1	0.9	1.1	1.2	0.9	1.2
Total yield	t yr^{-1}	4.1	2.6	1.0	0.8	7.7	3.6	2.3	2.2
Food self-sufficiency		4.6	2.4	1.0	0.9	6.6	3.0	2.6	1.8

3.2.5. Gross margin and labour productivity at farm level

Farm gross margin was higher in Dombe than in Zembe for all farm types (Fig. 2.7). Farm type 1 had the greatest grosss margin in both Posts (2840 US$ in Dombe) and (880 US$ in Zembe). In both Posts, the gross margin decreased in the order Farm types 1, 2, 3a and 3b. Maize contributed more to gross margin of the larger farms than the crops grown solely for cash. In Dombe, sesame contributed 40-45 % to the gross margin while in Zembe sunflower contributed only 10-15 %, as both price and yield of sunflower were low.

Also, labour productivity at farm level (Equation 4), was greater in Dombe than in Zembe for all farm types. Farm type 1 had a labour productiviy of 0.53 US$ h^{-1} in Zembe and 0.74 US$ h^{-1} in Dombe, mainly due to the high contribution of sesame compared with sunflower. In Zembe labour productivity at farm level was similar for Farm types 3a and 3b, i.e., 0.18 US$ h^{-1}. In Dombe the labour productivity decreased in the same order. The contribution of maize to farm level labour productivity in Dombe was similar to that in Zembe for all of the farm types, but cultivating sesame doubled the labour productivity of farmers in Dombe (Fig. 2.7). This was also observed on Farm type 1 despite the low productivity of cultivating sesame as a sole crop due to extra labour need for land preparation in this farm type.

Our calculations indicated that the amount of labour available on the poorer farms was not limiting for crop production even during peak periods (except for Farm type 3a in Dombe), which led us to hypothesise that the quality of labour might be affected by alcohol consumption (Fig. 2.4). Heads of households that belonged to Farm type 1 consumed significantly (P=0.001) less alcohol than household heads of the other farm types. Averaging breath alcohol contents for both Posts gave 0.2 ‰ for Farm type 1, 1.1 ‰ for Farm type 2, 1.5 ‰ for Farm type 3a and 1.6 ‰ for Farm type 3b (Fig. 2.6). No differences were observed between male and female household heads in breath alcohol contents.

The intermediate and smaller farms had average values above the legal threshold for driving of 0.6 ‰, suggesting that the quality of their labour might be impaired. While the selling of alcohol by these farmers in Posts could be seen as an important off-farm activity, it may contribute to the low productivity of these poorer farmers. Lawson *et al.* (2006) pointed out that alcohol abuse was one of key factors for persistent poverty in Uganda. Tellegen (1997) cited by Bryceson (1999) showed that alcohol consumption in the agricultural production sector tended to divert resources from productive investment. Whether excessive alcohol consumption is due to poverty (Khan *et al.*, 2002) or poverty results from alcohol consumption is open to debate.

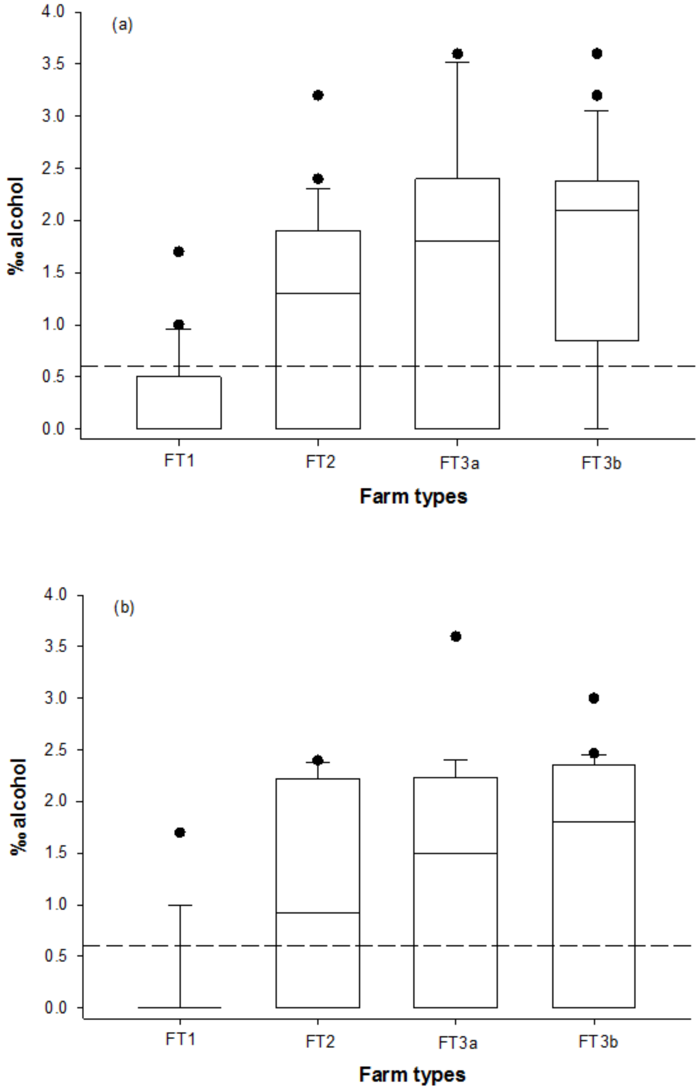


Fig. 2.6. Breath alcohol content (‰) for different farm types in Zembe (a) and Dombe(b) based on a total sample of n=176. The box-and-whisker plots show five statistics– the minimum, the lower quartile, the median, the upper quartile, the maximum. The black dots at the upper end of the box are outliers. The box contains the middle 50 % of data values. The line drawn across the box is the sample median for each farm type. The dashed horizontal line indicates the blood alcohol content limit above whichit is illegal to drive inMozambique.

Table 2.9 shows the prices for maize and the amounts sold in the different seasons. Prices in the lean season were higher due to scarcity. The needs for cash determined when farmers sold their maize. In Zembe all farm types sold part of their maize just after harvest and some farms in Farm types 3a and b sold everything they produced. Farm type 1 and 2 were able to benefit from the higher prices during the lean season, although the price difference was small compared with Dombe: in Zembe the price increased by 20 % and in Dombe by 130 % between harvest time and the lean season. In Dombe only Farm type 1 was able to sell maize in the lean season and sold none just after harvest. Sales from Farm types 2-3b were evenly spread over the harvest period and the middle season.

Table 2.9 Variation in the price of maize and the proportion of total surplus sold at different periods of agricultural season by different farm types at in Zembe and Dombe based on the detailed survey.

		Percentage sold per farm type (%)								
		Zembe (Farm types)					Dombe (Farm types)			
Period	Prices (US$ kg^{-1})	1	2	3a	3b	Prices (US$ kg^{-1})	1	2	3a	3b
Harvest period	0.18 (0.14-0.21)	20	50	100	100	0.12 (0.11-0.14)	0	40	60	60
Middle season	0.19 (0.18-0.21)	30	30	0	0	0.23 (0.18-0.28)	70	60	40	40
Lean season	0.21 (0.21-0.21)	50	20	0	0	0.28 (0.25-0.32)	30	0	0	0

In parentheses is the range of values from which the average price was calculated.

In Manica, the per capita poverty line was estimated to be 0.68 US$ per day (Alfani *et al.*, 2012) well below the international values of US$ 1.0 or US$ 1.25. If households fully relied on agriculture for their income, the average remuneration in Zembe would be 1.0, 0.39, 0.28 and 0.14 US$ per person per day for Farm types 1, 2, 3a and 3b, respectively. In Dombe, the remuneration was higher than in Zembe, i.e., 1.48, 0.67, 0.77 and 0.49 US$ per day for Farm types 1, 2, 3a and 3b, respectively. This indicates that in Zembe other activities are more important than in Dombe.

The farm level labour productivity in Dombe indicated that producing and selling their own crops is more financially-attractive than being employed in the farming sector in Mozambique at the prevailing rate of 0.46 US$ h^{-1} (Moçambique, 2012), except for Farm type 3b. Over a full year, all farm types in Zembe had a farm gross margin below the minimum wage for a full time labourer in the farming sector in Mozambique.

Comparison of farm level labour productivity with consumption per capita per day in (0.68 US$) provided a similar picture as remuneration per hour invested in the farm. All farm types in Zembe were below the poverty line, except Farm type 1. In Dombe, only Farm type 3b was below the poverty line.

Household members from all types of farms engaged in temporary jobs outside agriculture such as road construction, petty trade and self-employment (Fig. 2.5). They also sold charcoal, firewood or chickens in their village market or in Chimoio. Chickens were the most common source of extra income. We did not assess the revenues from those other activities, and smallholder farmers access food in a variety of ways (Ellis, 2000; Eriksen and Silva, 2009; Hahn *et al.*, 2009). The other activities were more important for livelihood support in Zembe than in Dombe. Zembe is located at a relatively short distance from the main urban market (Chimoio) compared with Dombe. Therefore, farmers in Zembe benefit more from off-farm opportunities, which makes them less dependent on agriculture. Off-farm income opportunities were particularly important for the small farms. Jones and Tarp (2012) highlighted the need of employment opportunities outside the agricultural sector in Mozambique as a means of breaking out of the poverty trap for smallholder farmers.

During our focus group discussions, we observed that perceptions on land and labour productivity varied across farmer types. For instance, among the farmers with larger farms (Farm type 1), those with smaller farms (Farm type 3a and 3b) were seen as people who were not fully committed to farming. To quote a few of them "*the smaller farmers have smaller yields than we do because they don't plan their activities on time. They do everything in a rush. Some of them are always drunk and lazy - we see this when they are working for us!" Farm type 1, Dombe, 2012 focus group discussion. The small-scale farmers, however, see themselves as "trapped in poverty*" as can be inferred from the following quote "*We own lands but small fields; we go and work for larger farmers; we need this money to do milling, buy soap, salt. Where do we go for cash when our children are sick? We don't have chickens or goats like large farmers to sell!*" Farm type 3b, Zembe 2012, focus group discussion.

Alwang and Siegel (1999) reported a similar situation with regard to the sale of casual labour by smallholders during peak periods in Malawi, which contributed to poor returns

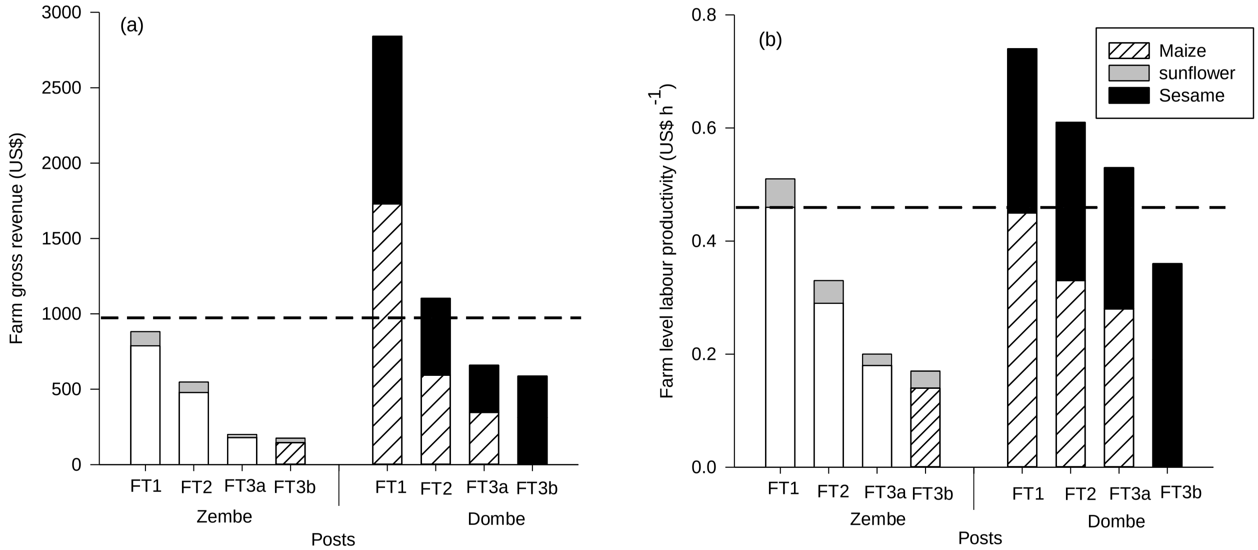


Fig. 2.7. Farm gross margin (a) and Farm level labour productivity (b) of maize, sesame and sunflower at farm scale for all farm types in both administrative posts. The dashed horizontal lines indicates (a) the annual minimum wage (b) the minimum wage per hour for farming sector In Mozambique.

to land and labour. Yet, a further analysis of income from hiring out labour showed that it can leverage the maize needed and allow Farm type 3a to achieve food security. As mentioned, we noticed excessive alcohol consumption among Farm types 3a and 3b which also presumably impacted their ability to earn income from selling their labour.

3.2.6. Opportunities to increase overall productivity

All current farming systems depend on fallow land to sustain crop production. Jones and Tarp (2012) identified lack of fertilizer use as a major reason for poor crop yields in Mozambique. In Zembe and Dombe, the better-endowed farmers have the best opportunities to use external inputs such as fertilizers. Type 1 farms cultivated an improved sesame variety, indicating some purchasing power. They also needed cash or maize to pay hired labour for weeding as they had relatively more land and they were able to use animal traction. If the use of animal traction could be extended to weeding, this would free labour during the most labour-constrained period, leading to opportunities for the larger-scale farmers to extend their land area and for the smaller-scale farmers to work on their own fields or on other activities.

For Farm types 2, 3a and 3b with little purchasing power, intercropping with legume crops seems to be one of the few options to enhance productivity. For instance, maize-pigeonpea intercropping systems in Ruaca (only 30 km from Zembe) supported maize yields of 5.6 t ha^{-1} without fertilizers (Rusinamhodzi *et al.*, 2012). One emerging crop in the country, and in particular in Manica Province, is soybean, driven by huge demand for feed from the poultry industry in urban centres (FAO, 2013). Soybean offers opportunities for the farmers to increase income and improve soil fertility. However, a further analysis is needed on the economic benefits of sunflower and sesame as opposed to or in addition to pigeonpea and soybean.

The location and agro-ecological characteristics of the Posts offer different pathways for improvement. In Dombe soils were better and hence yields were higher. We observed buyers using helicopters and large trucks to purchase maize for the market in the central and southern regions of Mozambique, pointing to the importance of the maize market in Dombe, despite the longer distance from a major city such as Chimoio. Most of the farmers sell maize individually and in small quantities. Cooperating in sales activities could offer them a better bargaining position (Markelova *et al.*, 2009; Kirsten and Sartorius, 2002). Currently, only 17 % of the farmers are affiliated with associations in Dombe. In Zembe soils were less fertile, yields were poorer and no such associations exist. The proximity to Chimoio market allowed farmers to transport their own produce to the market by bicycle and more non-agricultural activities for income generation were practised.

Poor soil fertility is considered the fundamental constraint to productivity of smallholder farmers in sub-Saharan Africa (Sanchez *et al.*, 1997; Stoorvogel *et al.*, 1993; Folmer *et al.*, 1998). This was clearly not the case in this region of Mozambique, which can be considered a fairly typical area with good agricultural potential and abundant land. Farmers in both Posts, in particular those in Dombe, cultivate as much land as possible with the labour available in order to have greater production instead of investing in yield increasing technologies such as fertilizers. These findings are in agreement with those of Baudron et al. (2012) who indicated that smallholder farmers tend towards extensification rather than intensification if land is abundant. Another possible reason is the relatively high prices of fertilizers in Mozambique – nearly twice those of its neighbouring countries such as Malawi and Zimbabwe (Benson *et al.*, 2012). Opportunities for intensification exist, especially for larger farms, but then financial resources for external inputs or labour saving technologies (e.g. machinery) are required (Udo *et al.*, 2011). In situations where labour-intensive innovations are not adopted, shortage of labour is often the main limiting factor for production (Woodhouse, 2010).

The result showed that in order to increase smallholder productivity, the main objective of the PEDSA, CAADP and NEPAD, heterogeneity of smallholder farmers within and across regions must be acknowledged. Different farm types require different technologies. In addition, partial introduction of a new technology did not lead to improvements for rural livelihoods, e.g. using improved sesame varieties without fertilizer resulted in lower labour productivity (at crop and farm level) and using cattle without the availability of a cultivator did not relieve labour constraints in the most critical period.

Our results also suggest that poverty alleviation may not be built on agriculture alone, especially for the smaller-scale farmers who are trapped in poverty. Off-farm jobs in large scale agriculture (such as biofuel plantations) or other industries could potentially provide an escape route.

4. Conclusions

Overall our study highlights the importance of addressing labour productivity at crop and farm levels rather than yields and farm level gross margin. The results paint a rather depressing picture of a vicious cycle of poverty for about 40% of smallholder farmers in this area of relatively high agricultural potential in Mozambique. All of the smallholder farms were food self-sufficient in maize, except for the poorest farmers (Farm type 3b) in Zembe. At farm level, maize provided more revenue to the household than sunflower and sesame. Overall revenues from sunflower were very poor. Access to labour during first weeding was the main factor determining crop yields. Large farms were able to hire in extra labour from small farms to weed in time and ensure relatively good yields. The small farms hired out their labour during that period at the expense of the yields of their own fields. They were forced to do so due to lack of food and cash stocks. In addition, they had to sell their maize in the period of low market prices i.e. at harvest. Together, these factors keep the poorest farmers trapped in poverty.

Our study has shown that to increase crop and farm level labour productivity of smallholder farmers there is a clear need to understand the diversity of farms and farmers' social and economic context. For large farms two development pathways exist: to increase production per ha (intensification) and to increase the area of land (extensification). For intensification, yield increasing measures are required, such as fertilizer application. For extensification, labour saving technologies, such as cultivators and herbicides are required. The large-scale farmers seem to have sufficient resources to choose either pathway. A further exploration is required to assess the impact of both development opportunities. The farm scale analysis suggested that the small farms could improve crop yields by adopting practices related to land and labour use similar to the large farms. However, they were constrained by a cash and food availability at a crucial period of the cropping cycle that forced them to work for other farmers. In addition the excess consumption of alcohol may impair on the quality of labour. For small farms with limited resources, intercropping of maize with pigeonpea could be an opportunity to increase revenues, particularly in Zembe, where revenues are smaller. However, in case of pigeonpea, farmers have not been exposed to this crop, so efforts of extension officers are needed to introduce this option to increase productivity. Given that land is abundant in Mozambique, large-scale capital intensive agriculture, including biofuel plantations or other industries could provide (permanent) off-farm labour opportunities that are more evenly spread throughout the year than only during the weeding period. For the poorer smallholder farmers this could contribute to poverty reduction. Our analysis suggests that the goals of PEDSA, CAADP and NEPAD related to improved agricultural production cannot be achieved without parallel developments in other sectors outside agriculture.

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Can farming provide a way out of poverty for smallholder farmers in central Mozambique?

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Abstract

Given that agriculture is the principal economic activity of the majority of people living in rural Africa, agricultural development is at the top of the agenda of African leaders. Intensification of agriculture is considered an entry point to improve food security and income generation in sub-Saharan African (SSA). We used a bio-economic farm model to perform ex-ante assessment of scenarios that could improve gross margin and maize sales of large and small farms in maize-based farming systems in two posts representative of rural Mozambique (Dombe and Zembe Administrative Posts in Central Province). We explored two options for increase agricultural productivity: (i) extensification, to expand the current cultivated area; and (ii) intensification, to increase input use per unit of land. We considered two scenarios for each of the two options. Extensification: current situation (SC1) and labour saving (SC2). Intensification: land saving (SC3) and combined improvement (SC4). For each scenario, we maximized gross margin and maize sales for both farm types and assessed the trade-offs between the two goals. We further explored the impact of increasing land and labour beyond the current observed levels. Scenario (SC4) substantially increased both gross margin and maize sales of large and small farms in both posts. Minor trade-offs were observed between the two goals on large farms whereas we saw synergies between the goals for small farms. In Dombe, the gross margin of large farms increased from $ 5550 to $ 7530 per farm and maize sales from 12.4 t to 30.4 t per farm. In Zembe, the gross margin increased from $ 1130 up to $ 2410 per farm and maize sales from 5.1 t up to 9.5 t per farm. For small farms in Dombe, the gross margin increased from $ 1820 to $ 2390 per farm and maize sales from 3.0 t to 9 t per farm. In Zembe, the gross margin increases from $ 260 to $ 810 and maize sales from 2.0 t to 3.6 t per farm. With the most optimistic scenarios and conditions of more hired labour and labour saving technologies, both farm types substantially increased both gross margin and maize sales. We conclude that with available resources, the possibilities for increasing gross margin and maize sales are greater where agroecological conditions are more favourable and are much higher for larger farms. Without interventions that allow small farms to assess more land and labour, intensification of agriculture is likely to happen only on farms of better-resourced households, indicating the need for alternative forms of on- and off-farm income generation for poorer farmers.

Keywords: gross margin, maize sales, farm model, bio-economic model, trade-offs

1. Introduction

Global food demand for agricultural products will increase due to growth in world population which is projected to reach 9 billion people by 2050 and to increasing incomes in developing countries (Godfray *et al.*, 2010). In addition, food production is challenged by global changes such as climate change (Eriksen and Silva, 2009). This challenge will be more pronounced in agriculturally dependent economies such as in sub-Saharan Africa (Van Ittersum *et al.*, 2016). Given that agriculture is the main economic activity of the majority of people living in rural areas, agricultural development is at the top of the agenda of African leaders (AGRA, 2015b). Intensification of agriculture is considered an entry point to improve food security and to achieve inclusive economic growth in sub-Saharan African (SSA) (World Bank 2008). Yet agricultural development is hampered by several factors, including depletion of soil fertility (Benson *et al.*, 2012) and poor access to external inputs such as improved seed, mineral fertilizers and irrigation (Jayne *et al.*, 2010). To tackle this problem, the African Union Member States committed to increase the use of improved seeds and fertilizers and promote good agricultural practices (Sanchez, 2015). This commitment is expressed through the Comprehensive African Agriculture Development Programme (CAADP) and the Maputo Declaration to increase agriculture funding to at least 10 % of the State budget, all policies aiming at agricultural development (NEPAD, 2003b). Although the Mozambique Government had gradually increased its budget allocation to agricultural development from 5.4 % in 2003 to above 10 % in 2005 after the Maputo Declaration, effectively the average expenditures in agriculture were only 3% in both years due to the slow delivery of the budget (Chamusso *et al.*, 2013).

In Mozambique, agricultural productivity is poor with, for example, an average yield of only 0.9 t ha^{-1} for the main staple crop maize (*Zea mays* L.) (MINAG, 2011). Only 3 % of the smallholder farmers use fertilizers (MINAG, 2012a). The Government of Mozambique developed a Strategic Plan for Agriculture Development (PEDSA) which made increasing agricultural productivity of smallholder farmers its top priority (MINAG, 2011). However, PEDSA is criticised to be too broad, with the risk to compromise the achievement of its primary goal of poverty reduction (Woodhouse, 2009). A main concern is the lack of attention for the diversity of socio-economic conditions of smallholder farmers: how can this be addressed in the endeavour for increased productivity?

Two main options available to smallholder farmers to increase agricultural production are (i) to expand the current cultivated area, i.e. extensification, and (ii) to increase input use per unit of land, i.e. intensification (Erenstein, 2006). Our previous study (Leonardo *et al.*, 2015) on agricultural production in central Mozambique showed differences in land and labour productivities among different types of smallholder farms with yields only a fraction of the potential. Expansion to farm larger areas was constrained by labour availability, especially during the weeding periods. Intensification was constrained by the lack of capital to buy external inputs such as improved seed and fertilizers.

Given the good agro-ecological conditions for crop production in Mozambique, productivity enhancing technologies, such as improved seed and fertilizers could increase maize yields up to 6 t ha^{-1} (Rusinamhodzi *et al.*, 2012). The abundance of land characterizes the region, hence technologies that reduce the amount of labour needed for cropping activities, for example the use of herbicides, may offer a valuable option to farm larger areas. Cultivation of legume crops such as soybean and pigeonpea appear promising options to improve production due to the emerging market and the contribution of nitrogen (N) to the soil-crop system. Soybean and pigeonpea have been widely promoted in Mozambique (MINAG, 2011). Improved crop management combined with intercropping of maize with pigeonpea (*Cajanus cajan* (L.) Millsp.) resulted in yields up to 4.8 t ha^{-1} without fertilizer inputs in central Mozambique (Rusinamhodzi *et al.*, 2012). However, to realize the potential offered by yield increasing technologies is not straightforward. At farm level, adoption of technologies depends on compatibility with biophysical conditions, resource availability and priorities of the household (Giller *et al.*, 2006; Tittonell *et al.*, 2007).

Smallholder farmers have multiple objectives that may compete or complement each other in terms of resource demand (Stoorvogel *et al.*, 2004), for instance achieving food security and increasing gross margin from farming. Farmers' objectives may conflict with or contribute to objectives at higher levels such as national food security (Bolwig *et al.*, 2010) or production of biomass for biofuel (Arndt *et al.*, 2008). Therefore, quantification and analyses of trade-offs and synergies of farmer´s and national objectives could guide policymakers and planners towards better-informed policy decisions for agricultural development.

Bio-economic models have been extensively used to explore alternatives to current systems, for example the use of legumes to increase maize yields in Tanzania (Baijukya *et al.*, 2004; Janssen *et al.*, 2010), to assess the trade-offs between economic and environmental objectives of Dutch dairy and arable farmers (Van de Ven and Van Keulen, 2007; Kanellopoulos *et al.*, 2012), and to analyse the impact of alternative crop residue management practices on crop and livestock productivity at different scales (Mujaya and Yerokun, 2003).

In this study, we develop and use a bio-economic farm model to explore the contribution of land and labour saving technologies to development opportunities for smallholder farmers. We focus on a region with a high agro-ecological potential for crop production, the Manica Plateau, aiming at increased gross margin from agriculture and food security at farm level. These objectives are aligned with the PEDSA. The Manica plateau is of particular importance as maize is consumed locally and sold to southern Mozambique, which has a large population and low agricultural potential. The Manica Plateau also produces cash crops (sunflower and sesame) for national and international markets. We focus on maize-based smallholder farming systems in two districts, Gondola and Sussundenga, and multiple farm types to cover the existing biophysical and economic variation among farms.

2. Methods

2.1. Farming on Manica Plateau

We selected two administrative posts on the Manica plateau, Dombe (19.97º S and 33.39º E) in Sussundenga district and Zembe (19.295º S and 33.354º E) in Gondola district. These posts are located about 145 km and 25 km from Chimoio, a major market centre, respectively. Rain-fed agriculture, with rainfall distributed in a unimodal pattern between October and March, dominates the farming systems of the smallholder farmers. Dombe receives on average 930 mm rainfall annually and Zembe 880 mm (USGS/FEWSNET, 2011). The predominant soil types in Dombe are Eutric Fluvisols and Arenosols and in Zembe Ferric Acrisols and Haplic Lixisols (FAO-UNESCO, 1988). Due to the relatively better bio-physical conditions (soils and water), crop yields are higher in Dombe than in Zembe (Leonardo *et al.*, 2015).

In a previous study we categorised the farmers in both posts into four major groups based on the size of their cultivated area and access to labour. These groups are (1) large farms hiring in labour, (2) medium farms hiring in and hiring out labour, (3) small farms sharing labour and (4) small farms hiring out labour. These groups were essentially similar in both posts, but the farm size in each category was larger in Dombe than in Zembe. In this study we focus on the large farms (1) and the small farms hiring out labour (4) (Table 3.1) as they represent both sides of the spectrum. Our previous study (Leonardo et al., 2015) indicated that the farming systems in both posts were largely based on production of local maize varieties in relay-intercropping with an improved sunflower variety in Zembe and with a local sesame variety in Dombe. Only on the large farms in Dombe an improved sesame variety was cultivated as a sole crop, preferably in newly-opened fields. Cassava and sweet potatoes were cultivated on field margins and vegetables (pumpkins and cowpea leaves) scattered on the field, all for home consumption. Maize provided 83 % and 77 % of the household energy demand on average in Dombe and Zembe, respectively. In Dombe, all farm types achieved maize self-sufficiency, whereas in Zembe the small farms were not self-sufficient for maize. Most agricultural activities were done by hand. About 11% and 14% of the farmers in Dombe and Zembe, respectively, used animal traction for land preparation only. Farmers relied primarily on family labour.

On-farm measurements showed that maize yields were higher on large farms than on small farms in each post (Table 3.1). The sunflower yields were poor for both farm types. The sesame yields were slightly better on large farms than on small farms. Delayed weeding because of hiring out labour was a major reason for lower crop production on small farms. Large farms, however, were able to hire in labour, mainly from the small farms in the region. None of the farmers used fertilizers to increase crop yields. In both posts, all farmers fallowed 25 % of their land on average. Soil analysis showed that in both posts nitrogen was the most limiting nutrient for crop production (Leonardo et al., 2015). Livestock, dominated by village poultry, was a source of cash for basic household expenditures, such as transport and school fees. Chickens were not housed, limiting the availability of manure in crop production. Households owned very few cattle and goats. Cattle were mainly used for animal traction and transport. Off-farm activities such as petty trade and temporary or fulltime wage jobs were important components of farmers' livelihood strategies. Yet, income for daily basic expenditures was largely generated from maize, sunflower and sesame (Leonardo et al., 2015).

Table 3.1. Description of the two farm types in Zembe and Dombe based on a household survey and on-farm measurements (Source: Leonardo et al., 2015).

Sites		Dombe farm groups		Zembe farm groups	
Variables	Unit	Large	Small	Large	Small
Proportion of the total no households	%	24	15	17	23
Cultivated area	Ha	4.4	1.3	2.1	0.8
Fallow area	Ha	1.1	0.3	0.5	0.2
Maize yields	t ha^{-1}	2.3	1.5	2.0	1.1
Sunflower yields	t ha^{-1}	-	-	0.3	0.3
Sesame yields	t ha^{-1}	1.3	0.9	-	-
Household size	#	9.8	5.2	8.1	4.0
Household labourers	#	4.2	3.2	3.8	2.6
Land:labour ratio (LLR)[v]	ha $person^{-1}$	0.8	0.4	0.6	0.3
Hired labour in a farm	d y^{-1}	16	-	18	-

[v] LLR is calculated as the cultivated area over household labour, taking into account children < 12 year as 1/4 labourer and excluding hired labour.

2.2. Bio-economic farm model

We developed a bio-economic farm model, based on the generic structure of the Farm System Simulator Model (FSSIM V2; (Louhichi *et al.*, 2010). We incorporated the main objectives of smallholder farmers and national policy goals related to the farming systems in Dombe and Zembe and we formulated intensification and extensification options for an average farm representing each of the farm types. This reference farm was based on data as presented in Table 3.1 and reported by Leonardo et al. (2015). This allowed us to explore options to improve farm productivity of smallholder farmers related to resource availability. Our bio-economic farm model has three main components: (a) the farmers' objectives, (b) constraints related to resource availability and input use, and (c) production activities, which are the main decision variables and are defined as a combination of crops (sole crops or intercropped) and their management, such as the quantity of fertilizer used and weeding practices. The objectives and constraints are formulated as linear functions. The mathematical formulation of the model is given in Appendix 3.1.

2.2.1. Objective functions

We defined two objective functions. The first objective function is maximization of total gross margin. We opt for gross margin instead of farm income due to the lack of data for a full economic analysis for calculation of farm income. Total gross margin was defined as the total value of the products sold (maize, sunflower, sesame, soybean and pigeonpea) minus the variable costs. To account for seasonality in maize prices in both posts, we considered prices at harvesting, middle season and lean season (Leonardo et al., 2015). The variable costs included costs of seed, fertilizers, herbicides, hired animal traction, plant protection agents, inoculants for legumes and hired labour. Hired labour and animal traction were priced according to the local prices. Based on information provided by AGRIMERC ODS (Sustainable Development Organization for Agriculture and Markets; Gil Mucave, personal communication 2016), prices of improved seed, fertilizers, herbicides and inoculants in Dombe and Zembe were assumed to be 20 % and 10 % above the prices at the Chimoio market due to the distance to this market. The second objective was maximization of the amount of maize for sale. The amount of maize for sale was the total maize production minus the amount needed for home consumption. This objective is related to national policy goals for increasing maize production for the national food market (MINAG, 2011) and does not necessarily coincide with the individual objectives of the farmer. However, both objectives were formulated and explored at the farm level, as that is the unit for decision making.

2.2.2. Current and alternative production activities

In Dombe the current production activities were cultivation of a traditional open pollinated variety of maize, maize intercropped with sesame and sesame as sole crop (Table 3.2). In Zembe the activities were cultivation of a traditional open pollinated variety of maize as sole crop and intercropped with sunflower. The quantification of crop yields and labour requirements of current production activities was based on a detailed household survey and on-farm yield measurements. The information on labour (the main input) used in the current production activities was gathered through interviews with farmers and further distributed across the weeks accounting for seasonality (Leonardo et al., 2015).

Table 3.2. Crop yields in current and alternative production activities used in the exploration of development opportunities for smallholder farmers in Zembe and Dombe.

Type of activity	Crop	Management	Yield ($t\ ha^{-1}$) Dombe	Zembe
Current	Maize local variety[a]	Sole, no fertilizer	2.3	2.0
		Intercropped with sunflower, no fertilizer	-	2.0
		Intercropped with sesame, no fertilizer	1.9	-
	Sunflower improved variety[a]	Intercropped with maize, no fertilizer	-	0.3
	Sesame improved variety[a]	Sole, no fertilizer	1.3	-
		Intercropped with maize, no fertilizer	1.0	-
Alternative	Maize improved variety[b]	Sole no fertilizer	3.3	1.3
		Sole with NP fertilizer	4.8	2.4
		Sole with NK fertilizer	5.1	2.5
		Sole with PK fertilizer	3.0	1.8
		Sole with NPK fertilizer	5.5	3.6
	Sunflower improved variety[c]	Sole with NPK fertilizers	-	1.2
	Sesame improved variety[d]	Sole with NPK fertilizer	1.5	-
	Soybean improved variety[b]	Sole no fertilizer	0.8	0.8
		Sole with K fertilizer	1.0	1.0
		Sole with P fertilizer	1.0	1.0
		Sole with PK fertilizer	1.0	1.0
		Sole with PK fertilizer and inoculants	1.0	1.0
	Pigeonpea improved variety[e]	Intercropped with maize	0.5	0.5

[a] On-farm measurements (Leonardo et al., 2015).
[b] On-farm trials - cropping seasons (2010/11)
[c] IIAM-FAEF (2010)
[e] Mujaya and Yerokun (2003)
[d] Rusinamhodzi et al. (2012)

The alternative production activities were defined to alleviate (i) labour constraints by using animal traction, cultivators or herbicides, referred to as labour saving activities or extensification, and (ii) yield constraints by using improved varieties combined with fertilizer application and legumes crops, referred to as land saving activities or intensification (Table 3.3A). Animal traction was selected given that farmers are already using it, though currently only for land preparation. Herbicides are available at Chimoio market at relatively affordable prices. We did not consider tractors given the high associated costs. We assume that our explorations have a short time horizon and we do not expect that in period farms will be accumulate enough resources to use tractors.

Table 3.3. Alternative land and labour saving technologies and scenarios explored in Dombe and Zembe. Details of the fertilizer regimes are given in Table S3.1 and S3.2.

A. Options	**Description**
a. Labour saving	1. Ploughing using animal traction 2. Weeding using cultivators (incl. animal traction) 3. Weeding using herbicides
b. Land saving	1. Improved crop varieties; with and without fertilizer 2. Sole soybean ; with and without fertilizers and inoculants 3. Cultivation of maize-pigeonpea intercropping
B. Scenarios	
SC1 Current situation	Current farming practices with allowing changes in proportion of area allocated to each crop. It includes the current situation with (SCR1) and without (SC1) a constraint on hired labour
SC2 Labour saving	Current situation + labour saving options
SC3 Land saving	Current situation + land saving options
SC4 Combined improvement	Current situation + labour saving options + land saving options

The labour required for the alternative production activities using cultivators and fertilizers was based on (IIAM and FAEF, 2010) and that for herbicide application on expert knowledge. Animal traction for ploughing and weeding with cultivators is rented at same price for each activity. This includes the labour to manage the cattle.

For the alternative land saving production activities, we considered improved varieties of maize and soybean. The yield data for maize and soybean was derived from on-farm researcher managed fertilizer omission trials carried out over two consecutive cropping seasons, 2010/11 and 2011/12 (Appendix 3.2). We quantified the response to N, P and K. We used the data from season 2010/2011, because it had an average rainfall distribution whereas the season 2011/12 was dry. Mean yields from on-farm trial are presented in the Table 3.2.

The maize-pigeonpea yields and labour input were based on experiments conducted by Rusinamhodzi et al. (2012) on the Manica plateau in a nearby location, with maximum maize yields adapted to the maximum yields achieved in our fertilizer trials for sole maize. For fertilized sesame we used yield data and fertilizers rates from Zimbabwe (Mujaya and

Yerokun, 2003), and labour requirements from IIAM and FAEF (2010). We assumed that large and small farms can be equally efficient in converting inputs into outputs, and they differ only in resource endowments. Detailed information on specific input-output coefficients that correspond to different production activities in Dombe and Zembe is presented in the Tables S3.1 and S3.2 respectively. Table S3.3 shows the input and output prices used in the simulations.

2.2.3. Constraints

The objectives were optimized subject to a set of constraints related to available resources and farm household needs. The available land constraint restricts the total land used by offered production activities to the total available land (Table 3.1). The labour constraints restrict the total labour input to the available household labour and the hired labour for each weekly period. Additional hired labour comes at a cost of $ 2.8 per day. Available family labour was estimated for each period based on interviews with farmers.

A food self-sufficiency constraint for all products was introduced in the model. However, in this specific case, self-suffiency was only relevant for maize as the other crops were exclusively cultivated for sale. The self-sufficiency constrain ensures that the quantity of maize produced at least covers the household energy needs. We assumed that maize should provide 85 % of the daily energy requirements in both posts and the remainder is covered by the other crops grown for home consumption. The per capita energy requirement for men was set to 2780 kcal per day, for women 2235 to kcal per day, and for children (6-11 years) to 2038 kcal per day (WHO, 1985).

Each week, sufficient cash to cover the basic household expenditures on milling, soap, salt and oil has to be available. We assumed that these basic expenditures were covered by selling crops, and they were set to a fixed value over the months, given the small fluctuations between weeks. In Dombe the expenditures were fixed at $ 1.4 for large farms and at $ 1.0 for small farms and in Zembe at $ 2.9 for large farms and $ 1.2 for small farms, based on our interviews with farmers. Therefore, the total gross margin should at least cover the total expenditures. We used an exchange rate of 1 Mt to US$ 0.035 (www.oanda.com; August 9, 2013).

2.3. Calculation of trade-offs and scenario description

The model was used to calculate the trade-offs between economic and food security objectives for both farm types. To assess the impacts of intensification and extensification options on gross margin and maize sales, we defined four scenarios (Table 3.3B).

SC1: In the *current situation* scenario we considered only production activities that are currently used in each post. The main objective is to identify optimal management practices based on currently available resources, i.e. land and labour. The hired labour was first restricted to the observed level, scenario SC1-R. Subsequently, this constrained was removed, scenario SC1.

SC2: In the *labour saving* scenario the production activities for reducing labour input per ha were added to the current situation scenario.

SC3: In the *land saving* scenario the production activities for increasing yields per ha and legume crops were added to the current situation scenario.

SC4: In the *combined improvement* scenario all possible combinations of labour saving and land saving production activities were added to the current situation.

For each of the four scenarios we calculated the trade-off between gross margin and maize sales. To quantify the trade-offs at farm level we calculated the optimal value of each objective separately without imposing restrictions on the other objective. For each objective we identified its maximum value (best value) and its value with the other objective at its maximum (worst value). Then we iteratively optimized one objective for different values of the other objective within the range set by the worst and best value (ε-constraint method; (Mavrotas, 2009). The model outcomes of each scenario were compared with the current situation.

2.4. Influence of resource availability

In Dombe and Zembe land is available to increase the currently cultivated area and farmers can acquire additional land through local mechanisms (Leonardo et al. 2015). The high unemployment rate in Mozambique (Jones and Tarp, 2012) offers opportunities to hire labour for agricultural activities either locally or from the vicinity of the two posts. Therefore, we explored the opportunity for both large and small farms to expand their land beyond the current farm area and to hire additional labour, both in Dombe and Zembe. We maximized gross margin iteratively with relaxing the constraints on available land (from 1 to 50 ha) and hired labour (from 1 to 50 man-days per week) (constrains 4 and 9, Appendix 3.1). We did not account for changes in the labour market and changes in prices of inputs and outputs if farms increase in size.

Given that inorganic fertilizer and seed prices were high for smallholder farms in Mozambique and policy aims at increasing input (MINAG, 2011), we explored the effect of subsidies on improved seed and fertilizers on land use for both large and small farms. We focused on labour saving and land saving technologies being available, but with constraints on hired labour at the current level, as this represent the situation to which subsidies in Mozambique apply. We stepwise increased the subsidies on seed and fertilizers by 10 % of the current input prices. Hence we explored the range from no subsidies up to 100 % of the input prices subsidized.

A sensitivity analysis was done to quantify the sensitivity of the outcome values to pigeonpea and labour prices. For pigeonpea we explored prices increasing and decreasing by 10, 30 and 50%. For labour we only considered the increasing on price by 10, 30 and 50%, as current labour prices are very low. However, the analysis showed little impact on the outcomes.

3. Results

In this section we first present the synergies or trade-offs between gross margin and maize production for the large and small farms in each post for the four scenarios. Secondly, we present the cropping patterns at both maximum gross margin and maximum maize sales. Finally, we present results of the influence of available farm resources land and labour on gross margin.

3.1. Trade-offs between gross margin and maize sales at farm level

3.1.1. Dombe

The large reference farm had a gross margin of $ 2830 and a maize production of 7.7 t. The quantity of maize required to meet household needs over a year was 1.1 t, with 6.6 t remaining for sale. With a constraint on hired labour to current amounts (SC1-R), the maximum gross margin was \$ 3210 per farm with a maize for sale of 7.5 t. Maximizing maize sales gave the same result, implying no trade-offs existed between both objectives (Fig. 3.1a). Without a constraint on hiring labour, the current situation (SC1), showed a substantial increase in both gross margin and maize for sale (Fig. 3.1a): a maximum gross margin of \$ 5550 per farm combined with maize sales of 5.2 t and maximum sales of 12.4 t per farm combined with a gross margin of \$ 1890. The labour saving scenario (SC2), only showed a slightly larger maximum gross margin of \$ 5835 per farm combined with a maize sales of 7.4 t. In both scenarios, maximizing gross margin while increasing maize sales up to 10 t per farm, cost about \$ 85 t^{-1} of extra maize. A further increase of maize sales up to the maximum cost \$ 600 t^{-1}. The land saving (SC3) and the combined improvement scenario (SC4) showed a substantially larger maximum gross margin (\$ 7530) and maximum maize sales (30.4 t). Maximum maize sales were achieved with a decrease in gross margin, of about \$11 per ton of extra maize.

The small reference farm had a gross margin of \$ 580 and maize production of 2.2 t (Fig. 3.1b). The quantity of shelled maize required to meet the household needs over a year was 1.2 t, leaving 1.0 t for sale. With a constraint on hired labour, (SC1-R), maximum gross margin was \$ 1390 per farm combined with maize sales of 3.0 t. Maximizing maize production had hardly any impact, as maize sales were only increased by 0.1 t with a decrease in gross margin of \$ 30 (Fig. 3.1b). Similar to large farms, the current situation (SC1) and labour saving scenario (SC2) showed both a larger gross margin and a larger amount of maize for sale (Fig. 3.1b). The maximum gross margin was \$ 1820 per farm for the current situation and \$ 1850 per farm for the labour saving scenario both combined with maize sales of 3.0 t. In both scenarios, maximum maize sales were 3.7 t per farm, combined with a gross margin of \$ 655, i.e. a cost of about \$ 1810 per ton extra maize production (0.7 ton extra maize reduces the gross margin by about \$ 1280). The land saving (SC3) and combined improvement scenario (SC4) both showed a higher gross margin of \$ 2390 per farm and a maize sale of 9 t. Contrary to the results observed with large farms, no trade-off between the two objectives was observed.

3.1.2. Zembe

The large reference farm had a gross margin of \$ 875 and maize production of 4.1 t per farm (Fig. 3.1c). The quantity of shelled maize required to meet household need over a year was 0.9 t, 3.2 t remaining for sale. With the restriction on hired labour (SC1-R), the maximum gross margin was \$1130 and maximum maize sales were 5.1 t per farm. The current scenario without a constraint on hired labour (SC1), and the labour saving scenario (SC2) had both the same maximum maize sales as in the scenario with hired labour restriction (SC1-R). However, the gross margin was a slightly higher in the labour saving scenario (\$1220 per farm). No trade-off was observed between maximizing gross margin and maximizing maize sales. Allowing the use of improved varieties in combination with fertilizers (SC3), the maximum gross margin was \$ 2390 per farm combined with a maize sales of 9.2 t. Maximizing maize sales, i.e., an increase up to 9.5 t per farm, decreased the gross margin by only \$ 9 in total. The combined improvement scenario (SC4) had similar impact as the land saving scenario, but only with a slightly larger gross margin of \$ 2410 per farm.

The small reference farm had a gross margin of \$ 175 and maize production of 0.8 t per farm (Fig. 3.1d). The quantity of shelled maize required to meet household need over a year was 0.9 t, indicating a maize deficit of 0.1 t. However, all the scenarios increased both gross margin and amount of maize for sale of small farms. Contrary to large farms, the same outcome was observed for all of the scenarios with SC-R, SC1 and SC2 giving the same solution and SC3 and SC4 also giving the same outcome.

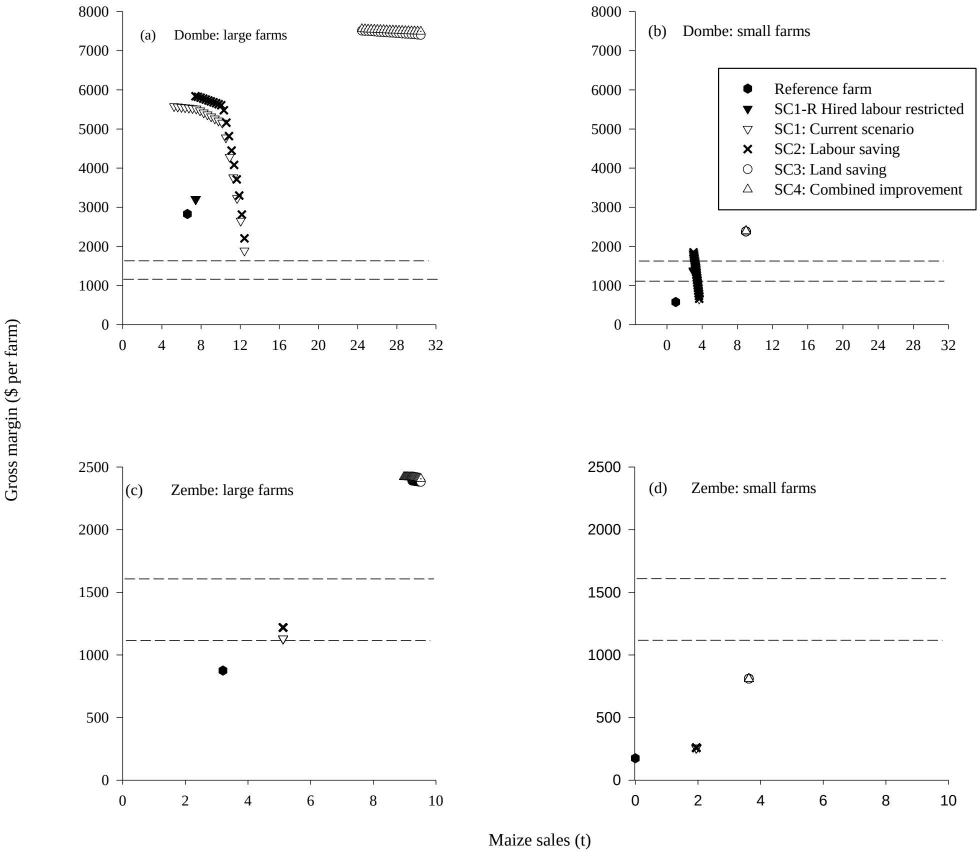

Figure 3.1. Trade-offs between gross margin and maize production for large and small farms in Dombe and in Zembe. The lower dotted line indicates the annual minimum wage in the agricultural sector of Mozambique. The upper dotted line is the average gross margin derived from other economic activities such as fishing, the public sector and the health sector in Mozambique. For the legend see small farms in Dombe

3.2. Cropping pattern and crop management

3.2.1. Dombe

The cropping pattern of the large reference farm in Dombe comprised 3.4 ha of maize and 1.0 ha of sole sesame (Fig. 3.2a). So, with a farm size of 5.5 ha, 1.1 ha of land was left fallow. With a constraint on hired labour (SC1-R), large farms cultivated 3.3 ha with sole maize and 1.7 ha with sole sesame, leaving 0.5 ha fallow. Without a restriction on hired labour, (SC1), all land was cultivated. To maximize gross margin, 2.8 ha was cultivated with maize-sesame and 2.7 ha with sole sesame. To maximize the amount of maize for sale, all available land was cultivated with sole maize. Offering labour saving technologies (SC2), maximum gross margin was achieved with 4.0 ha of maize-sesame intercrop and 1.5 ha of sole sesame. Herbicides were used to remove weeds on 2.0 ha of the maize-sesame and on the sole sesame fields. Maximum maize sales were achieved by cultivating only maize and herbicides were used on about half of the available land (2.8 ha). Animal traction was not selected by the model. In the land saving scenario (SC3), maximum gross margin was achieved with intercropping maize and pigeonpea on 4.4 ha and sole sesame on 1.1 ha, with land preparation and weeding according to current practice, using a hand-hoe. To maximize maize sales the best option was to intercrop maize and pigeonpea on all of the available land. Combining land saving with labour saving (SC4), resulted in the same cropping pattern as in the land saving scenario. To maximize gross margin, the large farms used animal traction to plough 1.1 out of the 4.4 ha for maize-pigeonpea. The remaining land (1.1 ha) was cropped with sole sesame according to current practice. To maximize maize sales, animal traction was used to plough 2.2 ha for maize-pigeonpea.

For the small reference farm, the cropping pattern was 0.9 ha of sole maize and 0.4 ha of maize-sesame (Fig. 3.2b). Restricting the hired labour to the observed level (SC1-R), the small farms cultivated 0.7 ha with sole maize and 0.9 ha with maize-sesame to maximize gross margin and all available land to sole maize to maximize maize sales. So all land was cultivated. Offering the possibility to hire as much labour as needed (SC1), small farms intercropped all available land (1.6 ha) with maize and sesame when maximizing gross margin, and sole maize to maximize maize sales. Offering labour saving technologies (SC2), the best option to maximize gross margin was to intercrop maize and sesame on all available land, with 1.4 ha cultivated using current technologies, and using herbicides on 0.2 ha of land. To maximize maize sales, small farms allocated all available land to sole maize. Animal traction was used for ploughing on 0.3 ha of land. For the land saving scenario (SC3), the best option to maximize both gross margin and maize sales was to intercrop maize and pigeonpea on all available land using improved varieties, with all cropping activities done using a hand-hoe. Combining land saving with labour saving (SC4), resulted in the same cropping pattern as in the land saving scenario.

3.2.2. Zembe

The observed cropping pattern of the large reference farm in Zembe comprised 0.7 ha of sole maize, 1.4 ha maize-sunflower intercropping and 0.5 ha was left fallow (Fig. 3.2c). With and without a constraint on hired labour (SC1-R), (SC1) and offering labour saving technologies, all available land (2.6 ha) was cultivated with maize and sunflower intercropping both for maximum gross margin and maximum maize sales. In SC1-R and SC1 current technologies were used and in in labour saving scenario (SC2), animal traction was used for ploughing 0.9 ha and herbicides were applied on 0.8 ha. In the land saving scenario (SC3), large farms responded by allocating most of the available land to maize-pigeonpea (2.5 ha) intercropping to maximize both gross margin and maize sales. Only 0.1 ha of soybean was cultivated with fertilizers (K) when gross margin was maximized. We observed the same cropping pattern in the combined improvement scenario (SC4). However, 0.5 ha was ploughed with animal traction. To maximize maize sales, maize-pigeonpea intercropped on all available land was the best option, and about the same land area (0.6 ha) was ploughed with animal traction.

The small reference farms allocated half of the total cultivated land (0.8 ha) to sole maize, the other half to maize-sunflower intercroping and 0.2 ha was left fallow (Fig. 3.2d). With a restriction on hired labour in the current situation (SC1-R), small farms cultivated all their land, 1.0 ha. To maximize both gross margin and maize sales, these farms intercropped maize with sunflower. The same activities were selected in the current situation (SC1) and in labour saving scenario (SC2), indicating that the current available labour was enough to cultivate all available land and perform farm operations in a timely fashion using current technologies. In the land saving scenario (SC3), however, small farms responded by intercropping maize with pigeonpea on all available land, at both maximum gross margin and maximum maize sales. The impact of combined improvement options, labour and labour saving (SC4), was similar to the land saving options at both maximum gross margin and maximum maize sales. Contrary to large farms, animal traction was not selected.

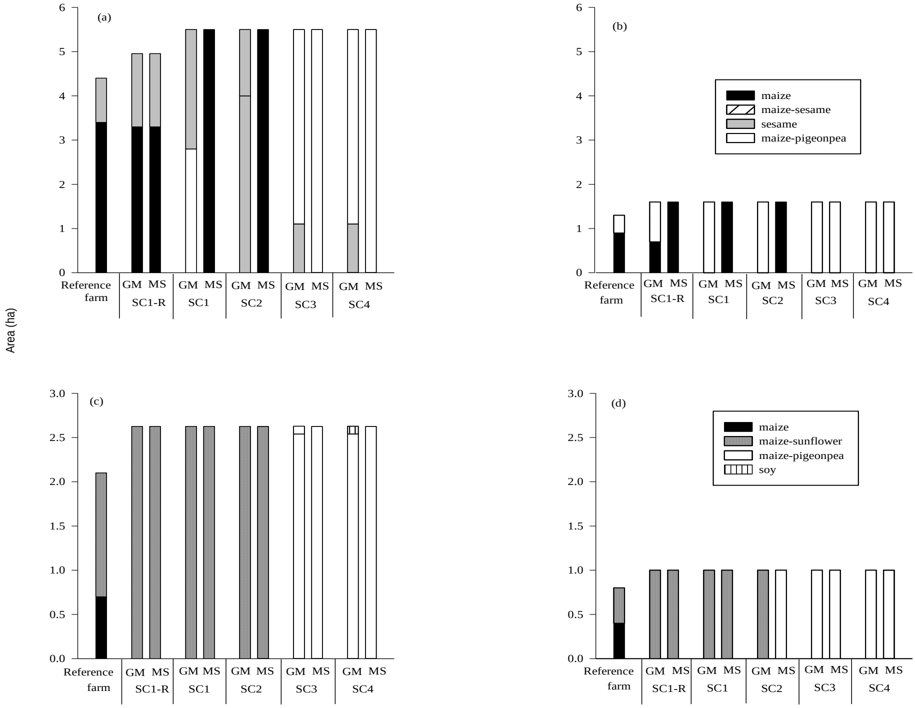

Figure 3.2. Cropping patterns for a reference farm and the five scenarios, at maximum gross margin (GM) and maximum maize production (MP) for large and small farms in Dombe (a-b) and in Zembe (c-d). SC1-R = current situation with hired labour restricted to observed level; SC1=current situation; SC2=labour saving; SC3= land saving; SC4= combined improvement

3.3. Influence of land and labour on gross margin

In our previous study (Leonardo et al., 2015) we highlighted labour as constraining crop production in both posts, especially during key periods of crop cycle such as weeding. Yet, when labour and land saving options were offered, a further increase on gross margin was limited by current cultivated area. Therefore, we explored the impact on gross margin due to the increase of land and labour availability at farm level, for both large and small farms. We focus on gross margin as this is the farmer's objective whereas the national objective is to maximize maize sales. While all scenarios showed improvement on gross margin compared with current situation scenario (SC1), we restricted our exploration to the scenario with combined improvement (SC4) as this scenario showed highest gross margin and maize sales for large and small farms in both Dombe and Zembe.

3.3.1. Dombe

Limiting the hired labour to one man-day per week, large farms in Dombe achieved a maximum gross margin of $ 8990 and cultivated 9.7 ha of land (Fig. 3.3a). They allocated 4.0 ha of the area to sole sesame, 2.7 ha to sole maize, 2.0 ha to maize-pigeonpea and 1.0 ha to soybean. About half of the land (4.9 ha) was ploughed with animal traction. Herbicides were only used on maize fields (2. 7 ha). Offering 50 man-days of hired labour per week, large farms achieved a maximum gross margin of $18 680 per farm, for which they cultivated 22.7 ha out of the 50 ha available. They allocated 40 % of their land to sole sesame, 29 % to sole maize, 18 % to maize-pigeonpea intercropping and 13% to soybean. The area ploughed with animal traction was 6.5 ha. Herbicides were used to weed 5.6 ha of sole sesame and all area allocated to maize and soybean. Fertilizer was used on 1.8 ha of sole sesame and 2.9 ha of soybean.

For small farms, hiring one-man days per week allowed them to achieve a maximum gross margin of $ 5950 and cultivated 7.0 ha of land (Fig. 3.3b). Contrary to large farms, hiring two man-days per week, increased both cultivated area by 1.0 ha and gross margin by $ 215. When small farms were allowed to hire 50 man-days of labour, a maximum gross margin of $ 15 610 per farm was achieved by cultivating 19.6 ha. The cropping pattern at 50 man-days hired labour was the same as for the large farms.

3.3.2. Zembe

Offering a maximum of one man-day per week of hired labour, large farms had a maximum gross margin of $ 2570 and cultivated 5.0 ha (Fig. 3.3c). At the maximum gross margin these farms allocated 2.6 ha to maize-sunflower, 1.0 ha to maize-pigeonpea and 0.7 ha to soybean. All land allocated to maize-sunflower was weeded with herbicides, with 1.0 ha ploughed with animal traction. Only 0.1 ha of soybean was ploughed using animal traction. To further increase the cultivated area from 5.0 to 6.0 ha, large farms had to hire seven man-days per week. Hiring 50 man-days per week, large farms had a gross margin of $ 6790 and cultivated about 15 ha of land where they allocated 9.3 ha to maize-sunflower, 3.0 ha to maize-pigeonpea and 2.6 ha to soybean. Herbicides were used to weed all area allocated to maize-sunflower plus 0.6 ha of soybean. Animal traction for ploughing was used on 4.8 ha, from which 3.2 ha were cultivated with maize-sunflower.

The cropping pattern of large and small farms was the same (Fig. 3.3d). They allocated 62 % of their land to maize-sunflower, 20 % to maize-pigeonpea intercropping and 17 % to sole soybean. To maximize gross margin, intercropping maize with sunflower using animal traction to plough half of the area and herbicides to weed the whole area were selected. One out of the three hectares was allocated to maize-pigeonpea was ploughed with animal traction. The sole soybean was cultivated using a hand-hoe and weeded with herbicides. Contrary to Dombe, the yield increase on soybean due to K-fertilizer was too small to off-set the cost of fertilizer, therefore, fertilizers was not attractive option.

3.4. Influence of prices on model results

3.4.1. Subsidies on seed and fertilizers prices

In Dombe, without subsidy on improved seed and fertilizers, large farmers invested 250 $ y^{-1} per farm in the combined improvement scenario with constraint on hired labour (SC4-R) (Fig. 3.4). Fertilizers was applied on 0.08 ha of sole sesame and 0.04 ha of sole soybean. The larger part of the investment was on improved seed of maize and pigeongea to cultivate 3.2 ha. Only with a 50 % subsidy on the current prices, the investment on seed and fertilizers increased. The additional fertilizer was applied to sole sesame (0.8 ha). Applying fertilizers on maize only became attractive at 90 and 100 % subsidy. At 100 % subsidy, large farmers used fertilizers on 0.5 ha of sole maize and 1.3 ha of sole sesame, so this is still only at 1.8 out of the 5.5 ha cultivated. The gross margin increased 1 from 7325 $ y^{-1} without subsidy up to 7965 $ y^{-1} per farm at 100 % subsidy. The further increase of gross margin was limited by labour availablity during the first weeding of maize.

The small farmers used 110 $ y^{-1} per farm to buy improved seed of maize and pigeonpea. All land was is maize-pigeonpea intercropping and that requires no fertilizer in this study. Hence, the gross margin increased by 110 $ y^{-1} from 2380 $ y^{-1} without subsidy up to 2490 $ y^{-1} per farm at 100 % subsidy.

In Zembe, without subsidy on the prices of improved seed and fertilizers, larger farmers invested 170 \$ y^{-1} per farm in the combined improvement scenario with current labour restrictions (SC4-R) (Fig. 3.4). The fertilizers were used on 0.08 ha of sole soybean. Investing in seed and fertilizer only became attractive at subsidies above 80 %. Offering a 90 % subsidy, fertilizers were applied to 0.4 ha of sole maize and 0.04 ha of soybean. A further increase in subsidy up to 100 %, slighltly increased the area of sole maize up 0.5 ha, but reduced the area of soybean by half. The gross margin of large farms increased from 2410 \$ y^{-1} without subsidy up to 2630 \$ y^{-1} per farm at 100 % subsidy. Contrary to large farms in Dombe, a further increase on gross margin was limited by land availability in the farm. Similarly to Dombe, smaller farmers only spent money on improved seed of maize and pigeonpea. The gross margin increased from 810 \$ y^{-1} without subsidy up to 870 \$ y^{-1} per farm at 100 % subsidy.

3.4.2. Prices of pigeonpea and labour

Changing the price of pigeonpea had only little influence on the results, as yields in the intercropping system with maize were low: 0.5 t ha^{-1} while maize yielded 5.5 t ha^{-1}. The changes in price of labour also hardly influnced the results, as it only refered to hired labour. The results are presented in Appendix 2, Figs 5 and 6.

4. Discussion

The current policy discourse in SSA, including Mozambique, is that intensifying land use by using improved crop varieties, appropriate fertilizer and other good agricultural practices can sustainably increase income and contribute to food security the for majority of smallholder farms (AGRA, 2015a). This study explores both extensification and intensification options of smallholder farms in Dombe and Zembe, on the Manica plateau.

Vanlauwe et al. (2014) proposed that in order to achieve sustainable development we need to acknowledge the diversity in agro-ecological conditions, farm household endowment and farming systems, a suggestion confirmed by our study. The model outcomes show that in both posts and on both large and small farms using the best available technologies, both gross margin and maize sales were improved compared with the respective reference farms.

The relatively better agro-ecological conditions for crop production in Dombe compared with Zembe (Leonardo et al., 2015) strongly influence the development possibilities through extensification and intensification of crop production. For instance, the maximum gross margin and the maximum maize sales of large farms across all scenarios in Dombe was more than three times of that in Zembe. Small farms gave a similar picture. In each post, large farms show larger improvements compared with small farms as a results of higher land and labour availability. These results are in agreement with other studies showing that development opportunities of smallholder farms are affected by resource availability at farm level (Dogliotti *et al.*, 2006; Tittonell *et al.*, 2007).

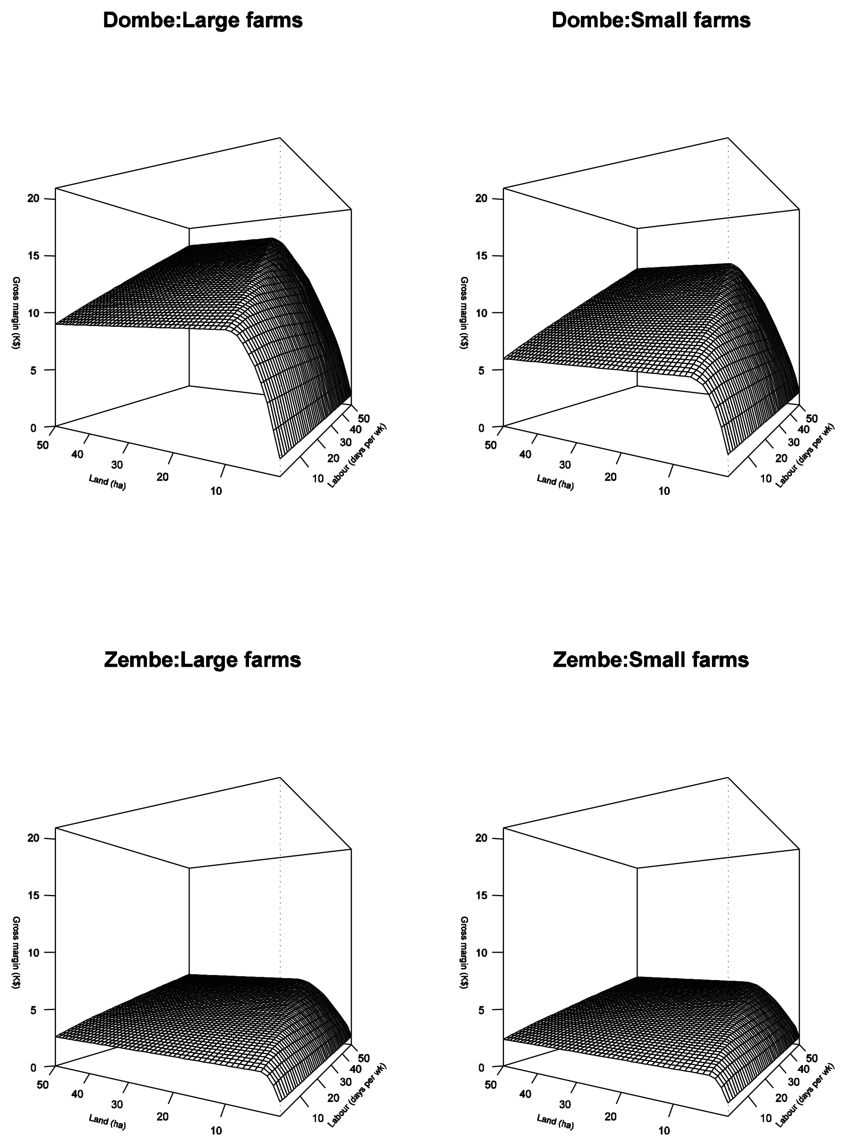

Figure 3.3. The relation between land and hired labour availability on gross margin of large and small farms in Dombe and Zembe

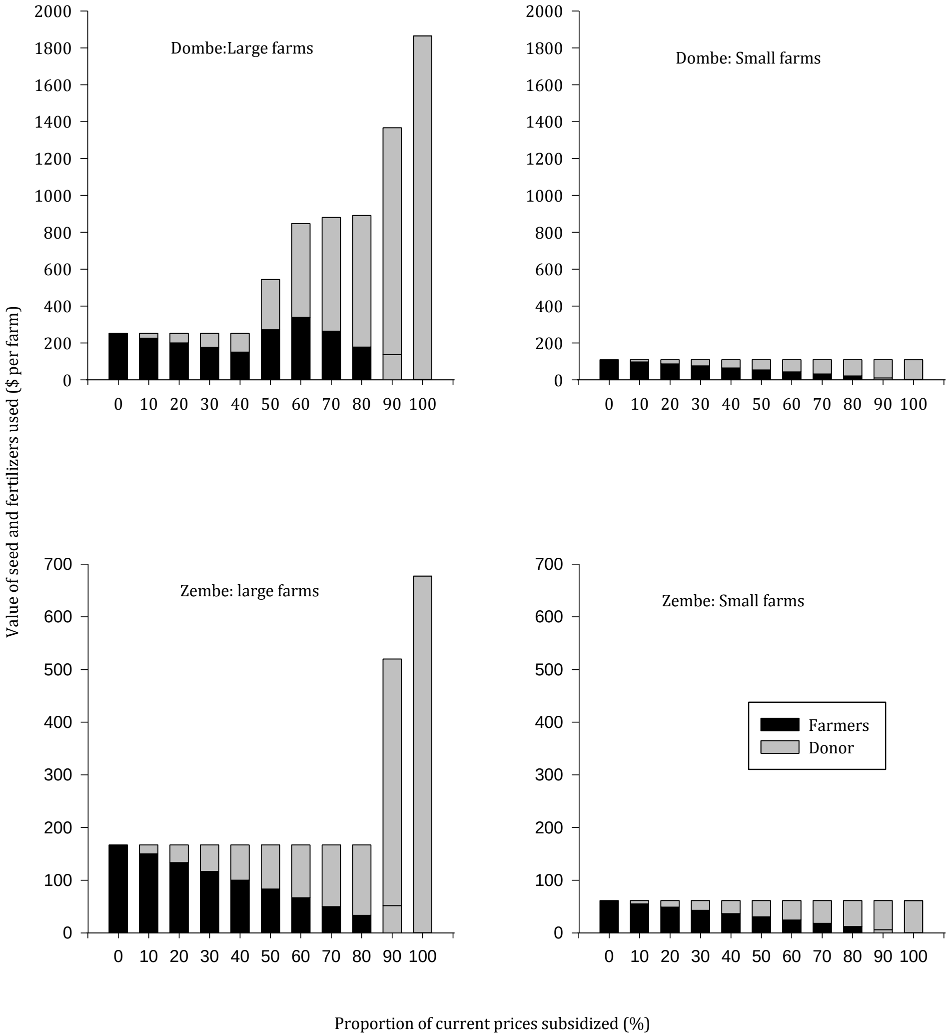

Fig. 3.4. Influence of subsiding seed and fertilizers on total share between farmers and donors for large and small farms in Dombe and Zembe at different subsidy levels

The labour saving options representing extensification pathways revealed strong trade-off between maximum gross margin and maize sales in Dombe but synergies in Zembe (Figs 3.1a-d). This is explained by the fact that in Dombe sesame is more profitable than maize. Farmers allocate more land to sesame to maximize gross margin, decreasing maize sales. In

Zembe, the sunflower price is relatively higher than maize price, but the sunflower yields when intercropped with maize are smaller (Table S3.2) off-setting the benefits of higher price. Therefore, maize in Zembe provides more gross margin than sunflower. Growing sunflower as sole crop, gives higher yield, but the profitability is less than maize-sunflower intercropping due to fertilizer costs (Table S3.2).

In general, the labour saving options, scenario (SC2), showed little impact when compared with scenario SC1. Particularly, cultivators for weeding, are not economically attractive due to the relatively high cost of renting animal traction, \$ 175 ha^{-1} (Table S3.3). Herbicides are cheaper, required less labour per hectare and were therefore selected by both farm types. For large and small farms in Zembe, the use of animal traction, herbicides and cultivators do not increase either gross margin or maize sales. In particular for small farms, the gross margin remains below the annual income of \$1110 that a farmer could earn by engaging in off-farm agriculture-related activities. The low gross margin is explained by the relatively small land area given that labour saving does not increase crop yield. Although the land saving options, scenario (SC3), substantially increased both gross margin and maize sales (Fig. 3.1), and showed the same cropping pattern (Fig. 3.2) as in the combined improvement (scenario SC4), more labour was hired in the scenario SC3 (164 man days versus 115 man days) at cost of \$ 2.8 per day. This explain the slightly lower gross margin in the scenario SC3 compared with scenario SC4. As such, in both posts, the most promising alternative to maximize gross margin and maize sales, is intercropping maize with pigeonpea using improved varieties in combination with labour saving options (scenario SC4), for both large and small farms. Given that maize yields are maintained, for both large and small farms, intercropping of maize with pigeonpea does not lead to any conflicts between maximum gross margin and maximum maize sales.

Although sesame has a higher gross margin than pigeonpea, maize yield for maize-pigeonpea intercropping is 2.6 times higher than that of maize-sesame intercropping: as such it off-sets the benefits of the higher sesame price. In the maize-pigeonpea intercropping systems, maize benefits from N2 biologically fixed by pigeonpea. So, fertilizer is not used contributing to lower cost. The yield of sole sesame is high, however, because of the self-sufficiency and expenditure constraints (constraints 6 and 7, Appendix 3.1), which make sure that maize self-sufficiency and daily expenditures have to be met at all periods from own production, sole sesame is not selected. Sesame is only sold between August and November, which further limits cash availability.

4.1. Influence of labour and land saving options on gross margin

In exploring the impact of more resource availability at farm level, we assumed that both large and small farms in each of the post have the same opportunities at their disposal and only their household size which determines food self-sufficiency requirements and household labour availability (determines labour costs) differ. This explains the same shape of the Figure 3.3a-d as well as the maximum value of gross margin achieved by each farm type.

In Dombe, increasing the land and labour availability at farm level, farms respond by combining both extensification and intensification options. Larger land areas are allocated to sole crops, i.e., sesame and maize, compared to that allocated to maize-pigeonpea.

While in Zembe we observe the same trends as in Dombe, larger areas are allocated to intercrops, maize-sunflower and maize-pigeonpea, rather than sole crops. The large area allocated to maize in Dombe combined with maize yield when gross margin is maximized indicates that Dombe has better prospects to address the national objective of producing more food for the national market compared with Zembe. Thus in Dombe both farmers´ and national objectives are achieved.

The results of our study of increasing resource availability should be interpreted with care. First, we did not account for changes in farm structures that might occur if farm area increases due to more labour availability. It is possible that constraints currently faced by small farms, for instance, may no longer be valid when farm size increases up to 15 ha. Farmers are dynamic and have changing aspirations. Therefore, to see these results as applicable for a short time horizons, e.g. five years, seems to be more realistic than for the long term. In addition, both large and small farms were assumed to be equally efficient in converting inputs into outputs, and to differ only in resource endowments.

4.2. Influence of subsidies on seed and fertilizers on land use

Under the current constraints on labour, a subsidy on seed and fertilizer below 50 % of the current prices, resulted mainly in purchases of improved seed rather than fertilizer purchases or both. The most remunerative production activity was maize-pigeonpea. As mentioned earlier, in the maize-pigeonpea intercropping, maize benefits from N_2 biologically fixed by pigeonpea. So we only accounted for the costs of seeds. Although at 100 % subsidy cultivating maize with fertilizers gives a similar gross margin as maize intercropped with pigeonpea (Tables S3.1 and S3.2), the intercropping systems also yields pigeonpea. In addition, fertilized maize requires labour to apply the fertilizers. So, maize-pigeonpea intercropping remains more profitable than sole maize. The Government of Mozambique and partners such as FAO have been implementing agro-input subsidy program targeting two groups of beneficiaries, namely, subsistence farmers and small emerging farmers (http://www.fao.org/mozambique/programmes-and-projects/success-stories/electronic-voucher/en/). The first group can be seen as less resourceful farmers (small farms in my typology) and the second group the more resourceful farmers (large farms in my typology). The subsidy is divided into two packages 1) 57% subsidy improved seed, fertilizers and chemical for better resourced farmers; 2) 75 % subsidy on improved seed and chemical for less resourced farmers). The target crops are maize, cowpeas, beans and soybean. This study shows that at 50 or 60 % subsidy, fertilizers are not attractive for farmers. We did not simulate the effect of subsidies on cowpea and beans, but it less likely that farmers will use fertilizers on these legume crops. In addition pigeonpea is more profitable than cowpea and beans. To promote pigeonpea Government and development organizations should ensure seed of good varieties is available together with a functioning market for the produce. It is important that farmers are trained on best crop management such as optimal panting dates, plant density and other risks management strategies such as maize-pigeonpea intercropping.

4.3. Implications for regional food production

The land saving and combined improvement options show greater increase in maize production compared with labour saving options, contributing positively for food availability in the region. While the picture emerging from the explored scenarios pointed at improvement of gross margin and food production especially for large farms, these farms are not currently practicing the proposed production activities. Smallholder farmers are risk-averse which may prevent them to invest on improved technologies such as fertilizers (Hansen, 2005). Whether farms will decide to maximize gross margin or maize sales, or for the compromise between the two objectives will largely be determined by their aspirations (Dorward *et al.*, 2009), enabling environments such as policy incentives for productivity increase (Vanlauwe *et al.*, 2014) such as a well-designed input subsidy programme for seed, fertilizer and agro-chemical, and supporting services to link them to end market (Poulton *et al.*, 2010). Training and advisory services on best crop management such as planting densities, planting time are important aspects to be considered, especially for poorer farms (small farms) (Roxburgh and Rodriguez, 2016).

The trade-offs presented here were based on an in depth farming systems analysis, participatory research and optimization approaches. These trade-offs should be seen as entry point for discussion among policy makers, farmers and other stakeholders in implementation of appropriate alternative approaches for long-term improvement of smallholder farming.

5. Conclusion

This study explores how a diversity of farm types in different agro-ecological conditions respond to different combinations of current and alternative activities to increase gross margin and food security. Results reveal that that intensification options increased both gross margin and food production at farm level, while the extensification options have more impact on increasing gross margin. The resource endowments of the farms as well as the agricultural potential influence the possibilities for development in the Manica Plateau. The prospects for increasing gross margin and food production are much better for large farms in Dombe compared with other farms. The effects of subsidies on seed and fertilizers show that subsidies support the use of improved seed rather than fertilizers. In particular for smaller farms, subsidies contribute positively to gross margin by reducing the costs of seed. For small farms fertilizers are not attractive even at very optimistic scenario of 100 % subsidies. Therefore, under current constraints on land and labour, farming their own fields cannot lift small farmers out of poverty. For these farmers, options for development may depend on earning income through employment in other cash yielding on-farm activities, or off-farm activities.

Our results are based on a number of assumptions such as no change in the labour market or input prices. In reality, when labour availability becomes limiting, pay rates are expected to rise or if more maize is available prices tend to fall. Our results should be seen as a contribution for policy makers and development practitioners to better frame interventions depending on smallholder settings rather than recipes for agricultural development in Mozambique.

Acknowledgements

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Which smallholder farmers benefit most from biomass production for food and biofuel? The case of Gondola District, central Mozambique

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Abstract

We analysed the influence of the mode of participation in biomass production for biofuels on food security of different farm types. We studied two modes of participation in biomass production: an outgrower scheme for sunflower and a jatropha plantation offering full time employment and assessed the four dimensions of food security: availability, access, stability and utilization in smallholder farms in Central Mozambique. We interviewed 80 households who were participating in the sunflower outgrower scheme, had a household member working on the jatropha plantation or were not participating with biofuel production. For each household we quantified four indicators: maize sales minus purchases, gross revenue, revenue diversity, and household dietary diversity scores. Involvement of smallholder farmers with biomass production for fuel had a positive or no impact on the four dimensions of food security at the farm level. Positive food security impacts from working on the biofuel plantation were improvements in availability for the larger farms and improvements in access for the smaller farms. Utilization of food was generally not impacted. Impacts on food security from the sunflower outgrower scheme were minor. There is scope to improve the outgrower scheme with services and inputs that increase sunflower yields and give positive spill-overs to other crops.

Key words: Food availability, access to food, food stability, utilization of food, farm types, outgrower, employment

1. Introduction

Global demand for biomass for food and feed is increasing rapidly due to population growth (Godfray *et al.*, 2010; Koning and Van Ittersum, 2009) and increased welfare (Delgado, 2003). Concern about climate change and the need for energy independence has further increased the demand for biomass (Rulli *et al.*, 2013). The quest for alternative energy sources has placed biofuel on the top of agendas of many national and multi-national government bodies (German and Schoneveld, 2012). Mozambique is seen as an important potential producer of biomass for biofuel (hereafter referred to as biofuel) due to its relative abundance of land and favourable agro-climatic conditions for production of biomass (Batidzirai *et al.*, 2006; Arndt *et al.*, 2008). By 2008 the request for land for biofuel production in Mozambique was estimated at about 12 million hectares (Arndt *et al.*, 2008). In 2009, the Mozambican biofuel policy was approved, highlighting the government's commitment in exploring opportunities for economic development for rural communities offered by increasing global biofuel demands (Moçambique, 2009).

In Mozambique approximately 70 % of the population live in rural areas with smallholder farming providing their main source of food and income (MINAG, 2008a) and, 55 % of the population live below the poverty threshold of 0.50 $ per day (Moçambique, 2011). The PEDSA (strategic plan for agricultural development) emphasizes food security and rural incomes as main policy objectives (MINAG, 2011). However, the same resources used to produce food, e.g. land and labour, are needed to produce biomass for biofuel. This highlights the potential conflict between food security and increase biofuel production (Van Eijck *et al.*, 2014). The wide diversity of smallholder farmers with respect to land and labour resources and livelihoods strategies determines different opportunities to improve food security as result of participating in biomass production for food and for cash, including biofuel (Negash and Swinnen, 2013). In the context of smallholders in Mozambique, food security needs to be interpreted at the household level, accounting for a diversity of strategies employed by different farmers and their family members to secure access to food (Eriksen and Silva, 2009). Engaging in on- and off-farm income earning opportunities to purchase food on the market is such a strategy, just as growing food and exchanging labour for food or cash.

In Mozambique, farmers can be engaged in biofuel production in outgrower schemes, in contractual arrangements with companies for production of specific crops, or as workers on biofuel plantations. We investigate how the food security of different smallholder farmers in Central Mozambique is impacted by participating in biomass production for food and biofuel. We specifically look at a jatropha (*Jatropha curcas* L.) plantation and a sunflower (*Helianthus annuus* L) outgrower scheme. Our main objective is to aid policy makers who are searching for pathways to improve the livelihoods of smallholder farmers in Mozambique.

2. Material and Methods

2.1. Site description and farming systems

This study was conducted on the Manica plateau in Manica Province, Central Mozambique. This region has experienced large amounts of foreign investment in biomass production for fuels due to its agro-ecological suitability for crop production (Schut *et al.*, 2010). We focussed on smallholders in two Administrative Post (Post) directly impacted by biofuel developments, Zembe (19.295° S, 33.354° E) and Matsinho (19.024° S, 33.472° E), located in Gondola district within the same agro-ecological region (Fig. 4.1). Chimoio city, the main urban market in the province is situated about 25 km from each of the two posts. Both posts experience two main seasons: a hot and wet season (November-March) and a cool and dry season (April-October). On average 880 mm of rainfall is received in an unimodal pattern that allows one main cropping season per year (USGS/FEWSNET, 2011). In Zembe, the total number of farms is 3844 and the average cultivated area is 1.7 ha per household. In Matsinho, the total number of farms is 7114 and the average cultivated area is 1.5 ha per household (SDAE-Gondola, 2012).

This study builds on a previous study on the diversity of smallholder farming systems and land and labour productivity in Zembe (Leonardo *et al.*, 2015). The study showed that access to labour during peak periods and cultivated area shapes the diversity of smallholder farming systems in Zembe and it distinguished four farm types: (1) large farms composed of households that cultivated more than 1.8 ha and only hired in labour (Farm type 1); (2) intermediate farms composed of households that cultivated between 0.9 and 1.8 ha and hired labour in and out (Farm type 2); (3) small farms that cultivated 0.9 ha or less and shared labour (Farm type 3a) and (4) small farms that cultivated less than 0.9 ha and only hired out labour (Farm type 3b). All four farm types shared the main goal of achieving maize self-sufficiency. Table 4.1 summarises key characteristics of the farm types. The large farms had more household members than the other farm types and produced more than four times the amount of maize that the household consumed per year. The intermediate and small farms produced just enough or less than the amount consumed by the household per year. The combination of higher maize (*Zea mays* L.) yields and larger cultivated areas enabled the Farm type 1 farms to be more market oriented than the Farm type 2, 3a and 3b farms. All of the households from Farm type 1 were male-headed, 73 % of the households from Farm type 2 were male-headed, while this was the case for half and less than half of the households from Farm types 3a and 3b. Women were primarily responsible for farming activities, such as land preparation, sowing, weeding and harvesting, as well as fetching water, cooking and looking after children. Mutual aid through local mechanisms such as gúmuè, i.e., exchange labour during weeding periods (peak period of labour demand) characterize this communities highlighting strong social capital. Patrilineal marriage dominates that culture which means incorporation of a woman in her husband's lineage.

Table 4.1. Distribution of households between farm types and household characteristics per farm type for Zembe (based on Leonardo et al. 2015).

Variables	Unit	Farm types			
		1	2	3a	3b
Distribution of households	%	17	44	15	23
Male headed households	%	100	83	50	42
Household size	#	8.1	5.4	4.9	4.0
Household labourers	#	3.8	3.7	3.1	2.6
Cultivated area	Ha	2.1	1.5	0.8	0.8
Maize yield	t ha^{-1}	2.0	1.7	1.1	1.1
Maize household need	t y^{-1}	0.9	1.1	1.1	0.9
Food self-sufficiency*	-	4.6	2.4	1.0	0.9
Gross revenue	\$ y^{-1}	830	510	190	160

* The food self-sufficiency ratio for maize was calculated as the annual on-farm maize production divided by the household's annual needs.

In September 2011, we conducted a rapid farming systems survey with lead farmers (n= 20) and discussions with key informants (community leaders and regulo) (n=3). The lead farmers are individuals recognised by the community by their depth knowledge on agriculture production. The regulo is the traditional chief who has rights to allocate land for cultivation and other land-use types. The results from a survey in Matsinho, showed the presence of the same farm types as in Zembe. It was also confirmed that farmers in Matsinho share the main goal to be self-sufficient in maize.

In both posts agriculture is rain-fed with a few small areas of irrigated vegetables. Maize is the main crop grown for both food and cash provision. In Zembe, maize is grown in a relay-intercropping system with sunflower on part of the cultivated area. In Matsinho, sunflower is not cultivated. Pumpkin (Cucurbita spp L.), sorghum (Sorghum bicolor (L.) Moench), and cowpea (Vigna unguiculata (L.) Walp) are mixed with maize at planting in both villages. This is the case for the whole cultivated area in Matsinho and two thirds of the cultivated area in Zembe. Sunflower and vegetables such as collard greens cabbage, tomatoes and onion are mainly cultivated for the market. The most consumed vegetables by the households are pumpkins and cowpea leaves. Village poultry is the dominant livestock, followed by goats, cattle and pigs. Charcoal production and off-farm activities are important livelihood strategies (Leonardo *et al.*, 2015).

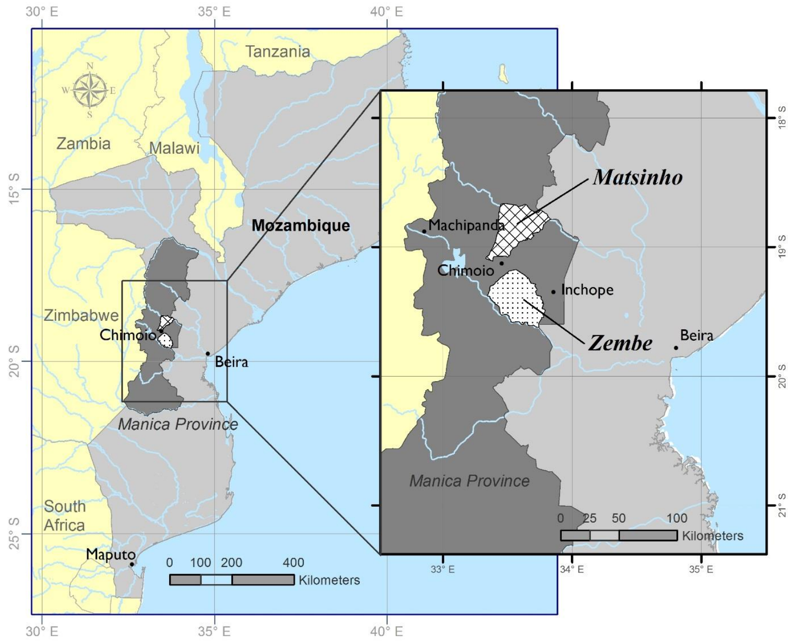

Fig.4.1. Map showing the location of Matsinho and Zembe within Gondola district located in Manica, Province, Central Mozambique.

2.2. Biofuel developments

Smallholders in Zembe and Matsinho are involved with biofuel production for fuel in two different ways, which we refer to as 'modes of participation'. These are a jatropha plantation offering full time employment and an outgrower scheme for sunflower. These two modes of participation in biofuel production are typical across Mozambique (Van Eijck *et al.*, 2014; Schut *et al.*, 2011). Jatropha was widely promoted in the country and received much attention from the government and foreign investors based on the idea that it could grow on 'marginal land' with virtually no inputs (Schut *et al.*, 2011). It is a perennial and only yields after three to four years. Sunflower is an annual crop that is already grown by smallholders.

The jatropha plantation for biodiesel production was established in 2007 and covered an area of 5000 hectares of which 2295 were in use at time of this study (MINAG, 2012b). The plantation employed people mainly its vicinity and paid a monthly salary. In 2011 the plantation employed a total of 1350 people from which 529 were full time workers and 821 were seasonal workers (General Manager, personal communication). Farm type did not appear to influence farmer's chance of gaining employment neither the gender of head of household. The majority of employees were engaged in field activities such as planting, weeding and harvesting. Few workers were employed as guards. The company paid the same minimum wage for agricultural sector in the country, regardless the gender. This study focused on households with a member working full time on the plantation, and we referred to this mode of participation as 'full time'.

Since 1994, a company has been working with smallholders in Zembe to supplement its own production of sunflower oil marketed as either edible or for biodiesel. Due to the relatively high price for edible oil at the time of this study, the company was selling into the edible oil market. Regardless of the end use sunflower was considered an additional cash crop next to maize for smallholder farmers. Therefore, this outgrower scheme allowed assessment of how smallholder involvement with biomass for cash, such as fuel production impacts farm-level food security. We referred to this mode of participation as 'outgrowers'.

2.3. Data collection

A detailed household survey was conducted at the beginning of the harvest of the 2011-12 maize cropping season in Matsinho and Zembe (March-April, 2012). The questionnaire was designed to collect information to quantify a set of indicators to support an assessment of impacts on food security (Sections 2.4 and 2.5). A stratified sampling scheme was designed to select households from each of the four farm types with members employed at the plantation in Matsinho (full time), non-participants in Matsinho (control), households participating as outgrowers of sunflower in Zembe (outgrowers) and non-participants in sunflower production in Zembe (control). Therefore, considering the four farm types and two modes of participation in biofuels developments and their control groups, five farmers were sampled from each of 16 strata (Table 4.2). In Zembe, we randomly selected and categorised households according to farm type and modes of participation using an existing list of 52 households surveyed from our previous study in Zembe (Leonardo *et al.*, 2015). In Matsinho, the selection and categorisation of households was based on a list of 357 households provided by the community leader. We randomly sampled households until 5 households per sampling strata were interviewed.

However, in Zembe only five households over all of the farm types did not grow sunflower (Table 4.2). This limited the possibility to compare the outgrowers and control groups in Zembe, but it also pointed to the extensive engagement of farmers in Zembe with sunflower production. In relay-intercropping, sunflower is planted later in the season after maize when labour is no constraint. This suggests that it is practical and attractive for farmers to grow sunflower for cash.

We interviewed household heads where possible. When the household heads was absent we interviewed the next most senior household member. From the full time group, there was only one household member per household working on the plantation and this was always the head of the household.

Table 4.2. Number of households sampled in Matsinho and Zembe per mode of participation and farm type.

Post	Mode of participation	Description	Number of farmers per farm type			
			1	2	3a	3b
Matsinho	Fulltime	Household with full time employment at plantation	5	5	5	5
	Control	Household without full time employment at plantation	5	5	5	5
Zembe	Outgrowers	Households growing sunflower as a cash crop	9	8	10	7
	Control	Household not growing sunflowers	1	2	0	3
	Total		20	20	20	20

2.4. Operationalizing food security

We used the definition of food security agreed upon in 1996 at the World Food Summit, that food security exists when "all people at all times have sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). We operationalized food security in accordance to the four dimensions of the FAO definition, namely food availability, food access, food utilization and food stability (FAO, 1996). Food availability refers to the physical presence of sufficient food of appropriate quality. Food access refers to the means and ability to obtain food, e.g. through own production or purchased on a market. Food utilization refers to use of food for an adequate diet to reach a state of nutritional well-being and meet all physiological needs. Food stability refers to availability of and access to adequate food at all times.

We selected a set of indicators relevant to the four dimensions of food security, based on insights gained into the smallholders' livelihoods during the preliminary survey among farmers and key informants. The indicators are summarised in Table 4.3 and defined and justified in the next sections. It is important to note that these dimensions of food security are interrelated. Thus, some indicators deal with the same dimensions of food security.

2.5. Definition and and justification of selected indicators

Indicators were calculated for an 'average' agricultural year, the cropping year 2010-2011. This season was defined as 'average' based on the rainfall impacts on crop production in light of the lead authors' observations during on-farm trials conducted between 2009 and

2012 cropping years, information from farmers and the Mozambique food outlook report by Famine Early Warning Network (FEWSNET, 2011).

Table 4.3. Four indicators selected to assess biomass production for food and biofuel impacts on each of the four food security dimensions.

		Food security dimension			
Indicator	Units	Availability	Access	Utilization	Stability
Maize sales minus purchases within household	Kg	+	+		
Gross revenue	$ y^{-1}		+		
Household dietary diversity score	# of food groups			+	
Revenue diversity index	-				+

* 1 Mt ≈ 0.032 $

2.5.1. Maize sales minus purchases

Maize is the most important staple food crop for all farm types and maize self-sufficiency is a major goal at the household level. Maize is also an important source of cash for all farm types (Leonardo *et al.*, 2015). The amount of maize sold and purchased by a household during a season reflects the interplay between self-sufficiency requirements and the need for cash. Therefore, the indicator 'maize sales minus purchases' was selected to capture impacts on food self-sufficiency. This indicator relates to the availability dimension of food security. Maize sales minus purchases was defined as the difference between maize sales and purchases of a household over a period of a year (interval between two consecutive harvests). Total sales included maize sold for cash and maize used to pay for hiring labour. Total purchases included maize purchased with cash and maize received in exchange for labour. Based on discussions with farmers and key informants we defined three seasons that cover the variation in maize availability and prices during a year:

(a) harvest season - April to July: high maize availability and low price;

(b) middle season – August to November: medium maize availability and intermediate price;

(c) lean season – December to March: low maize availability and high price.

Maize sales minus purchases was calculated for the entire year (2010-2011) and for the three seasons separately. When the annual maize sales exceeded annual purchases a household was considered a net seller (positive values of maize sales minus purchases), and we inferred that the household was self-sufficient in maize. When annual purchases exceeded annual sales a household was considered a net buyer of maize and we inferred that the household was not self-sufficient in maize. Detailed analysis of the components of maize sales minus purchases allowed insight in different means of accessing maize, namely with own labour and land (on-farm production), with own labour and other farmers land (selling labour for maize) and with money. This provided additional information on degree of market orientation and the access dimension of food security.

2.5.2. Gross revenue

Gross revenue was selected to capture impacts on cash as a key resource used by smallholders to access food. Cash is an important means of accessing food for smallholders in both Matsinho and Zembe. Purchasing maize, paying for milling and purchasing salt are three reasons why households need cash for food security. This indicator relates to the access and stability dimensions of food security. We calculated gross revenue of a farm household as the sum of gross revenue of each activity engaged in by all household members. Revenue generating activities included biofuel related activities (working on the plantation or cultivation of sunflower), crop production (maize, cowpea, groundnut), vegetable production, livestock production (sale of pigs and goats, hiring out cattle for draught power), natural resources based activities (charcoal, firewood, handcraft), processing (cakes, traditional beverages), off-farm employment (casual employment, i.e. mutrakita, regular employment out-side plantation) and remittances. Mutrakita is a local expression for coping strategies that involve working for someone else and being paid in kind, often with maize, and/or with money. We excluded revenues from chickens because this data seemed unreliable. Many farmers underestimated the quantities of chickens sold when compared with our observations made during three consecutive years of field research. An exchange rate of 1 Metical (MT: Mozambican currency) to 0.032 $ was used (www.oanda.com; April 30, 2011).

We assumed that when a household's gross revenue was high it was better able to access food.

2.5.3. Household Dietary Diversity Score

The household dietary diversity score was selected to measure the diversity of food groups consumed within a household. This indicator captures impacts on access to a variety of different foods and also provides insight into the nutritional value of diets which reflects utilization of food. The household dietary diversity score is a tool to measure the number of different individual foods or food groups eaten by any member of the household over a fixed time period (Ruel, 2003; Steyn *et al.*, 2006). High scores indicate a relatively diverse diet which is thought to ensure adequate intake of essential nutrients thus resulting in a relatively good nutritional status of the household. Given the rain-fed agriculture and unimodal rainfall pattern that allowed one main cropping season per year in both posts, dietary diversity is likely to be relatively high at the end or just after the rainy season compared with the dry season. All households were surveyed for this study during the harvesting season. We used three days as the recall period, as it was observed that the interviewed household member could provide information on foods consumed over this period. This recall period provided a more realistic picture of dietary diversity than the often-used 24-hour period, as households do not always consume the same foods each day. We collected data on individual food items that were aggregated into 12 food groups based on FAO guidelines (FAO, 2011). We further explored whether the consumed items were from own production or purchased in the market to explore if there is a relationship between modes of participation and purchased food items.

2.5.4. Revenue diversity index

The revenue diversity index was selected to measure impact on the diversity of activities used by a household to acquire cash. The revenue diversity index is an indicator of the number and relative contribution of activities to household revenue at a given moment in time (Ellis, 1998). This indicator relates to the stability dimension of food security. The Simpson diversity index (Simpson, 1949), which was designed to measure the diversity of species, was adapted and applied here for the calculation of the revenue diversity index. We calculated the revenue diversity index using the equation below:

$$Revenue\ diversity\ index = 1 - \sum_{i=1}^{n} I_i^2$$

where I refers to the fraction of total gross revenue from activity i and n is the number of revenue generating activities. The index takes values between zero and one, where zero indicates no diversity or only one source of revenue and close to one indicates a large diversity of sources. More diversity implies greater stability but the sources of gross revenue also play a role when interpreting this indicator. For example, one reliable source of income may be more stable than several unreliable sources.

2.6. Data analysis

Due to strong differences in indicator values between the two posts and between the four farm types, and in order to compare the impact of modes of participation, we treated the posts and the farm types separately. In Matsinho, we used the Shapiro-Wilk test for each indicator per farm type to check whether the data was normally distributed. For the normal data, indicator differences between means of the sample groups were tested using the Student T-test at P=0.05. When the assumption of normality was not verified the comparisons were based on ranking with the Mann-Whitney test at P=0.05. The P value is the significance test for the differences between means. It test the hypothesis that there is no real difference between the full time employed households and the non-employed households. The value 0.05 (significance level) is the threshold to accept or reject the null hypothesis. In order words, 0.05 is the value to which P is compared. If P value is less than 0.05 there is evidence against the null hypothesis in favour of alternative. A qualitative interpretation of meaningful differences is also provided. In Zembe, due to the lack of a control group, we present a descriptive analysis of the indicators and compared the farm types.

2.7. Integrated assessment of indicators

We integrated the relative impact on food security in each farm type based on the four indicators to support decision making of local farmers and national policy makers to better plan and design sustainable biofuel production systems. Indicator values were adjusted to fit on a single relative scale (between 0 and 1) using the formula:

$$Relative\ score = \frac{I_i - min(I_1 : I_n)}{max(I_1 : I_n) - min(I_1 : I_n)}$$

where *Ii* is the indicator value for farm I, *min (I1:In)* is the minimum value of the indicator in the data set and *max (I1:In)* is the maximum value of the indicator. The formula was applied once for the farm types and posts together.

3. Results

3.1. Maize sales minus purchases

Table 4.4 shows the mean values of the maize sales minus purchases for the whole year and for the harvest, middle and lean seasons per mode of participation for each farm type. Negative values indicate that the purchases were greater than the sales, while positive values indicate that sales were greater than purchases. This table illustrates that there were no statistically significant differences between the full time and control groups. Figure 2 shows the components of the maize sales minus purchases, namely the mean amount of maize purchased with labour and cash and the mean amount of maize sold for labour and cash for each farm type and mode of participation in both posts.

In Matsinho, regardless of the mode of participation, Farm types 1 and 2 were net sellers of maize on an annual basis while Farm types 3a and 3b were net buyers (Table 4.4). All households were net sellers during the harvest season, regardless of their farm type or mode of participation. In the lean season, only Farm type 1 farms were net sellers. The full time group in Farm type 1 used more maize (240 kg $y^{-1)}$ to buy hired labour than the control group did (30 kg y^{-1}) (Fig. 4.2a). In Farm type 2, the full time group purchased more maize with cash (120 kg y^{-1}) than the control group did (5 kg y^{-1}). In Farm type 3a the full time group purchased maize with labour, while the control group did not. In Farm type 3b the full time and control groups purchased similar amounts of maize with their labour (45 and 35 kg y^{-1}, respectively) and with cash (95 and 80 kg y^{-1}, respectively).

In Zembe, the outgrowers in Farm types 1 and 2 were net sellers of maize on an annual basis, while Farm types 3a and 3b were just balanced in sales and purchases (Table 4.4). In the lean season Farm type 1 farmers were net sellers and those of Farm types 3a and 3b were net buyers. Although the difference between maize and purchases was not statistically significant between farm types (p=0.15), the outgrowers in Farm types 1 and 2 tended to sell more maize for cash (390 and 245 kg y^{-1}, respectively) compared with Farm types 3a (60 kg y^{-1}) and 3b (40 kg y^{-1}) (Fig. 4.2). Farm type 1 farms did not purchase any maize and the quantity of maize purchased with cash by the outgrowers hardly differed between the other 3 farm types. The quantity of maize purchased with labour was slightly higher for farms in Farm type 3a.

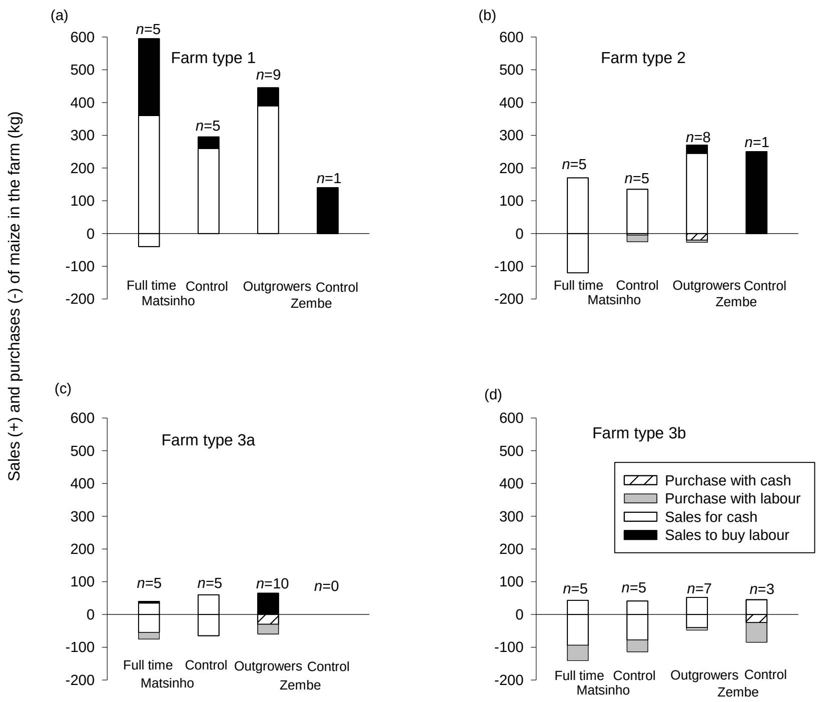

Fig. 4.2. Mean annual maize sales and purchases using labour and cash for each mode of participation per farm type for Matsinho (Full time vs. control) and Zembe (Outgrowers vs. Control). Negative values on the Y-axis indicate purchases and positive values indicate sales.

3.2. Gross Revenue

Figures 4.3 and 4.4 present the mean gross revenues for each farm type and mode of participation in Matsinho and Zembe, respectively. The mean contribution from biofuel-related activities (employment and sunflower), the two most important income generated activities and other sources of income. The statistical analyses comparing the modes of participation are presented in these figures.

In Matsinho, the gross revenue did not differ statistically between the full time and the control groups for Farm type 1 (P=0.78) and Farm type 2 (P=0.25). We did, however, observe statistically significant differences for Farm type 3a (P=0.03) and Farm type 3b (P=0.01). The salary from working at the plantation accounted for more than 85% of total gross revenue for each of the farm types. The variation in gross revenue within groups was larger for the control than it was for the full time groups (see standard errors of means in Fig. 4.3).

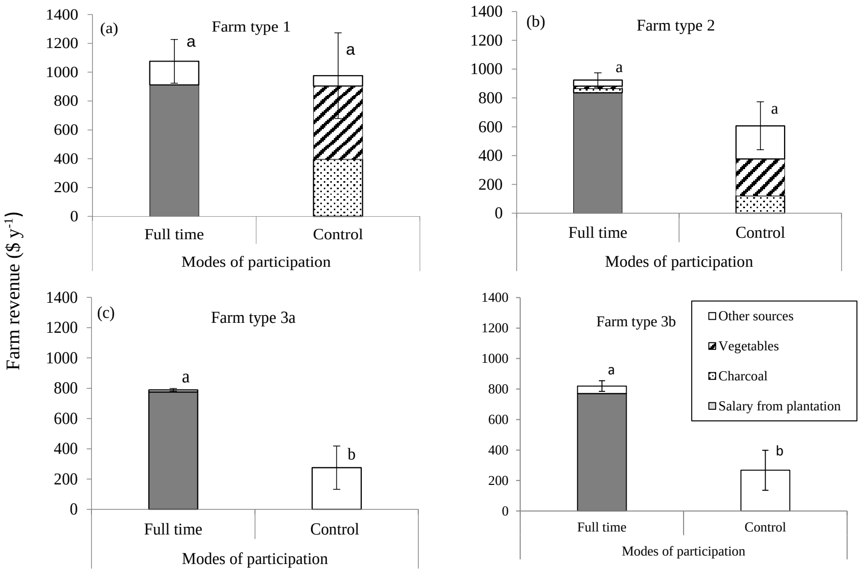

Fig. 4.3. Mean gross revenue in the farm ($ y^{-1}) for the full time and control groups per farm type in in Matsinho. Mean contributions from full time salary at Sun Biofuels is shown for all farm types and mean contributions of charcoal and vegetables are shown for Farm types 1 and 2. Vertical bars are standard errors of mean. Within the same year, means followed by the same letter are not significantly different at *P*=0.05.

Figure 4.3a shows that for the Farm type 1 control group, revenues from charcoal and vegetables are comparable with the salary from full time employment at the plantation. Figure 4.3b shows that for the Farm type 2 control group, revenues from charcoal and vegetables are approximately half the salary from full time employment at the plantation. For the other Farm types 3a and 3b, the dominant revenue generating activities varied. For instance, in Farm type 3a, one household sold only vegetables, one had regular employment, one sold charcoal and maize, one sold only maize, and one sold vegetables and maize. In Farm type 3b, one household sold only vegetables, one sold only maize, one sold charcoal and two sold maize and charcoal.

The largest contribution of sunflower to gross revenue (30 %) was observed in Farm type 1 (Fig. 4.4a). For other farm types, the revenue from sunflower was about 10 % of the total gross revenue.

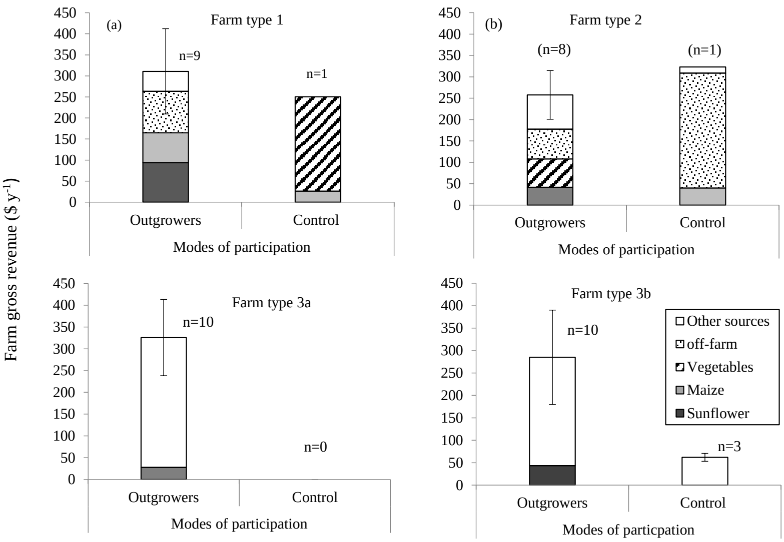

Fig 4.4. Mean gross revenue in the farm ($ y^{-1}) and mean contribution of revenue from sunflower for the outgrower and control groups per farm type in Zembe. Mean contributions of the two most important revenue sources are shown for Farm types 1 and 2. Vertical bars are standard errors of mean.

Table 4.4. Maize sales minus purchases for the whole year and the harvest, middle and lean seasons for different modes of participation per farm type in Matsinho and Zembe. The mean, standard deviation (SD) and *P*-values are presented.

Post	Farm type	Mode of participation	Annual (kg) Mean (SD)	Harvest (kg) Mean (SD)	Middle (kg) Mean (SD)	Lean (kg) Mean (SD)
Matsinho	1	Fulltime	560 (580)	150 (273)	335 (655)	70 (229)
		Control	295 (266)	5 (16)	190 (299)	95 (99)
		P-value	0.35#	0.37#	0.74#	0.82
	2	Fulltime	50 (418)	130 (290)	20 (40)	-95 (158)
		Control	110 (99)	85 (155)	30 (48)	-10 (47)
		P-value	0.78	0.41#	0.52#	0.30
	3a	Fulltime	-40 (16)	5 (16)	30 (64)	-75 (82)
		Control	-5 (39)	25 (39)	-20 (40)	-10 (123)
		P-value	0.72	0.44#	0.18#	0.37
	3b	Fulltime	-50 (94)	20 (48)	-15 (19)	-60 (113)
		Control	-35 (73)	14 (20)	5 (8)	-55 (100)
		P-value	0.81	0.70#	0.09#	0.96
Zembe	1	Outgrowers	445 (576)	20 (60)	120 (203)	305 (334)
		Control	140	15	0	125
	2	Outgrowers	245 (373)	150 (378)	35 (50)	60 (151)
		Control	250	0	250	0
	3a	Outgrowers	0 (30)	50 (45)	5 (11)	-55 (39)
		Control	-	-	-	-
	3b	Outgrowers	10 (82)	50 (68)	0	-40 (31)
		Control	-40	45	0	-85

Data not normally distributed, therefore the differences between group means were tested based on ranking with the Mann-Whitney test at *P*=0.05. For data following normal distribution the differences between group means were tested using the Student T-test at *P*=0.05. The standard deviation (SD) shows how much dispersion from the mean exists. High SD indicates that the data are far from the mean while low SD indicates that the data are close to the mean.

3.3. Household Dietary Diversity Score

Figure 4.5 displays the household dietary diversity score for each household by farm type and mode of participation. Table 4.5 shows the distribution of household dietary diversity scores for full time, outgrowers and respective control groups in Matsinho and Zembe.

In general, regardless of the posts and modes of participation, households consumed more seafood (dried fish) and sweets (sugar) than meats and fruits. In both posts, the diet was primarily composed of cereals, white tubers, vitamin-A rich vegetables (pumpkins, sweet potatoes) and dark green leaves e.g. collard greens, pumpkins and cassava leaves.

In Matsinho, the mean number of food groups consumed by the control group was significantly higher (P=0.02) compared to the full time group (7.0 versus 5.8) for Farm type 1. We did not observe statistically significant differences in the number of food groups consumed between the full time and the control groups for the other farm types. Between the full time and control groups, for all farm types there was no clear trend relating to the consumption of purchased foods (Table 4.5).

In Zembe, there was no variation in the number of food groups consumed by different farm types in the outgrowers group. However, the number of households that consumed meat decreased slightly from Farm type 1 to Farm types 3a and 3b.

Table 4.5. Percentage of households consuming food items purchased in the market during the 3 day recall period for each mode of participation per farm type in Matsinho and Zembe.

		Farm types							
Post		1		2		3a		3b	
Matsinho	Food items	Fulltime	Control	Fulltime	Control	Fulltime	Control	Fulltime	Control
	Fruits	0	40	0	20	40	0	20	0
	Meats	20	20	20	0	20	40	40	20
	Fish and sea foods	100	100	80	100	60	80	60	60
	Sweets	60	80	60	80	80	40	80	60
Zembe	Fruits	11	0	13	0	10	-	14	33
	Meats	33	0	25	0	10	-	14	0
	Fish and sea foods	78	100	50	0	40	-	86	33
	Sweets	33	100	38	0	50	-	29	33

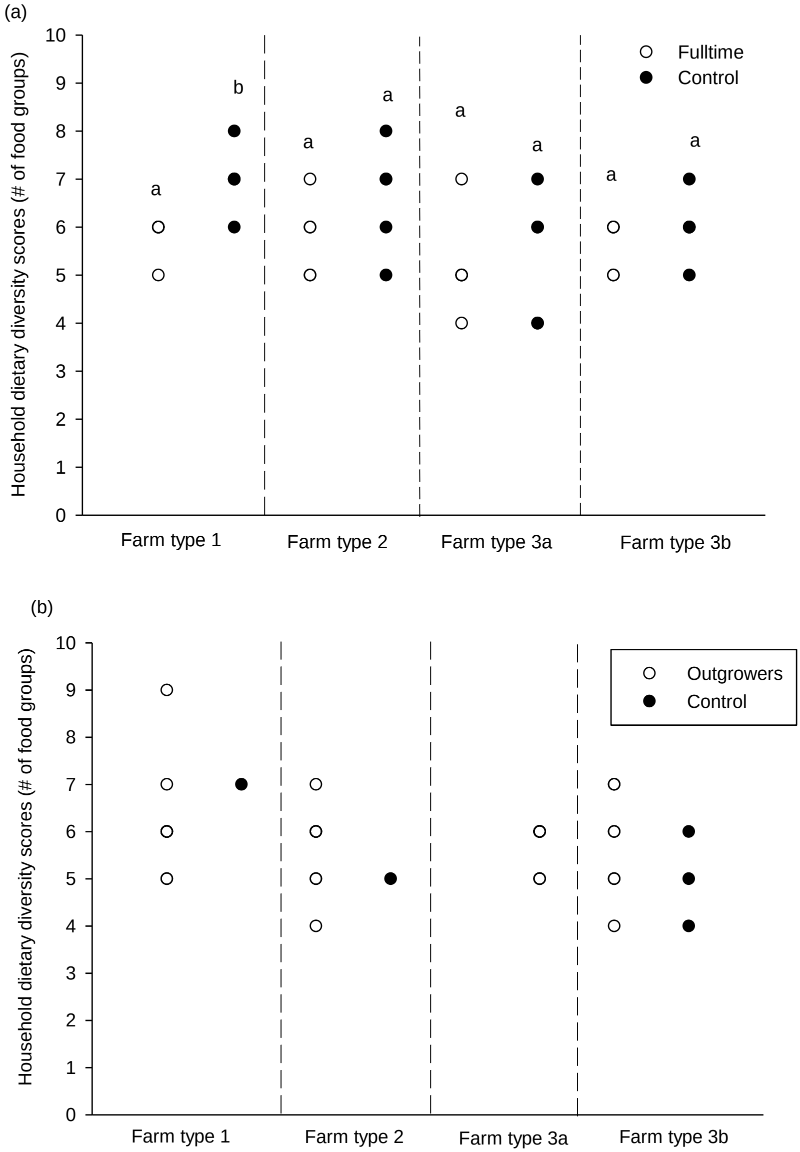

Fig. 4.5. Distribution of household dietary diversity scores for each mode of participation per farm type for (a) Matsinho and (b) Zembe. For Matsinho, the same letters indicate no significant difference for the means at *P*=0.05.

3.4. Revenue Diversity Index

Table 4.6 presents the mean revenue diversity index values for each farm type per mode of participation in Matsinho and Zembe. Across all the households we observed high variation in the revenue diversity index within each farm type (see standard deviations in Table 4.6), which explains the lack of statistically significant differences for most of the farm types.

In Matsinho, we did not observe statistically significant differences in the revenue diversity index for all farm types between the full time and control groups (Table4. 6). However, Farm types 1 and 2 in the full time group tended to have more revenue sources than Farm types 3a and 3b. In the control group, however, Farm types 3a and 3b had more revenue sources than Farm types 1 and 2. In Zembe, the revenue diversity index of the outgrowers group was higher for Farm type 3b compared with the other farm types.

Table 4.6. Revenue diversity index for the full time, outgrowers and control groups per farm type in Matsinho and Zembe. The mean, standard deviation (SD) and *P*-values are presented.

Post	Mode of Participation	Farm types			
		1 Mean (SD)	2 Mean (SD)	3a Mean (SD)	3b Mean (SD)
Matsinho	Full time	0.16 (0.14)	0.16 (0.17)	0.03 (0.03)	0.09 (0.13)
	Control	0.19 (0.20)	0.11 (0.12)	0.25 (0.19)	0.22 (0.24)
	P-value	0.77	0.66	0.07#	0.47#
Zembe	Outgrowers	0.37 (0.20)	0.34 (0.20)	0.34 (0.23)	0.50 (0.20)
	Control	0.19	0.29	-	0.44

data not normally distributed, therefore the differences between group means were tested based on ranking with the Mann-Whitney test at *P*=0.05. For data following normal distribution the differences between group means were tested using the Student T-test at *P*=0.05. The statistics are only presented for Matsinho due to small sample size for the control group in Zembe

3.5. Impact of the modes of participation on food security indicators

Figure 4.6 shows the mean relative scores for each of the modes of participation per farm type for the four indicators of food security. The annual values of maize sales minus purchases among households ranged between -50 and 560 kg, the values of gross revenue ranged between 62 $ y^{-1}$ and 1040 $ y^{-1}$, the revenue diversity index between 0.03 and 0.50, and the household dietary diversity score between four and nine.

In Matsinho, for Farm type 1, the full time group performed better than the control group for two (maize sales minus purchases and gross revenue) out of the four selected indicators. For the revenue diversity index, the full time and control groups had similar scores. A similar result was observed in Farm type 2, however, for the maize sales minus purchases indicator the higher score was observed for the control group. In Farm type 3a, gross revenue improved substantially due to full time employment. In Farm type 3b, full time employment improved gross revenue, yet these farms were less diversified.

In Zembe, the outgrowers in Farm type 1 performed better than other farm types for three (maize sales minus purchases, gross revenue and household dietary diversity score) out of the four selected indicators. Farm type 3b performed better for the revenue diversity index than the other farm types.

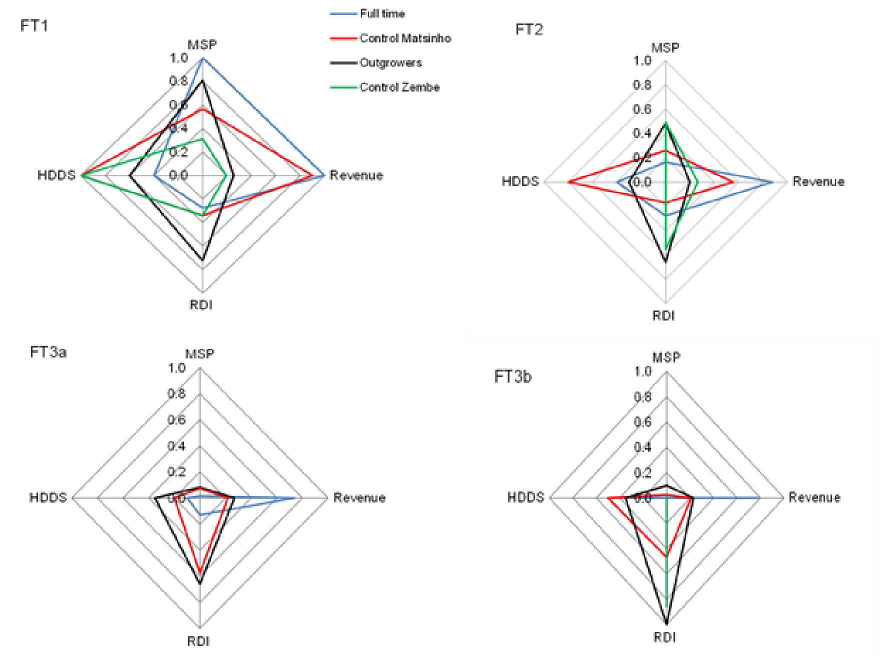

Fig. 4.6. Relative impact of each mode of participation on food security of smallholder farms in both villages, based on the four indicators as presented in the Table 3. MSP is the maize sales minus purchases; HDDS is the household dietary diversity score; RDI is the revenue diversity scores

4. Discussion

We discuss how food security of smallholder farmers in Gondola district is impacted by participating in biomass for biofuel production. Due to the lack of control groups in Zembe, we could not directly assess the effect of the sunflower outgrower scheme on food security. However, we were able to observe and compare food security indicators between outgrowers from each of the farm types. Finally, we discuss the strengths and weakness of the methodology.

4.1. Full time plantation employment and food security

The analysis of how farm level food security of smallholder farmers is affected by employment on a jatropha plantation showed that access to food was increased for small farms (Farm types 3a and 3b). These farms had an almost threefold increase in gross revenue when compared with farmers who were not employed. This increase is explained by the fact that most of the small farms are engaged with less remunerative activities (e.g. on-farm mutrakita) when compared with a full time plantation salary. For large and intermediate farms (Farm types 1 and 2) access to food was not impacted by employment on the plantation. The control group farmers were engaged in intensive vegetable and charcoal production, which provided revenues comparable to the salary from the plantation (Fig. 4.3a and b). The results indicate a farm-level trade-off between working on a plantation and engaging in vegetable or charcoal production for these larger farms. An explanation for the fact that Farm types 1 and 2 were involved with intensive vegetable and charcoal production while Farm types 3a and 3b were not is the gender of the head of the households. The heads of households from Farm types 1 and 2 were men while those from Farm types 3a and 3b were women. We observed that unique responsibilities of women, such as fetching water, cooking and looking after children were not compatible with the high labour requirements of intensive vegetable and charcoal production and therefore these activities are limited to male-headed households.

Schoneveld *et al.* (2011) concluded that an important perceived benefit of receiving an income from plantation labour is increased stability and security of income. A high dependence on one salary, however, raises concern about the potential risk associated with job loss. While the plantation initially employed 529 full time workers, by 2012 the company employed only 83 full time workers (MINAG, 2012b). This indicates that biofuel employment is not a stable income earning activity. Van Eijck *et al.* (2014)reported in their review study on global experience with jatropha plantation the risks of jobs loss that smallholders bear when employed at jatropha plantation that may lead to negative attitudes towards a new project. This calls for measures to encourage farmers to invest part of their income in food production.

Although the statistical analyses did not reveal significant differences between the full time and control groups for food availability in all farm types, the large farms (Farm type 1) tended to have more maize available when they worked on the plantation compared with those who did not (Fig 4.2a and Table 4.4). For example, on average, they sold 265 kg more maize during the year (Table 4.4). This difference is greater than the annual per capita maize consumption for small farms of 150 kg in the two posts (Leonardo *et al.*, 2015). It appears that when heads of households of large farms worked on the plantation they were able to hire more additional labour compared with the control group to support their maize production which in turn increased the farms' net sales of maize. Small farms were net buyers of maize and maize production for these farms remained low either when working on the plantation or not. The seasonal maize sales minus purchases also highlights that these farm types needed to purchase more maize during the lean season when the maize was most expensive. (Renkow *et al.*, 2004) also found that maize farmers in Kenya sold maize immediately after harvesting and purchased maize during the lean season.

Although our study does not highlight a trade-off between food availability and fuel production at the farm level, such a trade-off could still be cause for concern across regions if mitigation measures are not adopted as the plantation model can decrease food security (Van Eijck *et al.*, 2012).

Dietary diversity was similar regardless of participation with biofuel production. One exception was that in Farm type 1 the control group had greater dietary diversity than those working on the plantation. The general similarity between diets across all households is in agreement with several meta-analyses highlighting the weak link between agricultural interventions and household nutritional status (Berti *et al.*, 2004; Masset *et al.*, 2012). This could be due to the fact that households experience trade-offs between food and other basic needs such as maize milling services, soap, cooking oil, transport and communication (e.g. reducing cash availability to obtain market information). The household dietary diversity score indicator gives insight into the variety of foods consumed; however, it does not provide information on quantities consumed by households. The lack of significant differences in the number of food groups observed in many cases does not necessarily mean that these households consumed similar quantities of each food item.

Food safety aspects such as access to clean water for food preparation and sanitation affect the nutritional values (Pinstrup-Andersen, 2009). Nearly 50% of the interviewed households had access to public clean sources of water (public well). However, the remainder of households relied on traditional water wells and water from rivers. This lack of access to clean water might cause ingestion of pathogens that impact the body's ability to absorb nutrients from food therefore affecting their nutritional status (Pinstrup-Andersen, 2009). Access to clean water was not related to farm types or farmers' participation with biomass production for biofuel because the public wells are dispersed across the post.

Our analysis shows that food stability was not affected by full time employment at the plantation as indicated by the revenue diversity index. However, there was a clear tendency for famers employed at plantation to have fewer sources of revenue, i.e. lower revenue diversity index, when compared with the control group. The regular salary from full time employment may be a disincentive to diversify revenue sources. Moreover the risk of job loss as mentioned above is a major threat to income stability. While farmers have experience with vegetable and charcoal production that provides comparable year-round income, the labour required for these activities is intensive such that farmers are unable to combine these activities with full time employment. It appears that employment at the plantation would offer stable access to food with cash in a year with bad weather (e.g. drought or floods), however, food prices may be higher due to scarcity. In this scenario, Farms from Farm types 3a and 3b, who are net buyers of maize, are more vulnerable than Farm type 1 farms, who are net sellers. For Farm type 1 farmers the reduction in the amount of maize sold in the market due to bad weather may be offset by high prices due to scarcity.

4.2. Outgrower schemes and food security

We observed differences in food availability between farm types. The large and intermediate farms (Farm types 1 and 2) are net sellers of maize while the small farms (Farm types 3a and 3b) are net buyers. The explanation for the difference in food availability is that Farm types 1 and 2 cultivated larger areas compared with Farm types 3a and 3b. The relay-intercropping system of maize and sunflower does not strongly impact maize production, because peak labour periods differ between the two crops (Leonardo *et al.*, 2015) and crop growth is sequential. This result is in line with previous findings of (German *et al.*, 2011) in Zambia showing that intercropping of a food crop and jatropha did not negatively affect food availability. Arndt et al. (Arndt *et al.*, 2008) linked participation in outgrower schemes to technology spill-overs and increased production. (Riera and Swinnen, 2014) reported that food productivity increased due to technology spill-overs and technical assistance for smallholder farmers in Ethiopia involved with castor production for biofuel.

Sunflower cultivation contributed a relatively small fraction of total gross revenue across all farm types. This could be due to poor yields (0.3 t ha^{-1}) and small areas of sunflower cultivated (1.4 ha on large farms and 0.4 ha on small farms) (Leonardo *et al.*, 2015). Therefore, cultivating sunflower does not affect the access to food of different farm types. Food utilization was similar across all farm types as indicated by dietary diversity. The revenue diversity index for outgrowers is similar across all farm types indicating similar degrees of diversification.

4.3. Improving the food security indicators

This assessment of food availability could be improved by complementing the maize sales minus purchases indicator with information on the amount of maize consumed and stored by the households. Inclusion of other important foods would also be useful. Revenue from activities that households found difficult to recall, e.g. chickens, sale of snacks and cookies were not included in the gross revenue indicator, although they may have a considerable influence on access to food. These could be included by using observational methods of data collection next to the questionnaire, resulting in a more accurate indicator of access to food. The relative contribution of relative activities to gross revenue and the revenue diversity index provided a partial picture of food stability. This picture would be improved by accounting for the dynamics of gross revenue over a longer period, e.g 5-10 years. To get a better indication of the utilization of food, including quantities and qualities of the different foods as well as the intra-household distribution can enhance the household dietary diversity score.

The revenue diversity index indicator shows that in general farmers had one dominant source of revenue (revenue diversity index below 0.5). Therefore, food stability assessment would be enhanced with information on the long-term viability of each source. For example, is the charcoal production viable in the long term and how reliable is employment at the plantation?

5. Conclusions and implications for policy

Our research provides much needed insight into farm-level impacts of biofuel production. The main finding from this research is that working at jatopha plantation had a positive or no impact on the four dimensions of food security at the farm level.

Our observed positive or lack of impact on food availability when smallholder farmers were involved with biomass for fuel production suggests that smallholders continue to produce staple food crops even when working on a plantation or participating in outgrower schemes. In both Zembe and Matsinho, large and small farmers depended for food primarily on their own production, except those employed on the plantation. Small farmers supplemented their own production by purchasing maize with their labour and cash. Larger farmers with relatively more land and labour make a comparable living to full time employment by combining farming with off-farm activities. In addition to purchasing food with money, own production and mutrakita are important means of accessing food. The smaller farmers who supplement their own maize production with purchases, either with cash or labour, tended to purchase the same amount of maize with labour. Yet, if the costs of hiring in labour increase it is likely that maize production of farmers employed on the plantation will fall.

Access to food as impacted by full time employment was greatly improved though increased gross revenue for small farms. This was due to a salary from the plantation contributing more than 90% of their gross revenue. This was not the case for larger farms who were already engaged in other remunerative activities. The strong reliance on the salary from the plantation indicates a certain degree of risk related to the still unstable biofuel markets in general and in this case specifically to the uncertain opportunities for jatropha oil production. The impacts from the sunflower outgrower scheme on food security were minor. This was due to poor yields and farmers allocating small areas to sunflower cultivation. The outgrower scheme in Zembe could be improved by supporting farmers to increase productivity, resulting in larger volumes of production and benefiting both farmers and the company. In addition, sunflower has the advantage for farmers that sales do not depend solely on the biofuel market.

Our findings has important implications for a national policy that sees biomass production for biofuel and other large-scale agricultural investments as a path for smallholder farmers to improve food security. Close examination led to identification of recognisable differences in impacts between farmers. The smallest farms (Farm types 3a and 3b) employed on plantations benefited more than outgrowers and larger farms. While employment had positive impacts on the food security of smaller farmers, the risk of job loss calls for additional measures to enable them to accumulate the resources necessary to enter into sustainable food production and other income generating activities, possibly outside agriculture.

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The Windmill Diagram: combining transaction cost economics and farming systems theory to analyse farmer participation in value chains

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Abstract

A common theoretical approach for understanding smallholder farmers' choice of sales arrangements is Transaction Cost Economics (TCE). Several studies applying the TCEfocus on a single transaction. However, farmers produce different crops and participate in several value chains simultaneously. Based on two case studies in Central Mozambique, we evaluated the combined use of farming systems theory and TCE in understanding the choice for various sales arrangements. Using a *Windmill Diagram* we demonstrate that farmers decide on participating in various value chains on the basis of multiple objectives and aspirations. Farmers prioritize the allocation of available resources towards the sustainability of the whole farm. Policy to support smallholder farmers' market access should not focus on single transactions but on the combination of farming system and value chain costs and benefits.

Keywords: Decision making; farm typology; sales arrangements; smallholder farmers; Mozambique

1. Introduction

Improving smallholder farmers' access to markets has become an important aspect in strategies to promote rural development and poverty reduction (Donovan and Poole, 2012; Collier and Dercon, 2014). Studies on market access have applied insights from Transaction Cost Economics (TCE) theory to understand the rationality of farmers choosing particular sales arrangements (Staal *et al.*, 1997; Dorward, 2001). TCE analyses the costs associated with participating in particular sales arrangements, such as a spot market, informal contracting, formal bilateral contracting, multilateral contracting (i.e. a cooperative), gaining ownership in a processing or marketing company, or complete vertical integration (Peterson *et al.*, 2001; Raynaud *et al.*, 2005). Yet, smallholder farmers not only look at costs, but also at the returns of engaging in a particular arrangement. For this reason, transaction costs need to be assessed in relation to transaction benefits.

Much of market access research focuses on a specific crop and thus on a specific value chain (Collier and Dercon, 2014; Saenger *et al.*, 2013). Smallholder farmers cultivate multiple crops and are therefore simultaneously engaged in multiple value chains (Bolwig *et al.*, 2010). On the basis of their objectives and aspirations, farmers prioritize the allocation of resources for the farm as a whole, not the production of a single crop (Cittadini *et al.*, 2008; Groot *et al.*, 2012). Positive and negative experiences in one value chain may affect decisions related to another chain and another crop. Studies that focus on an individual value chain, often applying TCE, are too narrow to fully understand farmer choices. This is particularly important for supporting organisations such as NGOs, extension agents and policy makers that seek to strengthen farmer market access (Shepherd, 2007; Markelova *et al.*, 2009; Poulton *et al.*, 2010).

The shortcomings of traditional sales arrangement studies are particularly problematic when trying to understand farmers' decisions to cultivate a new crop, for instance a bio-energy crop. Before engaging in the cultivation of a new crop, farmers need to evaluate the consequences of changes in farm structure (e.g. a loss of self-sufficiency when shifting from food crop to cash crop) and tactical decisions regarding the allocation of fields, labour and other resources (Cittadini *et al.*, 2008; Fountas *et al.*, 2006). Strategic and tactical decisions are better understood at farm level, where investments and management decisions on resource allocation are taken and where the impacts are evaluated holistically.

For the integrated analysis of simultaneous decisions on producing a particular crop and choosing a particular sales arrangement, we develop the so-called Windmill Diagram. Like a windmill where several vanes contribute to pushing the axis and rotating the millstone, the farm is engaged in various value chains each contributing to the objectives and aspirations of farmers (Dorward, 2009). Farming systems analysis is an appropriate approach to analyse the integrated farming decisions and their effects (Giller, 2013). We argue that the combination of farming systems analysis and transaction cost theory, as illustrated in the Windmill Diagram, allows a better understanding farmer decisions to grow new crops.

Our Windmill Diagram has been developed on the basis of a case study of agricultural sales arrangements in Mozambique. About 75% of Mozambique´s population depends on agriculture for their livelihood. The Strategic Plan for Agricultural Development in Mozambique (PEDSA) (MINAG, 2011) aims at converting subsistence agriculture into competitive, sustainable and market-oriented agriculture. The PEDSA implementation focuses on development of agricultural value chains in areas with good agricultural potential, the so-called development corridors.

The objective of our study was to thus evaluate the combined use of farming systems theory and TCE in understanding the choice of various sales arrangements. We investigated smallholder farmers and their sales arrangements in Manica Plateau, Beira Development Corridor, Central Mozambique in 2013. In these maize-based farming systems, farmers also cultivate sesame and sunflower. Soybean has been introduced recently in the region. The study adds to existing literature on sales arrangements and transaction cost analysis of smallholder value chains. Our results allow policy makers to better frame policies that support market access of smallholders, particularly when introducing new crops.

2. Conceptual framework and operationalization

The central tenet of farming systems research is that the farm is the key level at which decisions are made in relation to resource allocation (Giller, 2013). While farmers are highly heterogeneous, repeated patterns emerge among their farm systems, strategies, constraints and aspirations (Giller *et al.*, 2011). These patterns, termed a typology, can be captured using various approaches ranging from simple participatory wealth ranking (Zingore *et al.*, 2007) to more complex approaches using multi-variate statistics (Bidogeza *et al.*, 2009; Tittonell *et al.*, 2010a). Given that is impossible to develop interventions for each single farm, the typologies are further used to gain insight in farmers' goals, priorities and drivers of livelihood strategies that can guide interventions and policies to link farmers to agricultural markets. For instance, less resourceful farmers may find opportunities for livelihood improvement in social promotion interventions whereas for more resourceful farmers agricultural markets may be the appropriate avenue. Farming systems analysis helps to explore future scenarios by asking "what if" questions (Van Ittersum *et al.*, 1998). For instance, what type of sales arrangements are likely to be chosen by various farmers when introducing soybean into the region?

The classical theoretical approach for understanding the choice of a particular sales arrangement is the theory of Transaction Cost Economics (TCE), as developed by (Williamson, 1985). Every economic exchange involves costs of information, negotiation and control, so-called transaction costs (North, 1990). Based on the literature of agrifood transactions (Peterson *et al.*, 2001; Raynaud *et al.*, 2005), we distinguish the following six sales arrangements: spot market, relational contract, formal contract, multilateral contract, equity participation and vertical integration. These arrangements allow the sales of the farm products at the lowest transaction costs. TCE posits that transactions involving non-specific investment, independent of frequency, will be governed by immediate exchange in the spot market, while in case of asset specificity the parties' exchange relations take on a stronger relational or hierarchical trading character (Maher, 1997; Riordan and Williamson, 1985). For operationalization of the sales arrangements we select the following main characteristics: frequency of transactions, relevance of identities of parties, price determination, formal or informal contracts, enforcement mechanisms and allocation of decision rights (Table 5.1).

Our empirical research focuses on the transaction between farmers and buyers, where the buyer could be a trader, a processor or a retailer. This transaction is part of a longer value chain, consisting of several sequential and often interdependent transactions. Thus, we acknowledge that the transaction between farmer and buyer could be influenced by the subsequent transaction of the buyer with his/her customer, but we do not include subsequent transactions in our analysis.

Table 5.1. Six sales arrangements and their main characteristics.

Name of arrangement	Main characteristics of the arrangement
Spot market Example: auction	- identity of parties is irrelevant - immediate exchange at current prices - no dependencies, as alternative trading parties are available
Relational contract (bilateral) Example: preferred supplier or buyer	- identity of parties is relevant (because of reputation effect and/or social ties) - immediate exchange at current prices - informal contract enforcement
Formal contract (bilateral) Example: contract farming	- identity of parties is relevant (because of reputation) - future exchange, applying an agreed-upon pricing scheme - contract is legally enforceable (although imperfectly) or third party intermediation
Multilateral contract Example: marketing cooperative	- identity of parties is relevant - immediate exchange at current prices - formal individual contract with producer organisation - contract legally enforceable (imperfectly), but commitment because of multiple ties and joint decision-making is more important for contract compliance than formal sanctions
Equity participation Example: farmer partly owner of processing firm	- identity of parties is relevant - immediate exchange or future exchange at prices determined by joint decision - formal contract, but joint decision-making more important for contract compliance than legal enforcement
Vertical integration (or hierarchy) Example: soybean crusher owning a soybean farm	- identity of parties is relevant; full information available - no market exchange, transfer pricing - labour contract - 'forbearance': conflicts are resolved within the organisation (no legal enforcement)

3. Methodology

Data were collected in 2013 in the Postos Administrativo (similar to ward) of Zembe-Gondola and Dombe-Sussundenga, on the Manica Plateau. Both Postos Administrativo are sparsely populated areas with a population density of 12.8 in Zembe and 24.2 inhabitants per km2 in Dombe. These sites were chosen because farmers cultivated both staple food and cash crops. Using farming systems analysis, we identified three categories of farm households (i.e. three farm types) in each Posto Administrativo. Farm type 1 represented farmers with more land, labour and some cattle compared with Farm types 2 and 3. Farm type 2 was moderate in land and labour. Farm type 3 included the less resourceful farmers. The distribution of the farm types was as follows: Farm type 1: 17% in Zembe and 24% in Dombe; Farm type 2: 44 % in Zembe and 31 % in Dombe; Farm type 3: 39 % of farmers in Zembe and 45 % in Dombe. Using questionnaires we collected information from farmers, buyers and supporting organisations in Zembe and Dombe on the marketing channels for maize, sunflower and sesame, production techniques, inputs used, yields, quantities sold per transaction, frequency of transaction, final market, selling period, distance to market, farm types, buyer characteristics, supporting organization, type of support, access to credit, role of producer organizations, and the content of the agreements between transaction parties for each farm type, and products prices in Meticais (The Mozambican currency). The exchange rate of 1 Mt to US$ was 0.035 (www.oanda.com; August 9, 2013). The data were collected immediately after harvest.

In Zembe, we interviewed 10 farmers across the three farm types, and four itinerant buyers. In Dombe, we interviewed 12 farmers, six itinerant buyers, one buying company, one local trader and the leaders of a cooperative. In each Posto Administrativo, we conducted two focus group discussions composed of 4-6 farmers per group. The farmer interviews as well as the focus group discussions were conducted at the homestead of a farmer. The interviews with the farmer cooperative and the supporting organizations were conducted in their respective offices. The interviews with itinerant buyers were conducted either at a posto or at the farm gate, while the interview with the company was conducted at the warehouse. A posto is an informal market organised by buyers, often located alongside the main unpaved road that connects each of the villages to urban centres. Each of the interviews lasted 60 to 90 minutes. We complemented the interview data with information gathered through observing the transactions between sellers and buyers, and data collected during three years of agronomic research in Zembe and Dombe. In addition, we interviewed three organizations involved in supporting sales arrangements in Dombe.

4. Sales arrangements in relation to farming systems

This section provides background information on the organizational environment that aims at supporting the sales of products beyond individual value chains. Next, we describe the common characteristics of the four main sales arrangements in the post (Table 5.1). These were spot market, relational contract, formal contract, and multilateral contract. Finally, we describe the specific characteristics of the sales arrangement for each crop and farm type, i.e. Table 5.2 (Zembe) and Table 5.3 (Dombe).

4.1. Supporting organizations

The CLUSA-Agrifuturo Project, the farmers' Cooperative Kuchanda Kuguta (CKK) and the Banco de Oportunidades de Moçambique (BOM) are the main supporting organizations in Dombe. Although BOM provides services for all farmers in the region, farmers in Zembe do not make use of the services of BOM and there are no supporting organizations such as in Dombe. The CLUSA-Agrifuturo Project aims at increasing sesame yields through better agricultural practices, using improved varieties and linking farmers to markets. In 2011, Cooperative Kuchanda Kuguta (CKK) was formed in Dombe with the assistance of CLUSA-Agrifuturo. The latter expected that through the cooperative farmers would be able to attract investments for agriculture development and would improve their bargaining power. Kixiquila, a consultancy enterprise, provided training to the CKK on developing a business plan, negotiating prices and selecting buyers. CLUSA-Agrifuturo linked CKK to BOM for micro-credit access to purchase the products from its members. However, given a small number of members, the CKK also purchased products from non-member farmers to supplement its need. To obtain credit from BOM the cooperative was required to present a contract with a buyer.

Table 5.2**.** Main characteristics of sales arrangements found in Zembe Post

Sales arrangement	**Main actors**		**Customer/Final destination**	
Type and Characteristics	**Maize**	**Sunflower**	**Maize**	**Sunflower**
Spot market One-off transaction; identity of partners are not relevant; immediate exchange of assets	Farm type 2 and 3, and itinerant buyer (*postos*)	Farm types 1 and 2, and Mafuaia Commercial Company	The final destination are the grain spot markets in Chimoio city	Edible oil market in Chimoio city (The company has oil crushing machine)
Relational contract Repetitive transactions; identity of parties is relevant; immediate exchange for current prices	Farm types 1 and 2 and itinerant buyer (farm gate)	All farm types and Girassol Manica Company	The final destination are the grain spot markets in Chimoio city	Edible oil market in Chimoio city (The company has oil crushing machine)
Formal contract repetitive transactions; identity of parties is relevant; post-pay based on current prices	None	Farmers and Girassol Manica Company	Not applicable	Edible oil market in Chimoio city (The company has oil crushing machine)

Table 5.3. Main characteristics of sales arrangements found in Dombe Post

Sales arrangement	Main actors		Customer/final destination	
Type and Characteristics	**Maize**	**Sesame**	**maize**	**Sesame**
Spot market One-off transaction; identity of partners are not relevant; immediate exchange of products	Farm types 2 and 3, itinerant buyer (*postos*)	None	maize grain market southern regions of Mozambique (spot market);	Not applicable
	Farm types 2 and 3, and CKK (*APC-postos*)	Farm types 2 and 3, and CKK (*APC-postos*)	CKK / World Food Program (WFP)	SENWES Company / final destination are the larger trader in Beira Corridor who further export to international market
Relational contract Repetitive transactions; identity of parties is relevant; immediate exchange of products for current prices	Farm types 2 and 3, and village traders	Farm types 2 and 3, and village traders	DECA Company / Maize flour market in the centre and southern regions of Mozambique	The final destination are the larger trader in Beira Corridor who further export to international market
	Farm types 1 and 2 and SENWES Company	Farm types 1 and 2 and SENWES Company	SENWES Company / Maize flour market in the centre and southern regions of Mozambique; poultry industry	SENWES Company/ Mozambican market
	Farm types 1 and 2, and DECA Company	None	Maize flour market in the centre and southern regions of Mozambique	Not applicable
Multilateral contract repetitive transactions; identity of parties is relevant; post-pay based on current prices	CKK and WFP	None	Word Food Program (WFP)/ aid programs	Not applicable

4.2. Common characteristics of the sales arrangements

Maize transactions take place throughout the year whereas transactions of sunflower and sesame occur during two months after harvest. In general, the quantities varied between 5 and 50 kg per transaction, the product was transported in bags, and farmers carried the bags to the markets on their head or on bicycles. When the maize was sold at the farm gate, the buyer took care of transporting the product to the final market. There were no delivery conditions or requirements on product quality, except for the maize transactions with the World Food Program (WFP). Prices were determined by the buyers based on supply and demand except when transactions occurred at farm gate where farmers determined the prices based on local and regional markets. The price of maize decreased with increasing distance from posto to centre of the Posto Administrativo in response to transport costs, and from harvesting to lean season due to low supply. The prices of sesame and sunflower, however, were relatively stable compared to the price of maize. So, regardless of the type of sales arrangement the price was the same for sesame and sunflower. The buyers did not offer technical assistance, credit or inputs.

We did not observe any specific investment by either party in the transactions. For the three crops, the farmers use saved seed from the previous harvest, except when engaged in outgrower schemes with a sunflower company. Under this contract the company provided the seed. Crop production was based on traditional knowledge, passed-on from generation to generation, except for the improved sesame variety. For this variety, farmers received technical assistance from CLUSA-Agrifuturo.

The main buyers were itinerant buyers, local traders, two milling companies (SENWES and DECA), two edible oil producers (Mafuaia Comercial and Girassol Manica), and a farmer cooperative (*Cooperative Kuchanda Kuguta-CKK*). In both Postos Administrativo, the itinerant buyers were only engaged in maize transactions. Whereas in Dombe the itinerant buyers were mainly women from the southern part of the country, in Zembe they were mainly men from Chimoio. The quantities purchased were larger in Dombe than in Zembe. The maize from Dombe was further transported to the south region at about 1000 km, indicating the importance of scale to minimize costs. In Zembe and Dombe, the itinerant buyers had some degree of literacy (while the farmers are mostly illiterate). The local traders were business men who owned a small shop. These traders were involved in selling various food and non-food products. All the companies had warehouses, milling and crushing facilities for maize and sunflower. The cooperative purchased the products through a Production and Commercialization Agent (APC) who was also a member of the cooperative.

4.3. Specific characteristics of the sales arrangements

Spot market

The postos were the typical spot markets where farmers sold maize to various buyers. These postos were active during the harvesting season, and the main farmers who sold maize at harvest season were the Farm type 3 who were women headed households or elderly or divorced farmers. Some Farm type 2 also sold maize at postos. Farm type 3 households were characterized by a lack of means to transport their products to the centre of the village. Farm type 3 represented 39 % of farmers in Zembe and 45 % in Dombe. The trade of maize and sesame with SENWES in the spot market involved Farm type 2 and Farm type 3 with CKK – the farm cooperative acted as a broker. SENWES paid a commission to the cooperative of 1 Mt kg^{-1} of maize and 2 Mt kg^{-1} of sesame purchased. SENWES advanced cash to CKK which in turn sub-allocated the money to each of the 10 APCs to purchase maize and sesame. Similarly to itinerant buyers, each APC had a posto located close to farmers' homestead which made the participation for all farm types possible. CKK used the same APCs for purchasing maize from non-member farmers. The cooperative bought at harvest time at lower price and sold to WFP at relatively high price for the benefit of its members. The transaction at postos was characterized by immediate exchange for current prices and the identity of the parties was not relevant. In Zembe, Farm types 1 and 2 transacted sunflower in bags of 50 kg with Mafuaia Comercial at warehouse gate of the company which is located at about 25 km from Zembe.

Relational contract

Farmers and buyers had a relational contract for the sales of maize, sunflower and sesame. In Zembe, the selling of maize took place at the farm gate during the middle and low seasons, and involved the same itinerant buyers as those of the postos. In Dombe, farmers transacted maize with village traders, SENWES and DECA. Maize transactions were characterized by immediate exchange based on current prices. The traded quantities with SENWES were larger than 100 kg per transaction compared with those traded with village traders and DECA. The transaction happened at a shop or warehouse and farmers were responsible for transporting their produce. Mostly Farm type 1 and to a lesser extent Farm type 2 participated in transactions with SENWES, whereas Farm type 2 and Farm type 3 were involved in the transactions with village traders and DECA. The latter two buyers purchased maize at harvesting and middle season while the former traded with farmers during all year. In sunflower trading, the farmers delivered their produce to Girassol Manica, based in Zembe. For quantities above 300 kg the company provided free transport from a farmers´ homestead to the processing plant. Payment was completed in two instalments: the first payment after 15 days and the remainder 30 days after delivery. The company determined the price. Sesame was transacted to village traders and SENWES at shop or warehouse premise at market price. The transaction involved mostly Farm types 1 and 2 who transported their produce on bicycles to the nearby warehouse. The price paid by SENWES varied according to quantity. For quantities above 100 kg, SENWES paid a premium of 1 Mt kg^{-1} above the prevailing market price.

Formal contract

Sunflower was the only crop that was also transacted in a formal contract arrangement and it involved all farm types and Girassol Manica. This transaction differed from a relational contract in that the company provided seed to the farmers as an in-kind loan. The farmers paid back the loan by doubling the amount of seed received. In addition, the farmers were obliged to sell their sunflower seeds to the company. The other characteristics of this transaction were similar to that reported above in a relational contract arrangement.

Multilateral contract

The CKK traded maize with WFP on behalf of its members (mostly Farm type 1). The agreed price was the market price at the time of signing the contract and the payment was made at delivery. If the price of maize increased in the period between the signing of the contract and delivery, the WFP adjusted the actual price. If the market price dropped, the price was as agreed in the contract. The WFP demanded high quality maize (cleaned, dried, graded and with no broken grain). The traded quantities varied from 30 to 60 tons per transaction. BOM acts as a supporting third party by providing credit to the cooperative.

5. Discussion

Transaction Cost Economics (TCE) is helpful in understanding the differences among the four market arrangements identified in these two case studies. For instance, the spot market can be explained by the absence of asset specificity and the low uncertainty in the farmer-buyer transaction. This allows for spot markets to be an efficient sales arrangement (Maher, 1997; Riordan and Williamson, 1985). Indeed, sales of maize and sesame do not require any specific investment at farm or processing. Our results showed that the relational contract sales arrangements observed for maize, sunflower and sesame is due to recurrent transactions between farmers and buyers rather than asset specificity. TCE also postulates that where transactions are repetitive, reputation between parties becomes important, and formal contracts will be the preferable sales arrangements. When these transactions are executed by a collective action organisation such as a cooperative, the arrangement is a multilateral contract. The formal contract between farmers and Girassol Manica for selling sunflower and the multilateral contract between CKK and WFP for selling maize confirm TCE hypotheses.

We do not questioning the multiple advantages of the TCE in explaining why certain arrangements prevail over others and the importance of the costs. However, TCE applies only a cost perspective overlooking that fact that a marketing arrangements employed by a farmer can be a result of a willingness to take risk, aspirations, ambitions, innovation or entrepreneurship. As acknowledged by Nooteboom (2004) institutional arrangements should not be explaining only from the perspective of reducing costs but also from innovations and knowledge generation when engage in certain transaction that parties acquire. Farm type 1, for instance, may aspire to "stepping out" and reach new markets apart from the default choice (spot market) whereas the Farm types 2 and 3 may pursue livelihoods strategies that allowed them to "hanging in" (see Dorward et al., 2009). These livelihoods strategies have a farmer as central of decision making process rather than the transaction as the basic unit of the analysis. Here, farming systems analysis can provide additional explanation. Important questions addressed by farmers before engaging in a (new) value chain relate to how a cash crop competes or complements with food crops, and how it competes for land and labour. As described in this study, sunflower and sesame are cultivated in relay intercropping systems with maize, therefore do not compromise the farmers' main objective of producing maize for self-sufficiency. In this system, farmers plant maize at beginning of the rainy season. One month later, when demand for labour on maize is low, farmers plant sunflower between the maize rows. So, the two crops share the same field allowing farmers to save labour that would have been needed when using other fields. In addition, the system allows simultaneous weeding of the two crops.

A spot market is often the default choice for smallholder farmers in developing countries (Fafchamps, 2004). Farming systems analysis and TCE show that the spot market constitutes a default option especially for less resourceful farmers (Farm type 3) while for resourceful farmers (Farm type 1) the transaction is governed by relational contracts. The relational and formal contracts for sunflower in Zembe involving Farm type 3 are the result of the need to prevent high transaction costs due to widely dispersed farms.

Smallholder farmers face numerous challenges to enter into new value chains due to the costs associated with accessing information, complying with market requirements and negotiating and managing the contractual arrangements (Tittonell *et al.*, 2010b; Poulton *et al.*, 2010). Given that large buyers such as WFP look for commodities in large volumes, smallholder farmers are squeezed out of value chains that require large volumes. In such situations, collective action can help smallholder farmers to achieve scale, improve bargaining power and benefit from new market opportunities (Staal *et al.*, 1997; Markelova *et al.*, 2009). Successful collective action assumes a certain degree of homogeneity among farmer interests. However, farming systems analysis informs us that smallholder farmers are not a homogeneous group, and collective action needs to accommodate this heterogeneity. As observed in Farm type 3, there is a need for measures beyond collective action that addresses the immediate selling of products by these farmers when market prices are low.

Our Windmill Diagram (Figure 5.1) emphasizes that each farmer participates in multiple value chains. The key point of this diagram is that farmer decisions on cropping and on sales arrangements are interdependent, and are all taken simultaneously within the farm system. Thus, the farm is the central axis of the model, while the value chains are the vanes. In our case studies, the vanes represent the maize, sunflower and sesame value chains with different cropping calendars and resources demands, while the axis (i.e. the node where all wings come together) is the farm type (or farm system) where simultaneous decisions on production and sales are made. While the TCE can be applied to multiple value chains, some studies tend to focus on one value chain at time (Fisher and Qaim, 2012; Saenger et al., 2013) resulting in limited understanding of why farmers cultivate certain crops as well as choose particular sales arrangements.The Windmill Diagram is particularly useful in exploring the possibilities of introducing a new crop, such as soybean in our case studies. The diagram can be seen as starting point for development of a framework or approach that combine the Farming Systems and TCE theories in better understanding s the institutional arrangements preferred by smallholder farmers in developing countries.

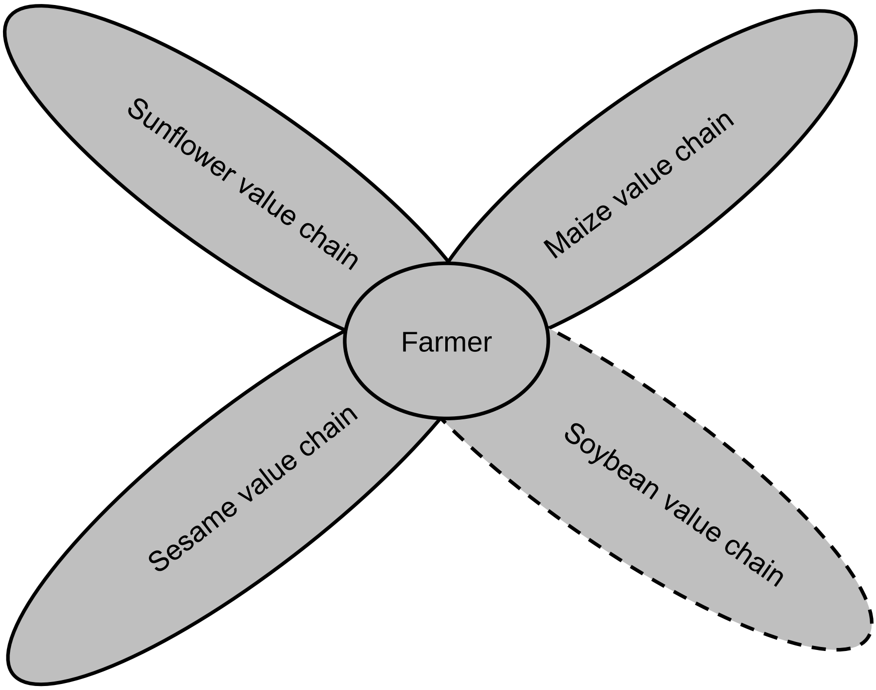

Fig. 5.1. The Windmill Diagram: The farmer engaged in maize, sunflower and sesame value chains. The dotted lines or the vane represent new value chain such as soybean.

6. Conclusion and policy implications

The empirical evidence from the two case studies allowed us to suggest that the combination of farming systems approach and transaction cost economics theory is useful to understanding farmer choices as to crops and value chains. This suggestion is visualized in the Windmill Diagram (Figure 5.1). To operationalize the Windmill Diagram, one should first acknowledge that farmers are diverse, adopt different strategies and engage in more than one value chain. Any rapid survey covering aspects related to resource endowment, production activities, and constraints to agricultural production can be used as entry point to understand the diversity among farmers. A farming systems approach deserves a more prominent place in understanding sales arrangements for agricultural products in smallholder farming settings.

Our paper is of interest both for development scholars and development practitioners who seek to analyse and promote sustainable market access for smallholders. We argue that a farmer decision to participate in a particular (new) value chain is determined by (a) the suitability of the new crop in the farm system (including the adaptability of the current farm system), and (b) the farmer's experiences with selling in various value chains. As methods for soybean production do not differ significantly with current cultivated cash crops, it is likely to be grown by all farm types. The scale of production required in the soybean industry suggests that soybean transactions are likely to be governed by relational or formal contracting for all farm types, similar to the current sunflower and sesame contracts. A key policy message is that farming systems analysis deserves more prominent place in understanding sales arrangements for agricultural products in smallholder farming settings. This is particularly relevant for the Mozambican agricultural development policy (PEDSA) objective of linking smallholder farmers into markets in sustainable manner.

Acknowledgement

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Chapter 6

General discussion

6. General discussion

6.1 Reflecting on the research process: adjusting the vanes of my thesis

As a PhD candidate at Wageningen University we are expected to develop knowledge that serves mankind and society at large. The candidate is also expected to learn how to formulate scientific questions based on social issues. While reflecting on the research process that I went through to accomplish my thesis, I came to the realization that I was capable to place the research aims and research results in a societal context as illustrated below.

The soaring of fossil fuel prices observed in 2007 until mid-2008 (von Braun, 2008), concerns with climate change and the need for energy independence contributed to a worldwide increase in demand for biomass for biofuel with focus on first-generation techniques (IPCC, 2007). Developing countries, especially in sub-Saharan Africa, were thought to be able to provide an answer to this demand due to available land and climatic conditions for crop production (Batidzirai *et al.*, 2006; Jumbe *et al.*, 2009) . However, at the same time there are opposing positions on potential benefits and risks of biofuel. Proponents claim that biofuel is an opportunity to promote rural development, to link farmers to markets, to increase yields of current food crops through technological spill-over from biofuel to food crops and to mitigate global warming (Peskett *et al.*, 2007; Arndt *et al.*, 2010). Opponents express their concerns on expected negative impacts on food availability, soil nutrient depletion and lack of environmental benefits (Rosegrant *et al.*, 2008; Bindraban *et al.*, 2009). Given that the debate was around potential and not feasible options, this was an excellent opportunity for a PhD research to shed some light on the debate.

Mozambique, a country well known for its abundant land and ample water resources was one of those sub-Saharan African countries that could not be overlooked in the biofuel debate (Batidzirai *et al.*, 2006; Arndt *et al.*, 2010). At the beginning of my thesis I had a clear idea on my research questions, (a) to identify the major factors determining the opportunities and risks for sustainable production of biomass for energy under agro-ecological and socio-economic conditions that prevail in Manica Province and (b) to identify the indicators to capture relevant environmental, economic and social issues in the production of biomass for biofuel.

In Mozambique, most of the biofuel initiatives were concentrated in the areas with high agro-ecological potential for crop production such as the *Beira Development Corridor* (Schut *et al.*, 2010). For instance, within Manica two biofuel investments that began in 2007, one for biodiesel (5000 ha) from jatropha and one for bioethanol (18000 ha) from sugarcane, were at an advanced stage of their establishment by late 2008, the peak of discussion on sustainability of biofuel investments. However, no sooner than I had identified the two study sites in 2009, the interest on biomass production for biofuel started to wane in Mozambique, particularly in my study areas. This situation left the smallholder farmers in a complicated situation given the expectations created around biofuel. Therefore, I adjusted the scope of my thesis similarly to what a farmer does, adjusting the priorities based on available resources and opportunities (see Chapter 5). I reformulated my objectives and focused on assessing opportunities and constraints for agricultural development in the context of smallholder farms in Mozambique. My starting point was that, biofuel crops are simply cash crops that can be grown by smallholder farmers, such as sunflower and sesame among others already under cultivation by these farmers to improve their livelihoods.

In this thesis I used a stepwise approach of which the major findings and conclusions are discussed in relation to major policy goals for agricultural development in Mozambique (PEDSA). The discussion is illustrated by a "staircase" (Fig. 6.1) in which I explore agricultural development from different levels of decision making (from farmer to policy maker) and scale of analysis (from field to country level). By ascending the staircase, the scale of analysis and the level of decision making shift from field to country and from farmers to policy makers, respectively. The steps 1 and 2 refer to decisions taken at farm level with a farm household as the main player. The steps 3, 4 and 5 are related to decisions taken at higher levels, e.g. decisions taken at government level through PEDSA. Different perspectives for agricultural development exist between livelihoods of smallholder farmers and the national interests (Giller *et al.*, 2008). The farmers' feedback to national interest largely depends on household resources, aspirations and livelihoods options (Udo *et al.*, 2011; Dorward, 2009). In each of the steps, I discuss the constraints and opportunities for smallholder farmers to contribute to agricultural development.

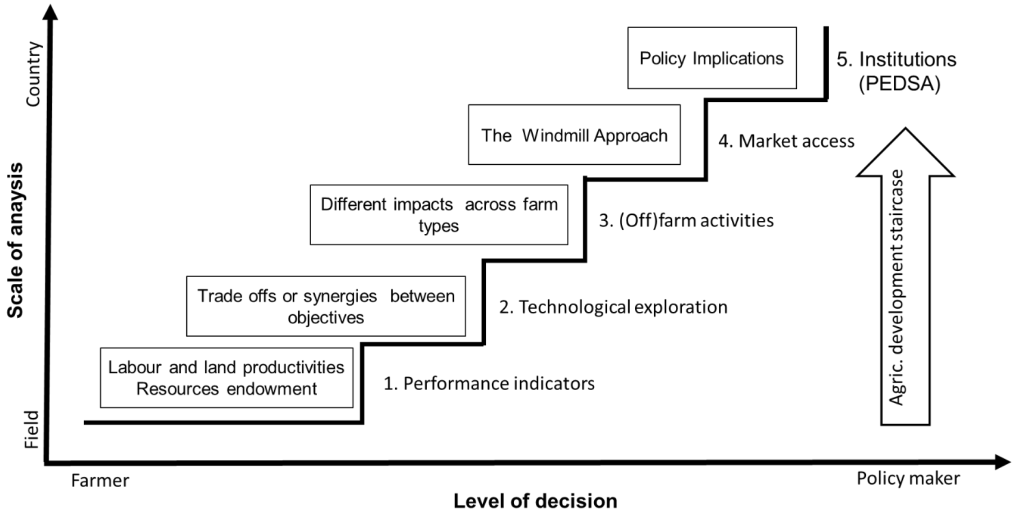

Fig. 6.1. Agricultural development staircase for smallholder farmers in Mozambique

6.2 Agricultural development in Mozambique

Performance indicators

Successful agricultural development in Mozambique, if to be based on small farms will require first, a recognition that these farms are diverse and that scope for improvement varies across farms. Thus, categorisation of this diversity is the first step in understanding drivers to better target agricultural innovations (Tittonell *et al.*, 2010b). Second, the productivity of current systems, socio-economic conditions of different farmers and their management decisions leading to land use activities (cropping systems, labour allocation) need to be understood.

In Chapter 2, I investigated the diversity, constraints and opportunities in the maize-based smallholder farming systems in Zembe and Dombe Administrative Posts, central Mozambique, to identify the constraints to increase productivity and achieve food security. While land, labour and capital are all important production factors. In my study area there is abundant land that farmers can clear if and when they have the resources to do so. Farmers also have very little capital to invest. However, in the context of Mozambique labour is an important factor that is often neglected. My literature review on the influence of labour availability on agricultural production in Mozambique yielded very few studies. In this context the study has rendered new insights for understanding entry points for improvement of agricultural productivity. The main findings is that labour and land are the key resources shaping the diversity of smallholder farms (Fig. 2.3) and as such useful entry points for improvement of agricultural productivity. Based on these two resources, smallholder farms in both posts were the categorized in large farms (hiring in labour), intermediate sized farms (hiring in and out labour), small farms (sharing labour) and small farms (hiring out labour). In both posts, the performance indicators labour and land productivity of maize, sunflower and sesame were higher on large farms than on small farms (Table 2.6). Several studies indicate an inverse relationship between size and productivity of the farm (Rao and Chotigeat, 1981; Barrett *et al.*, 2010). An inverse relationship is suggested to exist when small farms use more labour per hectare and thus carry out farm operations diligently allowing them to produce more per hectare than large farms. In addition, family labour is cheaper relative to hired labour used on large farms. While in my study, the smaller farms used more labour per hectare (Table 2.6), their productivity was low due to delayed weeding as they needed to sell their labour. Delayed weeding on their own fields meant that the competition between crop and weeds was severe requiring more labour to remove the weeds. Large farms are able to augment their own labour during the labour peak period by hiring in labour from small farms. One sensitive social-cultural issue that emerged from the farming systems analysis is the excessive amounts of alcohol consumed by small farmers which may reduce labour productivity. So the combined effect of delayed weeding and excessive alcohol consumption led to less productivity on the smaller farms. Dorward found similar trends in Malawi (Dorward, 1999), where a positive relationship between land size and productivity which was associated with selling labour by poorer farms and larger farms having better access to capital.

In Mozambique smallholder farms are categorised into small, medium and large farms based on cultivated area, number of livestock (depending on type) and area under irrigation (INE, 2011a). Following these criteria, a farm would fall into the small farm category if the cultivated area is less than 10 ha, it has less than 10 cattle and uses irrigation on less than 5 ha. According to this categorisation, all farms in my research area are small farms and, in principle, would face the same opportunities. Yet, the results (Table 2.6) show large differences in performance indicators among small farms that need to be considered in

planning technological interventions aiming to improve smallholder farming systems. One-size-fits-all policy solutions do not address this finding. The promotion of jatropha production by the Mozambican Government in 2004 in which farmers were all encouraged to grow this crop to become an oil exporting country (Schut *et al.*, 2010), is a good example of an one-size-fits all policy solution. It is a solution that did not work due to poor crop management and lack of finance. For instance, it was assumed that jatropha could grow in soil unsuitable for agriculture. However, jatropha requires external inputs such as fertilizers and water as well careful crop management just like any other crop (Tjeuw *et al.*, 2015).
Does this mean, then, that my results are refuting the argument that much agricultural development has been driven by small farms? The answer to this question needs to be contextualized within the diversity and complexities that characterizes smallholder farming systems (Giller *et al.*, 2011). For instance, Chapter 2 shows that large farms in Zembe cultivate 2.1 ha whereas in Dombe large farms cultivate 4.4 ha (Table 2.6). Small farms cultivate 0.9 ha in Zembe and 1.3 ha in Dombe. So, we should see the large farms as relatively large among the smallholder farms (≤10 ha). And an option suitable for improvement of large or small farms at any given location may not be the same for farms in another location. The results of crop and livestock census in Mozambique indicate that 99.3 % of smallholder farmers fall under category of small farms, with a cultivated area between 0.1 ha and 10 ha (INE, 2011a). Regardless the official classification, the picture that emerges from Chapter 2 (Table 2.6) is that productivity varies among 'small' farms which in turn determines different possibilities for improvement (Dorward, 2009).

Technological exploration

Building on the performance analysis across different farm types (Step 1 in the staircase), in this section I discuss the results from alternative technologies that I explored in Chapter 3 aiming at improving the livelihoods of smallholder farmers in Dombe and Zembe Administrative Post (post), and the contribution to food security at national level. While farmers in both posts share the common objectives of being self-sufficient in maize and achieving increased gross margin from crop production, the picture emerging from Chapter 2 shows different possibilities for the diversity of farms in both posts. Therefore, using a bio-economic farm model and I explored current and new production activities to address farmers´ and national objectives. I focused on the large (hiring in) and small farms (hiring out) labour as categorised in Chapter 2. Based on production of maize, sesame, sunflower, soybean and pigeonpea production, I showed that there are opportunities to increase farmer´s income without compromising regional maize self-sufficiency either through extensification (labour saving) or intensification (land saving) options or both. The explored labour saving options, use of animal traction and herbicides, were associated with strong trade-offs between increasing gross margin and producing maize for the national market, especially for large farms (Fig. 3.1). Although labour saving options allow farmers to increase cultivated area which may lead to more production, increase in gross margin was much higher than increases in maize sales (Fig. 3.1). So, the national objective is less likely to be achieved with extensification options only, especially in regions such as Dombe where sole sesame provides more income than sole maize, and maize-sesame intercropping has a relatively low maize yield. The most promising option to address both objectives, was the combination of labour and land saving options, i.e., the new cropping pattern of maize-pigeonpea cultivation using improved varieties and herbicides for weeding. The boom of pigeonpea for export marketing in Mozambique with relatively higher prices compared with other legumes such as groundnut, soybean and cowpea, offers a good opportunity for farmers to increase gross margin. In both posts, improvement options on the smaller farms are minor, which may be a disincentive for these farmers to invest cash in agriculture. To improve the livelihood of such poor and disadvantaged smallholder farmers other alternatives that provide regular income are needed, either inside or outside the agricultural sector.

(Off) farm activities

The performance indicators analysis (step 1) and the technological explorations (step 2) discussed above, indicate different pathways for smallholder farmers' livelihood improvements in the maize-based farming systems. Drawing on the analysis of smallholder farmers participating as workers on a jatropha plantation and in a sunflower outgrower scheme, in this step 3 of the staircase, I discuss how food security (food availability, food access, food utilization and food stability) of the farming households was impacted by participating in biomass production for food and for biofuel, as well as the associated risks.

The discussion on the potential impact of large scale investments in agriculture on smallholder farmers livelihoods remains polarized between visions that these investments are a new form of land and resources *grabbing* on the one hand (Cotula, 2012; Rulli *et al.*, 2013), and job opportunities and rural development, on the other (FAO, 2008). In this thesis I see the production of biomass for biofuel as source of income not so different from any other source, such as cotton, or tobacco where smallholder farmers can have direct (produce on own fields) or indirect (working on plantation) participation.

In Chapter 4, I investigated how the food security of large, intermediate sized and small farms in central Mozambique is impacted by participating in biomass production for food and biofuel by looking at two modes of participation: an outgrower scheme for sunflower and a jatropha plantation offering full time employment. Full time employment in a jatropha plantation improved food security, in particular the access dimension of food security, of small farms because of the regular income from plantation work. For the large farms the positive food security impacts were improvements in availability of food. While full time employment is an important escape route out of poverty for small farms, there are risks associated with being employed at large-scale plantation such as job losses when economic conditions dictate cuts in the workforce. For instance, the number of full time employees in my case-study area decreased from 529 employed in 2009 to 83 employed in 2012, due to collapse of Sun Biofuels Company (MINAG, 2012b). The annual income from sunflower was small compared with the salary from plantation (Figs 4.3 and 4.4) for both large farms ($ 840 versus $ 95) and small farms $ 790 versus $ 45), partially due to poor yields (Table 2.6B). Outgrower schemes are often linked to technology spill-overs and production increase (Arndt *et al.*, 2008). However, we did not observe such spill-overs. The outgrower scheme in Zembe only provided sunflower seed and technical backstopping on sunflower cultivation. It did not include access to fertilizers that could increase yields

Lessons learned from the analysis of how full time employment at a jatropha plantation improved the livelihoods of larger and smaller farmers can be used in designing large agricultural investments in Mozambique such as the (ProSavana Project), a tripartite project (Mozambique, Brazil and Japan) for food and cash crop production in northern Mozambique. If such investments are to include small farms, full time employment is the best option for these farmers. For large farms, this initiative may not be an attractive option given that these farms are able to make a comparable income as well as producing food beyond their own household need.

Market access

Linking smallholder farmers to agricultural markets is matter of great concern for smallholder development (Fischer and Qaim, 2012). Several studies have made significant contributions in understanding the advantages and disadvantages that smallholder farms face when trying to access agricultural markets (Barrett, 2008; Poulton *et al.*, 2010). For instance, the competitive advantages of smallholder farms over large farms on accessing and supervising household labour is countervailed by high transaction costs in almost all non-labour transactions such as procuring inputs, getting agronomic and technical information, accessing produce markets, obtaining credit and financial services (Key and Runsten, 1999; Poulton *et al.*, 2010). Farm dispersion, poor infrastructure, low education level are further weakening the possibilities of smallholder farmers to access agricultural markets (Markelova *et al.*, 2009). Smallholder farmers access to markets through different sales arrangements such as spot markets, informal contracting, formal bilateral contracting, multilateral contracting (i.e. a cooperative), gaining ownership in a processing or marketing company, or complete vertical integration (Peterson *et al.*, 2001; Raynaud *et al.*, 2005). Studies on the choice of particular marketing arrangements for selling the produce by smallholder farmers tend to focus on one value chain at a time (Collier and Dercon, 2014; Saenger *et al.*, 2013). In addition, studies on the rationality of farmers for choosing particular sales arrangements apply the Transaction Cost Economics (TCE) theory (Staal *et al.*, 1997; Dorward, 2001). Therefore, these studies tend overstate the transaction costs. In the Chapter 5, I used the farming system analysis and presented an diagram illustrating a farm participating in different value chains as well as the centrality of the farm system as the focus of decision-making. In this illustration I acknowledge that smallholder farmers cultivate multiple crops and therefore engage in multiple value chains and challenges the bias towards one value chain and TCE. It adds that the decision to engage in a specific sales arrangement is geared by resources endowment and not only by transaction costs.

Institutional setting

In Mozambique, agriculture is seen as a key to the overall economic development as summarized by government's strategy to boost food production across the country, the Strategic Plan for Agricultural Development (PEDSA) (MINAG, 2011). Yet, the goal of PEDSA seems far from being achieved.

I analysed opportunities for agricultural development of smallholder farms aiming to improve food security and increase gross margin, as well as to contribute to the national goal of producing more maize for local market (Chapters 2, 3, 4 and 5). These findings are timely given that the Mozambican Government has defined increasing agricultural productivity (yield per hectare) of smallholder farms to end hunger and lift people out of poverty. The poor land and labour productivities coupled with the wide differences among farms, as shown in Chapter 2, call for measures that are consistent with this diversity in farms. The farm typology developed demonstrates that by looking at land and labour most of the variability of smallholder farms can be captured. The further validation of the outcomes of our typology with the national representative agricultural census (TIA) (Leonardo *et al.*, 2015) reinforces how a simple and pragmatic approach of classification based on labour dynamics can provide a robust and insightful typology of farms. The observed labour dynamics are a common characteristic of smallholder farms in the country, therefore, its inclusion in the TIA census allows the development of farm typologies that can readily be understood by policy makers and translated into practical measures with immediate applicability to different farm types, avoiding one-size-fits-all solutions.

Chapter 3 shows that innovations introducing animal traction and herbicides can reduce farmers' labour constraints, so, allowing farmers to expand the current cultivated area into fallow land. By doing so, farmers can increase gross marginwhile maintaining maize production level beyond their immediate food need. One concern with continuous cultivation is soil fertility depletion (Sanchez, 2002), as farmers currently use no chemical fertilizers or manure. In my study sites, apart from nitrogen, the soil availability of the other two nutrients is currently adequate for maize production (Chapter 2). Legume crops are cost-effective sources of nitrogen due to the ability to fix atmospheric nitrogen biologically into the soils (Giller, 2001). The simulation results from Chapter 3, show that maize-pigeonpea intercropping has a potential of doubling the current maize yields in the region. For successful introduction of maize-pigeonpea intercropping there is need for smallholder capacity building on to best cultivate these crops as well as to set up mechanisms to allow them to access the improved varieties. Sales arrangements to sale maize and pigeonpea need to be discussed with farmers.

Since 2002, the Mozambican Government and its partners such as the FAO have been implementing an agricultural input voucher program primarily in response to disasters such as floods and droughts (Leonardo, 2000; Longley *et al.*, 2002) and more recently as part of a strategy to increase smallholder farm productivity (http://www.fao.org/in-action/fao-launches-the-first-electronic-voucher-scheme-in-mozambique/en/). A similar subsidy programme has been implemented by the Government of Malawi where improved seed and fertilizers were provided at reduced cost resulting in maize yield increase up to 5 t ha^{-1} in some locations (Denning *et al.*, 2009). In Mozambique, the programme subsidizes the price of improved seeds of cowpea, maize, soybean, beans, fertilizers and insecticides. It is expected that farmers will apply fertilizers on improved seed of maize. In Chapter 3 I explored the influence of subsidies on improved seed and fertilizers on land use. My results showed that even with a 100 % subsidy it is more attractive for farmers to buy improved seed rather than fertilizers, at least for the crops I analysed (maize, sesame, maize-sesame, soybean, sunflower, and maize-pigeonpea). In particular for small farms, fertilizers are not attractive at all. Evidence from direct observations and discussions with key informants and agrodealers involved in the current subsidy program indicate that farmers are applying fertilizers to vegetables because they are more profitable than any other crop included in the voucher program. The results from simulations that I carried out in the Chapter 3 shows that fertilizers are not selected at both maximum gross margin and maize sales. Indeed, applying fertilizers on maize is not profitable compared with maize-pigeonpea intercropping as maize benefits from N_2 biologically fixed by pigeonpea. As such I encourage the Mozambique Government to promote pigeonpea ensuring seed of good varieties is available together with a functioning market for the produce.

The analysis of biofuel investments (Chapter 4) clearly shows that the food security of small farms who are not maize self-sufficient because of hiring out labour and excessive alcohol consumption, therefore are trapped into poverty, is significantly improved when they can earn an income from working at a plantation. This indicates that biofuel plantations should be seen as any other large-scale investment in agriculture. As (Giller *et al.*, 2008) indicated, the national interest in agriculture production and objectives of smallholder farmers may be in conflict compromising the potential impacts of the development intervention. Consequently, transparency and inclusion of all stakeholders is necessary so that the interests of all parties are taken into account. Inclusion and consultation can help to avoid large investments in agriculture becoming another form of *land grabbing*. The high risk associated with sustainability of these large-scale investments (e.g. biofuel) has to be acknowledged *a priori* by designing measures that further stimulate small farms to invest cash from employment into their own farms.

Linking smallholder farmers to the market is vital in promoting rural development and poverty reduction (Fischer and Qaim, 2012). To do so, Government and NGOs in Mozambique are trying several approaches to assist farmers to organise such as cooperatives or farmers associations. One component that has been neglected is how these approaches address the diversity of smallholder farms. For instance, it assumed that all farmers will benefit equally from collective marketing initiatives of agricultural products such as farmers associations for marketing (Chapter 5). I have proposed a combination of farming systems analysis with TCE theory as approach that addresses the shortcomings of current approaches. For policy makers, NGOs, and other supporting organizations want to assist smallholder farmers to access agricultural markets, they need first to understand the diversity in resource ownership. This can be done through farming systems analysis (Chapter 2). Next, they need to understand what motivates the cultivation of current crops and how new crop(s) can fit within the existing farming systems. The TCE theory informs on costs incurred by particular sales arrangements. When the farming systems and TCE theories are combined, the constraints and opportunities of different sales arrangements in each farm type can be highlighted, allowing policy makers, NGOs, and other supporting organizations to define interventions to support smallholder farms. For instance, by applying this framework to smallholder farmers in Dombe and Zembe I have shown and explained why small farms hiring out labour farms benefit less from collective marketing initiatives such as the cooperative in Dombe as they sell the produce immediately after harvesting. Based on the above insight, policy makers and other development practitioners can propose an intervention can consist of addressing the poor price paid due to earlier selling of products at harvest, especially by small farms. This can be done through Warehouse Receipt Systems (WRS) as implemented in Zambia (Coulter and Onumah, 2002). In WRS a farmer or group deposit his or their produce in a warehouse and to meet his or their short term need for cash by he or they can borrow from a bank or other lending institution using issued documents by WRS. This type of intervention can help to address the PEDSA objective of converting "subsistence agriculture" into competitive, sustainable and market-oriented agriculture

The question that formed the basis of my research was how agricultural development based on smallholder farmers can be achieved in Mozambique while improving their livelihoods. The answer is that, one should first acknowledge that farmers are diverse in terms of farmers resources, aspirations and behaviour (Dorward, 2009). Therefore prospects for development differ among farms. It is important to recognize that farming will not be a route out of poverty for all farms, especially the smaller ones who hire out labour. These farmers are farmers by default; complementary efforts to support their livelihoods are needed (Wiggins, 2009).

6.3 Reflection on methodology and future study

To explore pathways for development of smallholder farms in maize based farming systems in central Mozambique, I used an integrated approach. In this I took into account different levels of decisions (farm to policy maker) and scale of analysis (field to country). This integrated approach was employed in this thesis. First, I gathered information from different sources such as literature, farm surveys, focus group discussions, key informants and on-farm experiments. Second, I used different methods such as modelling tools and direct observations, to understand the study sites, diversity of farms, constraints and opportunities to increase productivity. Third, I explored different scenarios for extensification and intensification of smallholder farming systems. Fourth, I investigated how food security of a diverse of farms is impacted by participating in production of biomass for fuel and food, and fifth I proposed an approach for policy makers, development scholars and practitioners who seek to analyse and promote sustainable market access for smallholders farmers.

The farm surveys were important in providing information for categorisation of farms. The information on labour use for crop production at field level is based on both rapid and detailed surveys at farm level (Chapter 2). Accurate data on labour can only be obtained through direct measurements. Yet, monitoring labour dynamics requires more resources and time than available. Our results clearly indicate that delayed weeding is the main constraint faced by small farms due to hiring out labour. I was not, however, able to measure the direct effect of the delay in weeding (by one week, two weeks, and so on) on crop production over time. This area needs more attention in future studies. The typology developed is a straight-forward approach to categorise farms in regions were land and labour are the main crop production factors. In regions with different level of inputs use such improved seed, fertilizers or herbicides, the financial capacity to access these inputs can be added in the categorisation of farms. So, the categorisation of farms needs to be adapted to the local circumstances. The focus group discussions (Chapter 2) and direct observations were crucial to understand other social dimensions such as alcohol consumption. This would not have been possible with only a farm survey.

Calculating trade-offs or synergies using the ε-constraint method (Mavrotas, 2009), allowed me to analyse and illustrate in transparent manner how gross margin and maize sales are impacted when several options are considered at farm level. However, in trade-off analysis (Chapter 3) I only considered two objectives (income and maize production) at a time. This is obviously a simplification as livestock keeping and charcoal production are some of the coping strategies of the farmers in Zembe and Dombe. For instance, Chapters 2 and 4 show that large farms have more livestock (Table 2.5) and a high income from charcoal production (Figs 4.3 and 4.4). The small farms, on the other hand, had less remunerative sources of income (Figs 4.3 and 4.4). Therefore, I expect that the emerging picture from my analysis showing better prospects for large farms would not be changed by the inclusion of other coping strategies employed by farmers. Stoorvogel et al. (2004), pointed out that, trade-off analysis should be seen as supporting decision-making and to help farmers and other practitioners to collectively discuss and choose between different pathways for development. For the calculations on gross margin I assumed that the daily expenditures are covered only by income from crop production. In reality, farmers may use income from other sources such as livestock. So, the current gross margin from crop production might be slightly higher. Yet, annual income of smaller farms will remain below what they could earn through employment in on-farm or off-farm activities.

Patrilineal systems dominate Mozambican culture in which men (head of household) have control over resources and women have little to say. This has implications in the intra-household distribution of food, with the head of the household getting the most nutritious food. The nutritional effect of food eaten by an individual is function of how food is cooked/prepared and stored. The incidence of pest and diseases affecting the quality of stored maize is common among smallholder farmers throughout Mozambique. The analysis of biofuel impacts on food security of smallholder farmers did not include the intra-household food distribution, food preparation, the quality of maize consumed and energy content. To understand the above issues would require close monitoring of each household, which was not practical within the framework of my thesis.

Excessive alcohol consumption indicated that labour quality was impaired on smaller farms, but more research is needed to understand the implications for agricultural productivity in my study areas. It is also important to understand the drivers for excessive alcohol consumption to identify entry points for improvement of the livelihood of farmers. Awareness campaigns for behaviour change led by traditional leaders (*regulo*) or respected people within the community have to be tested.

The integrated approach employed in this study can aid policy makers who are searching for pathways to improve the livelihoods of smallholders in Mozambique. Throughout the thesis and general discussion I have indicated how this approach can be implemented by policy makers and other practitioners.

6.4 Some final thoughts: Can agriculture be pathway out of poverty in Mozambique?

The Mozambique Constitution (Article 39) states "In the Republic of Mozambique agriculture is the basis of national development". Indeed, the abundant land (estimated at 36 million ha of cultivatable land in total) and favourable agroecological conditions for crop production suggest that Mozambique is well placed to make agriculture the engine for national development. And Mozambique's history testifies to that: the country was the world's largest cashew and copra producer, and more than self-sufficient in rice. Now, the large farms sustaining that agro-economy have all but disappeared and agriculture is highly dependent on smallholdings. Today, these smallholdings account for 96 % of the 5.6 million ha which is the current total cultivated area. Smallholder farmers are responsible for 95 % of the area allocated to food crops and 76 % of the cash crop area. Crop yields of smallholder farms are low because they use few inputs such as improved seed, fertilizers and mechanization (Chapter 2).

My results indicate that livelihoods of smallholder farmers can be improved through agriculture. But it is highly questionable that these farmers will be willing to invest resources in crop production beyond their immediate needs for cash and food self-sufficiency. The crop prices are low, in particular for maize, a staple food. Marginal gains from investments are small. Hence it is logical for smallholder farmers to opt for less intensified production systems that yield less but ensure their subsistence.

My observations during the three years that I spent in the Dombe and Zembe suggest that maize is a profitable crop but for other actors in the maize value chain. During my fieldwork I observed large trucks with itinerant buyers crossing the dusty tracks and wobbly bridges to purchase large quantities of maize. One businessman used to arrive by helicopter to pay for the maize his company bought at assembling points. He declined to be interviewed, but farmers told me that he used a helicopter to avoid the threat of robbery as he was carrying large amounts of cash and arriving at regular times. Him using this means of transport tells much about the lack of security in the area. It also speaks loudly about high transaction costs along the value chain, and the contrast between the lack of infrastructure in Dombe and Zembe, and the use of a helicopter to pay for the maize raises some questions as to the accrual of profit in the maize value chain.

The maize trading operations appear to make profit. No matter the reasons behind the use of vastly different sophistication of technology by different actors in the value chain, the question is who profits and who bears the burden of the costs? The amounts of maize sold each season result in an income of $ 2800 and $ 800 per season for the largest farms in Dombe and Zembe, respectively, and $ 700 and $180 per season for the smallest farms in Dombe and Zembe, respectively. The farmers' income shows that maize value chain is only profitable for the 'helicopter buyer', other company and itinerant buyers because they are trading in such large volumes of maize.

Certainly the farmers, especially those with very small farms, remain poor. The poorer farmers appear to be in a state of permanent anaesthesia due to the consumption of alcoholic beverages! My results (Chapter 2) paint a rather depressing picture of a vicious cycle of poverty for about 40 % of smallholder farmers in this area of relatively high agricultural potential in Mozambique. So, how can the smallholder farmers effectively benefit from marketing their produce? How can we avoid the so called "poverty penalty"? Is there a way for farmers to escape the poverty trap? Experience in other countries indicates that eventually the poor will be forced to abandon agriculture (Van Vliet *et al.*, 2015). In Mozambique this has yet to happen because the land has not been privatized and access to land remains a basic right of the farmers.

There are several initiatives in the region that aim to improve the productivity of smallholder farms. For example, the N2Africa project with goal of enabling African smallholder farmers to benefit from symbiotic N2-fixation by grain legumes through effective production technologies, including inoculants and fertilizers (www.N2Africa.org); the SIMLESA Project aiming it increasing farm-level food security and productivity; the PROMAC Project aiming at increasing crop yields with final goal of increase income through better practices of Conservation Agriculture (CA), just to mention a few. My results suggest that technologies that demand for more labour such as CA, given the lack of access to herbicides, are less likely to be a viable pathway to improve smallholder livelihoods in my study region. Insights from my thesis indicate that there is a need to tailor and adapt whichever technology that is introduced to socio-economic conditions of the farmers.

While writing this reflection, I interacted with key informants among the wealthier farmers in Dombe and Zembe by telephone to understand their thoughts on the way to lift the smaller farms out of poverty. The answer was simply: "Wilson – find them jobs!". These smaller farmers are simply farmers "by default". The opinions of these key informants confirmed my findings on the need of off-farm opportunities for this segment of the farming population to step out of agriculture. Otherwise these farmers may not be able to step up the poverty ladder, and may end up "falling down" (Dorward, 2009).

Taking this into consideration, the country must invest in productive agricultural systems adapted to smallholder farming setting (as shown in the Chapter 3), stabilize agricultural prices and ensure that farmers receive more for their produce. Balanced prices are important. High prices may inhibit access to food for the poor but low prices may hamper investment that should increase employment and moderate the cost of food production in poor countries (Koning and Mol, 2009). In parallel investment is required in creation of sources of income that can absorb the poorest, who produce food for their families and for sale but do not live on it, only survive. Though the paper is not on price policies, findings of my research shows that the current prices paid for agricultural produce, especially maize, are extremely low. In Chapter 2 I provided data on monetary return from agriculture. The results shows that maize is not a profitable crop for the farmers, but it remains the crop that produces the most calories of all available. Given that farmers have no reliable access to purchase food they continue to grow maize. Also in Chapter 3, the results from the exploration of alternative production activities shows the same results (see the value of maize sales).Good policies should go hand-in-hand with good understanding of local context, so that all players in each value chain get a fair share of the profits. In other words, more inclusiveness. Inclusiveness or fair sharing of profit requires a basic sense of solidarity with the producers (Tressell, 1914) if national development is to include small rural farms.

References

AGRA (2015a).Agriculture for Africa's economic transformation. Transforming Africa’s agriculture for sustainable inclusive growth, improved livelihoods and shared prosperity. 11 Addis Ababa Ethiopia: Alliance for A green Revolution in Africa.

AGRA (2015b). Agriculture for Africa's economic transformation. Transforming Africa’s agriculture for sustainable inclusive growth, improved livelihoods and shared prosperity. 11 Addis Ababa Ethiopia: Alliance for A green Revolution in Africa.

Alfani, F., Azzarri, C., d'Errico, M. & Molini, V. (2012).Poverty in Mozambique. New evidence from recent household surveys. In *Policy Rsearch Working Paper 6217*, 33 African Region: The World Bank.

Alwang, J. & Siegel, P. B. (1999). Labor shortages on small landholdings in Malawi: implications for policy reforms. *World Development* 27(8): 1461-1475.

Arndt, C., Benfica, R., Tarp, F., Thurlow, J. & Uaene, R. (2008).Biofuels, poverty, and growth: a computable general equilibrium analysis of Mozambique. 21 Washington, DC.: International Food Policy Research Institute.

Arndt, C., Benfica, R., TARP, F., Thurlow, J. & Uaiene, R. (2010). Biofuels, poverty, and growth: a computable general equilibrium analysis of Mozambique. *Environment and Development Economics* 15(01): 81-105.

Baijukya, F. P., Giller, K. E. & Ridder, N. d. (2004).Adapting to change in banana-based farming systems of northwest Tanzania: the potential role of herbaceous legumes. PhD Thesis. In *Plant Production Systems Group*, Vol. PhD, 192 The Netherlands: Wageningen University.

Barrett, C. B. (2008). Smallholder market participation: concepts and evidence from eastern and southern Africa. *Food Policy* 33(4): 299-317.

Barrett, C. B., Bellemare, M. F. & Hou, J. Y. (2010). Reconsidering Conventional Explanations of the Inverse Productivity–Size Relationship. *World Development* 38(1): 88-97.

Barrett, C. B., Reardon, T. & Webb, P. (2001). Nonfarm income diversification and household livelihood strategies in rural Africa: concepts, dynamics, and policy implications. *Food Policy* 26(4): 315-331.

Batidzirai, B., Faaij, A. P. C. & Smeets, E. (2006). Biomass and bioenergy supply from Mozambique. *Energy for Sustainable Development* 10(1): 54-81.

Baudron, F., Andersson, J. A., Corbeels, M. & Giller, K. E. (2012). Failing to yield? Ploughs, conservation agriculture and the problem of agricultural intensification: An example from the Zambezi Valley, Zimbabwe. *Journal of Development Studies* 48(3): 393-412.

Benson, T., Cunguara, B. & Mogues, T. (2012).The supply of inorganic fertilizers to smallholder farmers in Mozambique. Evidence for fertilizer policy development. 40 Washington, DC: The International Food Policy Research Institute.

Berti, P. R., Krasevec, J. & FitzGerald, S. (2004). A review of the effectiveness of agriculture interventions in improving nutrition outcomes. *Public Health Nutrition* 7(05): 599-609.

Bidogeza, J. C., Berentsen, P. B. M., Graaff, J. & Oude Lansink, A. G. J. M. (2009). A typology of farm households for the Umutara Province in Rwanda. *Food Security* 1(3): 321-335.

Bindraban, P. S., Bulte, E. H. & Conijn, S. G. (2009). Can large-scale biofuels production be sustainable by 2020? *Agricultural Systems* 101(3): 197-199.

Bolwig, S., Ponte, S., Du Toit, A., Riisgaard, L. & Halberg, N. (2010). Integrating poverty and environmental concerns into value-chain analysis: a conceptual framework. *Development Policy Review* 28(2): 173-194.

Bryceson, D. F. (1999). African rural labour, income diversification and livelihood approaches: a long‐term development perspective. *Review of African Political Economy* 26(80): 171-189.

Chamusso, A., Zikhali, P., Musaba, E., Gêmo, H. & Osvaldo, L. (2013).Trends in publicaAgricultural spending in Mozambique. 8 South Africa: The Regional Strategic Analysis and Knowledge Support System (ReSAKSS).

Cittadini, E. D., Lubbers, M., de Ridder, N., van Keulen, H. & Claassen, G. D. H. (2008). Exploring options for farm-level strategic and tactical decision-making in fruit production systems of South Patagonia, Argentina. *Agricultural Systems* 98(3): 189-198.

Cohen, M. J., Tirado, C., Aberman, N. & Thompson, B. (2008).Impact of climate change and bioenergy on nutrition. 86 Washington, D.C and Rome, Italy: International Food Policy Research Institute and Food and Agricultural Organization of the United Nations.

Collier, P. & Dercon, S. (2014). African Agriculture in 50 Years: Smallholders in a Rapidly Changing World? *World Development* 63: 92-101.

Cotula, L. (2012). The international political economy of the global land rush: A critical appraisal of trends, scale, geography and drivers. *The Journal of Peasant Studies* 39(3-4): 649-680.

Coulter, J. & Onumah, G. (2002). The role of warehouse receipt systems in enhanced commodity marketing and rural livelihoods in Africa. *Food Policy* 27(4): 319-337.

De Schutter, O. (2011). How not to think of land-grabbing: three critiques of large-scale investments in farmland. *The Journal of Peasant Studies* 38(2): 249-279.

Delgado, C. L. (2003). Rising consumption of meat and milk in developing countries has created a new food revolution. *Journal of Nutrition* 133(11 SUPPL. 2): 3907S-3910S.

Denning, G., Kabambe, P., Sanchez, P., Malik, A., Flor, R., Harawa, R., Nkhoma, P., Zamba, C., Banda, C., Magombo, C., Keating, M., Wangila, J. & Sachs, J. (2009). Input Subsidies to Improve Smallholder Maize Productivity in Malawi: Toward an African Green Revolution. *PLoS Biol* 7(1): e1000023.

Dogliotti, S., van Ittersum, M. K. & Rossing, W. A. H. (2006). Influence of farm resource endowment on possibilities for sustainable development: A case study for vegetable farms in South Uruguay. *Journal of Environmental Management* 78(3): 305-315.

Donovan, J. & Poole, N. (2012). Asset building in response to value chain development: lessons from taro producers in Nicaragua. *International Journal of Agricultural Sustainability* 11(1): 23-37.

Dorward, A. (1999). Farm size and productivity in Malawian smallholder agriculture. *Journal of Development Studies* 35(5): 141-161.

Dorward, A. (2001). The effects of transaction costs, power and risk on contractual arrangements: a conceptual framework for quantitative analysis. *Journal of Agricultural Economics* 52(2): 59-73.

Dorward, A. (2009). Integrating contested aspirations, processes and policy: development as hanging in, stepping up and stepping out. *Development Policy Review* 27(2): 131-146.

Dorward, A., Anderson, S., Bernal, Y. N., Vera, E. S., Rushton, J., Pattison, J. & Paz, R. (2009). Hanging in, stepping up and stepping out: livelihood aspirations and strategies of the poor. *Development in Practice* 19(2): 240-247.

Ellis, F. (1998). Household strategies and rural livelihood diversification. *Journal of Development Studies* 35(1): 1-38.

Ellis, F. (2000). The determinants of rural livelihood diversification in developing countries. *Journal of Agricultural Economics* 51(2): 289-302.

Erenstein, O. (2006). Intensification or extensification? Factors affecting technology use in peri-urban lowlands along an agro-ecological gradient in West Africa. *Agricultural Systems* 90(1–3): 132-158.

Eriksen, S. & Silva, J. A. (2009). The vulnerability context of a savanna area in Mozambique: household drought coping strategies and responses to economic change. *Environmental Science and Policy* 12: 33-52.

Fafchamps, M. (2004). *Market institutions in Sub-Saharan Africa: theory and evidence.*

FAO-UNESCO (1988).FAO-UNESCO Soil Map of the World. Revised legend. In *World Soil Resources Report 60*(Ed ISRIC). Rome: Food and Agriculture Organization of the United Nations.

FAO (1996).Rome Declaration on World Food Security. Report of the World Food Summit. Rome, Italy. http://www.fao.org/docrep/003/w3613e/w3613e00.htm. Accessed 12 April 2013.

FAO (2008).The state of food and agriculture. Biofuels: Prospects, risks and opportunities., 138 Rome, Italy: Food and Agriculture Organization.

FAO (2009).How to Feed the World in 2050 In *High Level Expert Forum*, 4 Rome, Italy: Food and Agriculture Organization (FAO).

FAO (2011).Guidelines for measuring household and individual dietary diversity. Food and Agriculture Organization of the United Nations. 60 Rome, Italy.

FAO (2013).Poultry Sector Mozambique. FAO Animal Production and Health Livestock Country Reviews. No. 5. Rome.

FEWSNET (2011). Mozambique food security outlook update - May 2011. Famine Early Warning Systems Network (FEWSNET), Maputo. Available at:www.fewsnet/mozambique.

Fischer, E. & Qaim, M. (2012). Linking smallholders to markets: determinants and impacts of farmer collective action in Kenya. *World Development* 40(6): 1255-1268.

Folmer, E. C. R., Geurts, P. M. H. & Francisco, J. R. (1998).Assessment of soil fertility depletion in Mozambique. 159-167: Elsevier Science Bv.

Fountas, S., Wulfsohn, D., Blackmore, B. S., Jacobsen, H. L. & Pedersen, S. M. (2006). A model of decision-making and information flows for information-intensive agriculture. *Agricultural Systems* 87(2): 192-210.

German, L. & Schoneveld, G. (2012). A review of social sustainability considerations among EU-approved voluntary schemes for biofuels, with implications for rural livelihoods. *Energy Policy* 51(0): 765-778.

German, L., Schoneveld, G. C. & Gumbo, D. (2011). The Local Social and Environmental Impacts of Smallholder-Based Biofuel Investments in Zambia. *Ecology and Society* 16(4 C7 - 12).

Geurts, P. M. H. & Van den Berg, M. (1998). A simple agro-ecological zonation for fertilizer recommendations in Mozambique. *Soil Use and Management* 14: 136-141.

Giller, K. E. (2013). Guest editorial: Can we define the term 'farming systems'? A question of scale. *Outlook on Agriculture* 42(3): 149-153.

Giller, K. E., Leeuwis, C., Andersson, J. A., Andriesse, W., Brouwer, A., Frost, P., Hebinck, P., Heitkönig, I., Van Ittersum, M. K., Koning, N., Ruben, R., Slingerland, M., Udo, H., Veldkamp, T., Van de Vijver, C., Van Wijk, M. T. & Windmeijer, P. (2008). Competing claims on natural resources: what role for science? *Ecology and Society* 13(2).

Giller, K. E., Rowe, E. C., de Ridder, N. & van Keulen, H. (2006). Resource use dynamics and interactions in the tropics: Scaling up in space and time. *Agricultural Systems* 88(1): 8-27.

Giller, K. E., Tittonell, P., Rufino, M. C., van Wijk, M. T., Zingore, S., Mapfumo, P., Adjei-Nsiah, S., Herrero, M., Chikowo, R., Corbeels, M., Rowe, E. C., Baijukya, F., Mwijage, A., Smith, J., Yeboah, E., van der Burg, W. J., Sanogo, O. M., Misiko, M., de Ridder, N., Karanja, S., Kaizzi, C., K'ungu, J., Mwale, M., Nwaga, D., Pacini, C. & Vanlauwe, B. (2011). Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. *Agricultural Systems* 104(2): 191-203.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M. & Toulmin, C. (2010). Food security: the challenge of feeding 9 Billion people. *Science* 327(5967): 812-818.

Groot, J. C. J., Oomen, G. J. M. & Rossing, W. A. H. (2012). Multi-objective optimization and design of farming systems. *Agricultural Systems* 110(0): 63-77.

Hahn, M. B., Riederer, A. M. & Stanley, O. F. (2009). The livelihood vulnerability index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique. *Global Environmental Change* 19: 74-88.

Hansen, J. W. (2005). Integrating seasonal climate prediction and agricultural models for insights into agricultural practice. *Philosophical Transactions of the Royal Society B: Biological Sciences* 360(1463): 2037-2047.

Hengsdijk, H., Franke, A. C., Van Wijk, M. T. & Giller, K. E., 2014. (2014).How small is beautiful? Food self-sufficiency and land gap analysis of smallholders in humid and semi-arid sub Saharan Africa., 68: Plant Research International, part of Wageningen UR. Report number 562.

Howard, J., Jeje, J., Tschirley, D., Strasberg, P., Crawford, E. & Weber, M. (1998).What makes agricultural intensification profitable for Mozambican smallholders? An appraisal of the inputs subsector and the 1996/97 DNER/SG2000 Program. In *MSU International Department of Agricultural Economics*, 124 USA: Michigan State University.

IFAD (2003). Promoting market access for the rural poor in order to achieve the Millenium Dvelopment Goals. Roundtable Discussion Paper for Twenty-Fifth Anniversary Session of IFAD’s Governing Council. *Discussion paper. International Fund for Agricultural Development. Rome, Italy*: 27.

IIAM & FAEF (2010). *Fichas técnicas de culturas. 1a Edição.* Maputo, Mozambique: Instituto de Investigação Agrária de Moçambique and Faculdade de Agronomia e Engenharia Florestal.

INE (2011a).Censo Agro-Pecuário - CAP 2009-2010: Resultados definitivos - Moçambique. Maputo: Instituto Nacional de Estatística.

INE (2011b).III Censo Geral da População e Habitação 2007. In *10 anos* www.ine.gov.mz: Instituto Nacional de Estatística.

IPCC (2007).Climate Change 2007: The Physical Science Basis. Summary for Policymakers., 18 Geneva: Intergovernmental Panel on Climate Change.

Janssen, S., Louhichi, K., Kanellopoulos, A., Zander, P., Flichman, G., Hengsdijk, H., Meuter, E., Andersen, E., Belhouchette, H., Blanco, M., Borkowski, N., Heckelei, T., Hecker, M., Li, H., Oude Lansink, A., Stokstad, G., Thorne, P., Keulen, H. & Ittersum, M. (2010). A generic bio-economic farm model for environmental and economic assessment of agricultural systems. *Environmental Management* 46(6): 862-877.

Janvry, A. d., Fafchamps, M. & Sadoulet, E. (1991). Peasant household behaviour with missing markets: some paradoxes explained. *The Economic Journal* 101(409): 1400-1417.

Jayne, T. S., Mather, D. & Mghenyi, E. (2010). Principal Challenges Confronting Smallholder Agriculture in Sub-Saharan Africa. *World Development* 38(10): 1384-1398.

Jones, S. & Tarp, F. (2012).Jobs and Welfare in Mozambique. Country case study for the 2013 World Bank Report. In *World Development Reports. Background Papers*, 89: World Bank.

Jongman, R. H. G., Ter Braak, C. J. F. & Tongeren, O. F. R. v. (1995). *Data analysis in community and landscape ecology.* Cambridge: Cambridge University Press.

Jumbe, C. B. L., Msiska, F. B. M. & Madjera, M. (2009). Biofuels development in Sub-Saharan Africa: Are the policies conducive? *Energy Policy* 37(11): 4980-4986.

Kanellopoulos, A., Berentsen, P. B. M., van Ittersum, M. K. & Oude Lansink, A. G. J. M. (2012). A method to select alternative agricultural activities for future-oriented land use studies. *European Journal of Agronomy* 40(0): 75-85.

Key, N. & Runsten, D. (1999). Contract farming, smallholders, and rural development in Latin America: the organization of agroprocessing firms and the scale of outgrower production. *World Development* 27(2): 381-401.

Khan, S., Murray, R. P. & Barnes, G. E. (2002). A structural equation model of the effect of poverty and unemployment on alcohol abuse. *Addictive Behaviors* 27(3): 405-423.

Kirsten, J. & Sartorius, K. (2002). Linking agribusiness and small-scale farmers in developing countries: is there a new role for contract farming? *Development Southern Africa* 19(4): 503-529.

Koning, N. & Mol, A. (2009). Wanted: institutions for balancing global food and energy markets. *Food Security* 1(3): 291-303.

Koning, N. & Van Ittersum, M. K. (2009). Will the world have enough to eat? *Current Opinion in Environmental Sustainability* 1(1): 77-82.

Kydd, J. & Dorward, A. (2004). Implications of market and coordination failures for rural development in least developed countries. *Journal of International Development* 16(7): 951-970.

Lanjouw, P., Quizon, J. & Sparrow, R. (2001). Non-agricultural earnings in peri-urban areas of Tanzania: evidence from household survey data. *Food Policy* 26(4): 385-403.

Lawson, D., Mckay, A. & Okidi, J. (2006). Poverty persistence and transitions in Uganda: a combined qualitative and quantitative analysis. *Journal of Development Studies* 42(7): 1225-1251.

Leonardo, W., van de Ven, G. J., Udo, H., Kanellopoulos, A., Sitoe, A. & Giller, K. (2015). Labour not land constrains agricultural production and food self-sufficiency in maize-based smallholder farming systems in Mozambique. *Food Security* 7(4): 857-874.

Leonardo, W. J. (2000). *Organizing seed fairs in emergency situations.* Mozambique: International Crops Research Institute for the Semi-Arid Tropics.

Longley, C., Dominguez, C., Saide, M. A. & Leonardo, W. J. (2002). Do Farmers Need Relief Seed? A Methodology for Assessing Seed Systems. *Disasters* 26(4): 343-355.

Louhichi, K., Kanellopoulos, A., Janssen, S., Flichman, G., Blanco, M., Hengsdijk, H., Heckelei, T., Berentsen, P., Lansink, A. O. & Ittersum, M. V. (2010). FSSIM, a bio-economic farm model for simulating the response of EU farming systems to agricultural and environmental policies. *Agricultural Systems* 103(8): 585-597.

Lukanu, G., Green, M. & Worth, S. (2007). The influence of smallholder labour demand on cultivation of cash crops in Northern Mozambique. *Development Southern Africa* 24(4): 553-573.

Maher, M. E. (1997). Transaction cost economics and contractual relations. *Cambridge Journal of Economics* 21(2): 147-170.

Maria, R. M. & Yost, R. (2006). A survey of soil fertility status of four agroecological zones of Mozambique. *Soil Science* 171(11): 902-914.

Markelova, H., Meinzen-Dick, R., Hellin, J. & Dohrn, S. (2009). Collective action for smallholder market access. *Food Policy* 34(1): 1-7.

Masset, E., Haddad, L., Cornelius, A. & Isaza-Castro, J. (2012). Effectiveness of agricultural interventions that aim to improve nutritional status of children: systematic review. *BMJ* 344.

Mavrotas, G. (2009). Effective implementation of the ε-constraint method in Multi-Objective Mathematical Programming problems. *Applied Mathematics and Computation* 213(2): 455-465.

Milgroom, J. & Giller, K. E. (2013). Courting the rain: rethinking seasonality and adaptation to recurrent drought in semi-arid southern Africa. *Agricultural Systems* 118(0): 91-104.

MINAG (2008a).Plano de Acção para a Produção de Alimentos. 144 Maputo: Ministério da Agricultura.

MINAG (2008b).Trabalho de Inquérito Agrícola 2008. (Ed D. d. Economia). Ministério de Agricultura. Maputo.

MINAG (2008c).Zoneamento Agrário - Resultados do exercício de validação de resultados da terra disponível a nível local (Fase 2). (Ed I. d. I. A. d. M. (IIAM).). Maputo.

MINAG (2011).Plano Estratégico para o Desenvolvimento do Sector Agrário. PEDSA 2011-2020. Maputo: Ministério de Agricultura.

MINAG (2012a).National Agricultural survey 2012. Maputo, Mozambique: Ministry of Agriculture.

MINAG (2012b).Promoting sustainable and poverty-reducing investments in biofuels production in Mozambique. Annual report 2012. CEPAGRI-Ministry of Agriculture. Maputo.

Moçambique, G. d. (2009).Política e estratégia de biocombustíveis. 22 (Ed C. d. Ministros). Maputo.
Moçambique, G. d. (2011).Plano de Acção para Redução da Pobreza (PARP) 2011-2014. 53 Maputo.
Moçambique, G. d. (2012).Diploma Ministerial nrs 77,78, 79, 80, 81 82 e 83. Maputo, Moçambique.
Mujaya, I. M. & Yerokun, O. A. (2003).Response of sesame (Sesamum indicum L.) to plant population and nitrogen fertilizer in north-central Zimbabwe. In *Sesame and Safflower Newsletter* Vol. 18, 6 Zimbabwe.
Nations, U. (2015).Draft outcome document of the United Nations summit for the adoption of the post-2015 development agenda. Draft resolution submitted by the President of the General Assembly, Sixty-ninth session, Agenda items 13 (a) and 115, A/69/L.85, August 12, 2015. (Ed U. Nations). New York.
Naudin, K., Scopel, E., Andriamandroso, A. L. H., Rakotosolofo, M., Andriamarosoa Ratsimbazafy, N. R. S., Rakotozandriny, J. N., Salgado, P. & Giller, K. E. (2012). Trade-offs between biomass use and soil cover. the case of rice-based cropping systems in the Lake Alaotra region of Madagascar. *Experimental Agriculture* 48(2): 194-209.
Negash, M. & Swinnen, J. F. M. (2013). Biofuels and food security: Micro-evidence from Ethiopia. *Energy Policy* 61(0): 963-976.
NEPAD (2003a).Comprehensive Africa Agriculture Development Programme. South Africa: New Partnership for Africa's Development (NEPAD). ISBN 0-620-30700-5.
NEPAD (2003b).In *Second Ordinary Assembly of the African Union, 10-12 July 2003, Maputo, Mozambique. Available at:http://www.nepad.org/resource/au-2003-maputo-declaration-agriculture-and-food-security, accessed on 3rd August, 2016*.
North, D. C. (1990). A transaction cost theory of politics. *Journal of Theoretical Politics* 2(4): 355-367.
Peskett, L., Slater, R., Stevens, C. & Defuy, A. (2007). Natural Resource Perspectives. *Overseas Development Institute* 107: 6.
Peterson, H. C., Wysocki, A. & Harsh, S. B. (2001). Strategic choice along the vertical coordination continuum. *The International Food and Agribusiness Management Review* 4(2): 149-166.
Pinstrup-Andersen, P. (2009). Food security: definition and measurement. *Food Security* 1(1): 5-7.
Poulton, C., Dorward, A. & Kydd, J. (2010). The Future of Small Farms: New Directions for Services, Institutions, and Intermediation. *World Development* 38(10): 1413-1428.
Rao, V. & Chotigeat, T. (1981). The Inverse Relationship between Size of Land Holdings and Agricultural Productivity. *American Journal of Agricultural Economics* 63(3): 571-574.
Raynaud, E., Sauvee, L. & Valceschini, E. (2005). Alignment between quality enforcement devices and governance structures in the agro-food vertical chains. *Journal of Management & Governance* 9(1): 47-77.
Renkow, M., Hallstrom, D. G. & Karanja, D. D. (2004). Rural infrastructure, transactions costs and market participation in Kenya. *Journal of Development Economics* 73(1): 349-367.

Riera, O. & Swinnen, J. F. M. (2014). Household Level Spillover Effects from Biofuels. Available at SSRN: https://ssrn.com/abstract=2530425 or http://dx.doi.org/10.2139/ssrn.2530425.
Riordan, M. H. & Williamson, O. E. (1985). Asset specificity and economic organization. *International Journal of Industrial Organization* 3(4): 365-378.
Rosegrant, M. W., Zhu, T. J., Msangi, S. & Sulser, T. (2008).Global scenarios for biofuels: impacts and implications. 495-505: Blackwell Publishing.
Roxburgh, C. W. & Rodriguez, D. (2016). Ex-ante analysis of opportunities for the sustainable intensification of maize production in Mozambique. *Agricultural Systems* 142: 9-22.
Ruel, M. T. (2003). Operationalizing dietary diversity: a review of measurement issues and research priorities. *Journal of Nutrition* 133(11 SUPPL. 2): 3911S-3926S.
Rulli, M. C., Saviori, A. & D'Odorico, P. (2013). Global land and water grabbing. *Proceedings of the National Academy of Sciences*.
Rusinamhodzi, L., Corbeels, M., Nyamangara, J. & Giller, K. E. (2012). Maize–grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in central Mozambique. *Field Crops Research* 136(0): 12-22.
Saenger, C., Qaim, M., Torero, M. & Viceisza, A. (2013). Contract farming and smallholder incentives to produce high quality: experimental evidence from the Vietnamese dairy sector. *Agricultural Economics* 44(3): 297-308.
Sanchez, P. A. (2002). Soil fertility and hunger in Africa. *Science* 295(5562): 2019-2020.
Sanchez, P. A. (2015). En route to plentiful food production in Africa. 1.
Sanchez, P. A., Shepherd, K. D., Soule, M. J., Place, F. M., Buresh, R. J., Izac, A.-M. N., Mokwunye, A. U., Kwesiga, F. R., Ndiritu, C. G. & Woomer, P. L. (1997). Soil fertility replenishment in Africa: an investment in naturalrResource capital. *Replenishing Soil Fertility in Africa* sssaspecialpubl(replenishingsoi): 1-46.
Schoneveld, G. C., German, L. A. & Nutakor, E. (2011). Land-based Investments for Rural Development? A grounded analysis of the local impacts of biofuel feedstock plantations in Ghana. *Ecology and Society* 16(4).
Schut, M., Cunha Soares, N., van de Ven, G. & Slingerland, M. (2014). Multi-actor governance of sustainable biofuels in developing countries: The case of Mozambique. *Energy Policy* 65(0): 631-643.
Schut, M., Slingerland, M. & Locke, A. (2010). Biofuel developments in Mozambique. Update and analysis of policy, potential and reality. *Energy Policy* 38(9): 5151-5165.
Schut, M., van Paassen, A., Leeuwis, C., Bos, S., Leonardo, W. & Lerner, A. (2011). Space for innovation for sustainable community-based biofuel production and use: lessons learned for policy from Nhambita community, Mozambique. *Energy Policy* 39(9): 5116-5128.
SDAE-Gondola (2012).Relatório da campanha agrícola 2010-2011. (Ed S. D. d. A. E. d. Gondola). Gondola: Ministério de Agricultura.
Senthilkumar, K., Bindraban, P. S., de Boer, W., de Ridder, N., Thiyagarajan, T. M. & Giller, K. E. (2009). Characterising rice-based farming systems to identify opportunities for adopting water efficient cultivation methods in Tamil Nadu, India. *Agricultural Water Management* 96(12): 1851-1860.

SETSAN (2010).Relatório da Avaliação da Situação da Segurança Alimentar e Nutricional em Moçambique. Secretariado Técnico de Segurança Alimentar e Nutrição. Ministério de Agricultura. 67 Maputo.

Shepherd, A. W. (2007).Approaches to linking producers to markets. A review of experiences to date. 80 Rome, Italy: Food and Agriculture Organization of the United Nations, FAO.

Shepherd, K. D. & Soule, M. J. (1998). Soil fertility management in west Kenya: dynamic simulation of productivity, profitability and sustainability at different resource endowment levels. *Agriculture, Ecosystems and Environment* 71(1–3): 131-145.

Shiferaw, B., Obare, G. & Muricho, G. (2008). Rural market imperfections and the role of institutions in collective action to improve markets for the poor. *Natural Resources Forum* 32(1): 25-38.

Simpson, E. H. (1949). Measurement of diversity. *Nature* 163(4148): 688-688.

Smeets, E. M. W., Faaij, A. P. C., Lewandowski, I. M. & Turkenburg, W. C. (2007). A bottom-up assessment and review of global bio-energy potentials to 2050. *Progress in Energy and Combustion Science* 33(1): 56-106.

Sousa, C. d. (1999).Rebuilding rural rivelihoods and social capital: Mozambique's experience. In *Working Papers*Helsinki United Nations University and World Institute for Development Economics Research (UNU-WIDER).

Staal, S., Delgado, C. & Nicholson, C. (1997). Smallholder dairying under transactions costs in East Africa. *World Development* 25(5): 779-794.

Steyn, N. P., Nel, J. H., Nantel, G., Kennedy, G. & Labadarios, D. (2006). Food variety and dietary diversity scores in children: Are they good indicators of dietary adequacy? *Public Health Nutrition* 9(5): 644-650.

Stoorvogel, J. J., Antle, J. M., Crissman, C. C. & Bowen, W. (2004). The tradeoff analysis model: Integrated bio-physical and economic modeling of agricultural production systems. *Agricultural Systems* 80(1): 43-66.

Stoorvogel, J. J., Smaling, E. M. A. & Janssen, B. H. (1993). Calculating soil nutrient balances in Africa at different scales - I Supra-national scale. *Fertilizer Research* 35(3): 227-235.

Tittonell, P. (2008).Targeting resources within diverse, heterogeneous and dynamic farming systems of East Africa. In *de C.T. de Wit Graduate School: Production Ecology and Resource Conservation*, Vol. PhD Thesis, 335: Wageningen University, The Netherlands.

Tittonell, P., Corbeels, M., van Wijk, M. T. & Giller, K. E. (2010a). FIELD—A summary simulation model of the soil–crop system to analyse long-term resource interactions and use efficiencies at farm scale. *European Journal of Agronomy* 32(1): 10-21.

Tittonell, P. & Giller, K. E. (2012). When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Res* (0).

Tittonell, P., Muriuki, A., Shepherd, K. D., Mugendi, D., Kaizzi, K. C., Okeyo, J., Verchot, L., Coe, R. & Vanlauwe, B. (2010b). The diversity of rural livelihoods and their influence on soil fertility in agricultural systems of East Africa - A typology of smallholder farms. *Agricultural Systems* 103(2): 83-97.

Tittonell, P., Van Wijk, M. T., Rufino, M. C., Vrugt, J. A. & Giller, K. E. (2007). Analysing trade-offs in resource and labour allocation by smallholder farmers using inverse modelling techniques: A case-study from Kakamega district, western Kenya. *Agricultural Systems* 95(1-3): 76-95.

Tjeuw, J., Slingerland, M. & Giller, K. (2015). Relationships among Jatropha curcas seed yield and vegetative plant components under different management and cropping systems in Indonesia. *Biomass and Bioenergy* 80: 128-139.

Tressell, R. (1914). *The Ragged-Trousered Philanthropists.* Grant Richards, United Kingdom (UK).

Tschirley, D. L., Abdula, D. C. & Weber, M. T. (2006).Toward improved maize marketing and trade policies to promote household food security in central and southern Mozambique. In *Food Security Collaborative Working Papers*, 43: Michigan State University. Department of Agricultural, Food, and Resource Economics.

Uaiene, R. (2004).Maize and sorghum technologies and the effects of marketing strategies on farmers' income in Mozambique. Vol. Msc Thesis, 150: Purdue University.

Udo, H. M. J., Aklilu, H. A., Phong, L. T., Bosma, R. H., Budisatria, I. G. S., Patil, B. R., Samdup, T. & Bebe, B. O. (2011). Impact of intensification of different types of livestock production in smallholder crop-livestock systems. *Livestock Science* 139(1-2): 22-29.

UNDP (2011).Human Development Report 2011. Sustainability and equity: a better future for all. 185 New York: United Nations Development Programme.

USGS/FEWSNET (2011).Rainfall estimate by mean of remote sensing. Available at: http://earlywarning.usgs.gov/fews/africa/

Van de Ven, G. W. J. & Van Keulen, H. (2007). A mathematical approach to comparing environmental and economic goals in dairy farming: Identifying strategic development options. *Agricultural Systems* 94(2): 231-246.

Van Eijck, J., Romijn, H., Balkema, A. & Faaij, A. (2014). Global experience with jatropha cultivation for bioenergy: An assessment of socio-economic and environmental aspects. *Renewable and Sustainable Energy Reviews* 32: 869-889.

Van Eijck, J., Smeets, E. & Faaij, A. (2012). The economic performance of jatropha, cassava and eucalyptus production systems for energy in an East African smallholder setting. *GCB Bioenergy* 4(6): 828-845.

Van Ittersum, M. K., Rabbinge, R. & Van Latesteijn, H. C. (1998). Exploratory land use studies and their role in strategic policy making. *Agricultural Systems* 58(3): 309-330.

Van Ittersum, M. K., van Bussel, L. G. J., Wolf, J., Grassini, P., van Wart, J., Guilpart, N., Claessens, L., de Groot, H., Wiebe, K., Mason-D'Croz, D., Yang, H., Boogaard, H., van Oort, P. A. J., van Loon, M. P., Saito, K., Adimo, O., Adjei-Nsiah, S., Agali, A., Bala, A., Chikowo, R., Kaizzi, K., Kouressy, M., Makoi, J. H. J. R., Ouattara, K., Tesfaye, K. & Cassman, K. G. (2016). Can sub-Saharan Africa feed itself? *Proceedings of the National Academy of Sciences* 113(52): 14964-14969.

Van Vliet, J. A., Schut, A. G. T., Reidsma, P., Descheemaeker, K., Slingerland, M., Van de Ven, G. W. J. & Giller, K. E. (2015). De-mystifying family farming: Features, diversity and trends across the globe. *Global Food Security* 5: 11-18.

Van Wijk, M. T., Tittonell, P., Rufino, M. C., Herrero, M., Pacini, C., Ridder, N. d. & Giller, K. E. (2009). Identifying key entry-points for strategic management of smallholder farming systems in sub-Saharan Africa using the dynamic farm-scale simulation model NUANCES-FARMSIM. *Agricultural Systems* 102(1-3): 89-101.

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., Nziguheba, G., Schut, M. & Van Asten, P. (2014). Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability* 8: 15-22.

von Braun, J. (2008).Food and Financial Crises: Implications for Agriculture and the Poor. In *Food Policy Report*(Ed IFPRI). Washington, DC International Food Policy Research Institute.

WHO (1985).Energy and protein requirements. In *Report of a Joint FAO/WHO/UNU Expert Consultation*Genebra: World Health Organization.

Williamson, O. E. (1985). *The economic institutions of capitalism: Firms. Markets, Relational Contracting.* New York, 26ff.

Woodhouse, P. (2009).Productivity Constraints in African Agriculture. In *II Conferência IESE "Dinâmicas da Pobreza e Padrões de Acumulação Económica em Moçambique"* 18 (Ed I. d. E. S. e. E.-. IESE). Maputo: IESE.

Woodhouse, P. (2010). Beyond industrial agriculture? Some questions about farm size, productivity and sustainability. *Journal of Agrarian Change* 10(3): 437-453.

World Bank (2006).Mozambique Agricultural Development Strategy. Stimulating smallholder agricultural growth. In *AFTS1. Agriculture, Environment, and Social Development Unit. Country Department 2. Africa Region*, 123: World Bank.

World Bank (2008).Agriculture for Development. In *World Development Report 2008*(Ed W. Bank). Washington, DC: World Bank.

World Bank (2011).Rising global interest in farmland: can it yield sustainable and equitable benefits? , Vol. 1, 266 Washington, DC: World Bank.

Zingore, S., González-Estrada, E., Delve, R. J., Herrero, M., Dimes, J. P. & Giller, K. E. (2009). An integrated evaluation of strategies for enhancing productivity and profitability of resource-constrained smallholder farms in Zimbabwe. *Agricultural Systems* 101(1–2): 57-68.

Zingore, S., Murwira, H. K., Delve, R. J. & Giller, K. E. (2007). Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. *Agriculture, Ecosystems & Environment* 119(1–2): 112-126.

Appendix 1. Labour not land constrains agricultural production and food self-sufficiency in maize-based smallholder farming systems in Mozambique

Appendix 2. Can farming provide a way out of poverty for smallholder farmers in central Mozambique?

Appendix 3: The Windmill Approach: combining transaction cost economics and farming systems theory to analyse farmer participation in value chains

Appendix 1: Labour not land constrains agricultural production and food self-sufficiency in maize-based smallholder farming systems in Mozambique

Table S2.1. Summary of household characteristics in the two Posts studied (Zembe and Dombe) compared with Manica Province as a whole and the country. Data for Manica and country are based on a nationally representative household survey in Mozambique (Trabalho de Inquérito Agrícola – TIA 2008). For statistical tests we only considered the TIA 2008, one year before the study was initiated.

Variable	Unit	Zembe *n*=52	Dombe *n*=72	All sample (*n*=124)	Manica (TIA 2008)
Households hiring labour	%	17	24	21	21.5
Gender	%	Male: 71.2 Female: 28.8	Male: 79.2 Female: 20.8	Male: 75.8 Female: 24.2	Male: 77.6 Female: 22.4
Cultivated area	ha	1.2 (0.5)	2.1 (1.6)	1.7 (1.3)	1.8 (1.6)
Number of household member	#	5.5 (2.6)	7.4 (3.4)	6.6 (3.3)	5.7 (2.8)
Number of household labourers	#	3.3	3.9	3.6	3.5 (2.05) [c]
Land:labour ratio (LLR)[d]	#	0.4	0.5	0.5	0.7 (0.6)
Number of households with chickens	%	92.3	88.9	90.3	81
Number of households with cattle	%	13.5	11.1	12.1	20.5
Number of households with goats	%	50.4	56.9	50	52.1
Number of households growing maize	%	100	100	100	95.8
Number of households using fertilizers	%	0	0	0	3.6
Number of households using irrigation	%	0	0	0	15.6

Standard Deviation values are in parentheses. [a] Based on Chi-square test. [b] Based on T-test.
[c] Estimated based on TIA by excluding household members below 10 years and above 60 years from the average household size.
[d] LLR is calculated as the cultivated area in hectares over number of household labourers

Appendix 2. Can farming provide a way out of poverty for smallholder farmers in central Mozambique?

Table S3.1. Cropping patterns, management practices, yield, costs, labour inputs and gross margin at field level for the current and alternative production activities used in different scenarios for large and small farms in Dombe

Cropping patterns	Variety type	Land preparation	Weeding	Fertilizers (N-P-K), kg ha^{-1}	Yield (t ha^{-1})	Seed and fertilizer costs ($ ha^{-1})	Total Costs ($ ha^{-1})	Total labour (man-days ha^{-1})	Gross margin ($ ha^{-1})	Scenario
Maize	Local	Hand	Hand	0-0-0	2.3	0	0	148	474	Current
Maize	Local	Hand	Herbicides	0-0-0	2.3	0	34	85	441	Labour saving
Maize	Local	Animal	Hand	0-0-0	2.3	0	87	114	387	Labour saving
Maize	Local	Animal	Herbicides	0-0-0	2.3	0	121	57	353	Labour saving
Maize	Local	Animal	Cultivator	0-0-0	2.3	0	175	58	299	Labour saving
Maize	Improved	Hand	Hand	0-0-0	3.3	37	37	144	660	Land saving
Maize	Improved	Hand	Hand	0-50-200	3.0	763	796	157	-170	Land saving
Maize	Improved	Hand	Hand	200-50-0	4.8	758	758	157	245	Land saving
Maize	Improved	Hand	Hand	200-0-200	5.1	771	804	157	260	Land saving
Maize	Improved	Hand	Hand	200-50-200	5.5	1127	1127	157	34	Land saving
Maize	Improved	Hand	Herbicides	0-0-0	3.3	37	70	85	627	Combination
Maize	Improved	Hand	Herbicides	0-50-200	3.0	763	796	98	-170	Combination
Maize	Improved	Hand	Herbicides	200-50-0	4.8	758	792	98	212	Combination
Maize	Improved	Hand	Herbicides	200-0-200	5.1	758	792	98	272	Combination
Maize	Improved	Hand	Herbicides	200-50-200	5.5	1127	1161	98	0	Combination
Maize	Improved	Animal	Hand	0-0-0	3.3	37	124	110	573	Combination
Maize	Improved	Animal	Hand	0-50-200	3.0	763	850	101	-224	Combination
Maize	Improved	Animal	Hand	200-50-0	4.8	758	846	101	158	Combination
Maize	Improved	Animal	Hand	200-0-200	5.1	771	858	101	206	Combination
Maize	Improved	Animal	Hand	200-50-200	5.5	1127	1215	101	-54	Combination
Maize	Improved	Animal	Herbicides	0-0-0	3.3	37	158	35	539	Combination
Maize	Improved	Animal	Herbicides	0-50-200	3.0	763	884	44	-258	Combination
Maize	Improved	Animal	Herbicides	200-50-0	4.8	758	879	44	124	Combination
Maize	Improved	Animal	Herbicides	200-0-200	5.1	771	892	44	172	Combination
Maize	Improved	Animal	Herbicides	200-50-200	5.5	1127	1248	44	-87	Combination
Maize	Improved	Animal	Cultivator	0-0-0	3.3	37	212	36	486	Combination
Maize	Improved	Animal	Cultivator	0-50-200	3.0	763	937	45	-311	Combination
Maize	Improved	Animal	Cultivator	200-50-0	4.8	758	933	45	71	Combination
Maize	Improved	Animal	Cultivator	200-0-200	5.1	771	946	45	118	Combination
Maize	Improved	Animal	Cultivator	200-50-200	5.5	1127	1302	45	-141	Combination
Sesame	Improved	Hand	Hand	0-0-0	1.3	0	12	89	1125	Current
Sesame	Improved	Hand	Herbicides	0-0-0	1.3	0	37	65	1099	Labour saving
Sesame	Improved	Animal	Hand	0-0-0	1.3	0	99	52	1037	Labour saving
Sesame	Improved	Animal	Herbicides	0-0-0	1.3	0	124	27	1012	Labour saving
Sesame	Improved	Animal	Cultivator	0-0-0	1.3	0	143	28	993	Labour saving
Sesame	Improved	Hand	Hand	195-28-30	1.5	414	439	89	872	Land saving
Sesame	Improved	Hand	Herbicides	195-28-30	1.5	414	465	71	847	Combination
Sesame	Improved	Animal	Hand	195-28-30	1.5	414	527	83	784	Combination
Sesame	Improved	Animal	Herbicides	195-28-30	1.5	414	552	65	759	Combination

Appendix 2

Cropping patterns	Variety type	Land preparation	Weeding	Fertilizers (N-P-K), kg ha^{-1}	Yield (t ha^{-1})	Seed and fertilizer costs ($ ha^{-1})	Total Costs ($ ha^{-1})	Total labour (man-days ha^{-1})	Gross margin ($ ha^{-1})	Scenario
Sesame	Improved	Animal	Cultivator	195-28-30	1.5	414	571	75	741	Combination
Maize_sesame	Local	Hand	Hand	0-0-0	1.9-1.0	0	12	214	1253	Current
Maize_sesame	Local	Hand	Herbicides	0-0-0	1.9-1.0	0	37	163	1227	Labour saving
Maize_sesame	Local	Animal	Hand	0-0-0	1.9-1.0	0	99	181	1165	Labour saving
Maize_sesame	Local	Animal	Herbicides	0-0-0	1.9-1.0	0	124	129	1140	Labour saving
Maize_sesame	Local	Animal	Cultivator	0-0-0	1.9-1.0	0	143	130	1121	Labour saving
Soybean	Improved	Hand	Hand	0-0-0	0.8	76	87	81	332	Land saving
Soybean	Improved	Hand	Hand	0-0-40	1.0	149	161	88	363	Land saving
Soybean	Improved	Hand	Hand	0-50-0	1.0	432	444	88	81	Land saving
Soybean	Improved	Hand	Hand	0-50-40	1.1	506	518	88	59	Land saving
Soybean	Improved	Hand	Hand	0-50-40	1.1	506	524	90	53	Land saving
Soybean	Improved	Hand	Herbicides	0-0-0	0.8	76	103	63	317	Combination
Soybean	Improved	Hand	Herbicides	0-0-40	1.0	149	177	70	348	Combination
Soybean	Improved	Hand	Herbicides	0-50-0	1.0	432	459	70	65	Combination
Soybean	Improved	Hand	Herbicides	0-50-40	1.1	506	533	70	44	Combination
Soybean	Improved	Hand	Herbicides	0-50-40	1.1	506	539	72	38	Combination
Soybean	Improved	Animal	Hand	0-0-0	0.8	76	175	46	245	Combination
Soybean	Improved	Animal	Hand	0-0-40	1.0	149	249	53	276	Combination
Soybean	Improved	Animal	Hand	0-50-0	1.0	432	531	53	-7	Combination
Soybean	Improved	Animal	Hand	0-50-40	1.1	506	605	53	-28	Combination
Soybean	Improved	Animal	Hand	0-50-40	1.1	506	611	55	-34	Combination
Soybean	Improved	Animal	Herbicides	0-0-0	0.8	76	190	28	230	Combination
Soybean	Improved	Animal	Herbicides	0-0-40	1.0	149	264	35	261	Combination
Soybean	Improved	Animal	Herbicides	0-50-0	1.0	432	547	35	-22	Combination
Soybean	Improved	Animal	Herbicides	0-50-40	1.1	506	621	35	-44	Combination
Soybean	Improved	Animal	Herbicides	0-50-40	1.1	506	626	37	-50	Combination
Soybean	Improved	Animal	Cultivator	0-0-0	0.8	76	262	28	157	Combination
Soybean	Improved	Animal	Cultivator	0-0-40	1.0	149	336	35	189	Combination
Soybean	Improved	Animal	Cultivator	0-50-0	1.0	432	619	35	-94	Combination
Soybean	Improved	Animal	Cultivator	0-50-40	1.1	506	693	35	-116	Combination
Soybean	Improved	Animal	Cultivator	0-50-40	1.1	506	698	37	-122	Combination
Maize_Pigeonpea	Improved	Hand	Hand	0-0-0	5.5-0.5	67	67	197	1304	Land saving
Maize_Pigeonpea	Improved	Animal	Hand	0-0-0	5.5-0.5	67	154	152	1217	Combination

Table S3.2. Cropping patterns, management practices, yield, costs, labour inputs and gross margin at field level for the current and alternative production activities used in different scenarios for large and small farms in Zembe

Cropping patterns	Variety type	Land preparation	Weeding	Fertilizers (N-P-K), kg ha^{-1}	Yield (t ha^{-1})	Seed and fertilizer costs ($ ha^{-1})	Total Costs ($ ha^{-1})	Total labour (man-days ha^{-1})	Gross margin ($ ha^{-1})	Scenario
Maize	Local	Hand	Hand	0	2.0	0	0	99	420	Current
Maize	Local	Hand	Herbicides	0	2.0	0	31	57	389	Labour saving
Maize	Local	Animal	Hand	0	2.0	0	87	64	332	Labour saving
Maize	Local	Animal	Herbicides	0	2.0	0	118	57	301	Labour saving
Maize	Local	Animal	Cultivator	0	2.0	0	175	58	245	Labour saving
Maize	Improved	Hand	Hand	0	1.7	34	34	98	323	Land saving
Maize	Improved	Hand	Hand	0-50-200	2.0	699	699	107	-279	Land saving
Maize	Improved	Hand	Hand	200-50-0	2.3	695	782	107	-300	Land saving
Maize	Improved	Hand	Hand	200-0-200	2.3	707	794	107	-311	Land saving
Maize	Improved	Hand	Hand	200-50-200	3.8	1033	1208	107	-411	Land saving
Maize	Improved	Hand	Herbicides	0	1.7	34	64	63	292	Combination
Maize	Improved	Hand	Herbicides	0-50-200	2.0	699	730	72	-310	Combination
Maize	Improved	Hand	Herbicides	200-50-0	2.3	695	813	72	-331	Combination
Maize	Improved	Hand	Herbicides	200-0-200	2.3	707	825	72	-342	Combination
Maize	Improved	Hand	Herbicides	200-50-200	3.8	1033	1239	72	-442	Combination
Maize	Improved	Animal	Hand	0	1.7	34	121	50	236	Combination
Maize	Improved	Animal	Hand	0-50-200	2.0	699	786	67	-367	Combination
Maize	Improved	Animal	Hand	200-50-0	2.3	695	782	67	-300	Combination
Maize	Improved	Animal	Hand	200-0-200	2.3	707	794	67	-311	Combination
Maize	Improved	Animal	Hand	200-50-200	3.8	1033	1121	67	-324	Combination
Maize	Improved	Animal	Herbicides	0	1.7	34	152	36	205	Combination
Maize	Improved	Animal	Herbicides	0-50-200	2.0	699	817	47	-398	Combination
Maize	Improved	Animal	Herbicides	200-50-0	2.3	695	813	47	-331	Combination
Maize	Improved	Animal	Herbicides	200-0-200	2.3	707	825	47	-342	Combination
Maize	Improved	Animal	Herbicides	200-50-200	3.8	1033	1152	47	-354	Combination
Maize	Improved	Animal	Cultivator	0	1.7	34	208	33	148	Combination
Maize	Improved	Animal	Cultivator	0-50-200	2.0	699	874	44	-454	Combination
Maize	Improved	Animal	Cultivator	200-50-0	2.3	695	870	44	-387	Combination
Maize	Improved	Animal	Cultivator	200-0-200	2.3	707	881	44	-399	Combination
Maize	Improved	Animal	Cultivator	200-50-200	3.8	1033	1208	44	-411	Combination
Sunflower sole	Improved	Hand	Hand	24-48-24	1.2	241	241	53	95	Current
Sunflower sole	Improved	Hand	Herbicides	24-48-24	1.2	241	241	35	95	Labour saving
Sunflower sole	Improved	Animal	Hand	24-48-24	1.2	241	329	57	7	Labour saving
Sunflower sole	Improved	Animal	Herbicides	24-48-24	1.2	241	329	39	7	Labour saving
Sunflower sole	Improved	Animal	Cultivator	24-48-24	1.2	241	416	39	-80	Labour saving
Maize-sunflower	Local-improved	Hand	Hand	0	2.0-0.3	0	0	113	503	Current
Maize-sunflower	Local-improved	Hand	Herbicides	0	2.0-0.3	0	31	71	473	Labour saving
Maize-sunflower	Local-improved	Animal	Hand	0	2.0-0.3	0	87	76	416	Labour saving

Appendix 2

Cropping patterns	Variety type	Land preparation	Weeding	Fertilizers (N-P-K), kg ha^{-1}	Yield (t ha^{-1})	Seed and fertilizer costs ($ ha^{-1})	Total Costs ($ ha^{-1})	Total labour (man-days ha^{-1})	Gross margin ($ ha^{-1})	Scenario
Maize-sunflower	Local-improved	Animal	Herbicides	0	2.0-0.3	0	118	52	385	Labour saving
Maize-sunflower	Local-improved	Animal	Cultivator	0	2.0-0.3	0	131	58	372	Labour saving
Soybean	Improved	Hand	Hand	0-0-0	0.8	69	80	81	340	Land saving
Soybean	Improved	Hand	Hand	0-0-40	0.9	137	148	88	324	Land saving
Soybean	Improved	Hand	Hand	0-50-0	0.9	396	407	88	65	Land saving
Soybean	Improved	Hand	Hand	0-50-40	1.0	464	475	88	50	Land saving
Soybean	Improved	Hand	Hand	0-50-40	1.0	464	480	90	44	Land saving
Soybean	Improved	Hand	Herbicides	0-0-0	0.8	69	95	63	324	Combination
Soybean	Improved	Hand	Herbicides	0-0-40	0.9	137	163	70	309	Combination
Soybean	Improved	Hand	Herbicides	0-50-0	1.0	396	422	70	102	Combination
Soybean	Improved	Hand	Herbicides	0-50-40	1.0	464	490	70	34	Combination
Soybean	Improved	Hand	Herbicides	0-50-40	1.0	464	495	72	29	Combination
Soybean	Improved	Animal	Hand	0-0-0	0.8	69	167	46	252	Combination
Soybean	Improved	Animal	Hand	0-0-40	0.9	137	235	53	237	Combination
Soybean	Improved	Animal	Hand	0-50-0	0.9	396	494	53	-22	Combination
Soybean	Improved	Animal	Hand	0-50-40	1.0	464	562	53	-38	Combination
Soybean	Improved	Animal	Hand	0-50-40	1.0	464	567	55	-43	Combination
Soybean	Improved	Animal	Herbicides	0-0-0	0.8	69	183	28	237	Combination
Soybean	Improved	Animal	Herbicides	0-0-40	0.9	137	250	35	222	Combination
Soybean	Improved	Animal	Herbicides	0-50-0	0.9	396	510	35	-38	Combination
Soybean	Improved	Animal	Herbicides	0-50-40	1.0	464	577	35	-53	Combination
Soybean	Improved	Animal	Herbicides	0-50-40	1.0	464	583	37	-58	Combination
Soybean	Improved	Animal	Cultivator	0-0-0	0.8	69	255	28	165	Combination
Soybean	Improved	Animal	Cultivator	0-0-40	0.9	137	323	35	150	Combination
Soybean	Improved	Animal	Cultivator	0-50-0	0.9	396	582	35	-110	Combination
Soybean	Improved	Animal	Cultivator	0-50-40	1.0	464	649	35	-125	Combination
Soybean	Improved	Animal	Cultivator	0-50-40	1.0	464	655	37	-130	Combination
Maize-Pigeonpea	Improved	Hand	Hand	0	3.6-0.5	61	61	197	904	Combination
Maize-Pigeonpea	Improved	Animal	Hand	0	3.6-0.5	61	149	152	816	Combination

Mathematical description of the model

Objectives:

The gross margin is calculated as follow:

$$Z = \sum_{p,t} Pr_{p,t} \cdot S_{p,t} - \sum_{i,m} C_{i,m} \cdot X_{i,m} - \sum_{t} w \cdot HL_t \quad (1)$$

where Z is the total gross margin (Mt y^{-1}; 1 US$ equals 28.6 Mt (www.oanda.com; August 9, 2013)), $Pr_{p,t}$ is the price of product p in period t (Mt kg^{-1}). $S_{p,t}$ is the quantity of product p sold in period t (kg), $C_{i,m}$ is the cost of cropping activity i under management m (Mt ha^{-1}), $X_{i,m}$ are the activity levels defined as combinations of cropping activity i and the corresponding management m, such as the quantity of fertilizer, inoculants and pesticides (Appendix 3 Table...). w is the daily wage of hired labour for activity (Mt d^{-1}), and HL_t is the hired labour in period t (d).

Total maize production is calculated as follows:

$$P_{maize} = \sum_{i,m} Y_{i,m,'maize'} \cdot X_{i,m} - HHN_{'maize'} \quad (2)$$

where here P_{maize} is the maize production for the market (kg y^{-1}), $Y_{i,m,'maize'}$ is the maize yield from cropping activity i under management m (kg ha^{-1}y^{-1}), $X_{i,m,}$ is area of activity i under management m (ha), HHN_p is the household need of product p (kg y^{-1}) and $HHN_{'maize'}$ is the household need of maize (kg y^{-1}).

The total labour is calculated as follows:

$$L = \sum_{i,m,t} (Lr_{i,m,t} \cdot X_{i,m}) \quad (3)$$

where, L is the labour needed (d) and Lr_{imt} is the labour requirement of cropping activity i with management m in period t (d ha^{-1}y^{-1}).

Constraints

The area under crops cannot exceed the available land:

$$\sum_{i,m} X_{i,m} \leq AL \quad (4)$$

where AL is the total available land of the farm (ha). The total labour requirements in period t should be less or equal to the total available household (unpaid) and hired labour in period t (Equation 2).

$$\sum_{i,m} Lr_{i,m,t} \cdot X_{i,m} \leq HHL_t + HL_t, \quad \forall\, t \quad (5)$$

where HHL_t is the available household labour in period t (d).

The self-sufficiency constraints was calculated as follow:

$$\sum_{i,m} Yield_{i,m,p} \cdot X_{i,m} - \sum_{t} S_{p,t} \geq HHN_p \qquad \forall\, p \tag{6}$$

In this specific case, self-sufficiency was only relevant for maize because the other crops were cultivated exclusively for sale

Next, we accounted for the cash needed for the essential household expenditures in each period *t*. In each period the total sales minus the labour costs should be greater or equal to the expenditure of the household.

$$\sum_{p} Pr_{p,t} \cdot S_{p,t} - \sum_{i,m} C_{i,m} \cdot X_{i,m} - w \times HL_t \geq Ex_t, \ \forall_t \tag{7}$$

Ex_t (\$ y^{-1}) is amount needed for essential expenditure in period *t.* Total gross margin should be greater or equal to total expenditure

$$Z \geq \sum_{t} Ex_t \tag{8}$$

Hired labour constraints was calculated as follow:

$$HL_t \leq HL_t^o \qquad \forall\, t \tag{9}$$

where HL^o_t (d y^{-1}) is the observed level of hired labour in period t.

On-farm trials report: Dombe and Zembe

1. Introduction

The objectives of the study were twofold (a) assess water-limited as related to soil fertility variability and (b) assess the most limiting nutrients for maize and soybean production in Dombe and Zembe Administrative Posts.The ultimate goal was to identify options for intensification of the current production systems in both posts.

2. Material and methods

We carried out on-farm researcher managed nutrient omission trials with maize (*Zea mays* L.) and soybean (*Glycine max* (L.) Merrill) over two consecutive cropping seasons, 2010-11 and 2011-12, and we quantified the response to N, P and K nutrients in Dombe and Zembe Administrative Posts.

The experimental fields were prepared/tilled by hand at the start of rainy season. All the previous harvest crop residues (maize and sesame, in Dombe), (maize and sunflower, in Zembe) and weeds were removed before planting. To control unwanted variability, fields with substantial shade of trees, steep slopes and termite hills were avoided during the selection of the plots.

The experimental treatments were randomised within replicates, with one full replicate block on each farm in both villages. Each farmer's field consisted of five plots of 5 m × 10 m of maize and five plots of 2 m × 10 m of soybean. A total of ten and five farmers participated in 2010-11 in Dombe and Zembe, respectively. In 2011-12, five farmers participated in the experiment in each post.

The treatments consisted of: control with no nutrients added; 2) complete supply of nitrogen (N), phosphorus (P), potassium (K); 3) complete minus N; 4) complete minus K; 5) complete minus P. For soybean the treatments were: control with no nutrients added; 2) complete supply of phosphorus (P), potassium (K) and rhizobium; 3) complete minus K; 4) complete minus P; 5) complete without rhizobium. In order to successfully assess the influence of one of the three nutrients (N, P or K), we applied the other two at sufficiently high rates. Therefore, the maize treated plots received N at 200 kg ha^{-1}, P at 50 kg ha^{-1} and K at 200 kg ha^{-1}. For soybean, the treated plots received P at 50 kg ha^{-1} and N at 40 kg ha^{-1}.

Using hand-hoe we made planting stations of 12-15 cm deep for maize. For soybean, we dig a trench of approximately 12 cm. For maize, all the fertilizers were mixed and placed in each hoe/station whereas for soybean we spread into the trench. We covered the fertilizers with 5-6 cm of soil. Urea was split-applied (half at planting and the other half at 5 weeks after planting) only on maize.

Our initial farming systems characterisation revealed the predominance of two major soil types in each post. Soils dominated by a clay texture and soils with a mixture of clay and sandy textures. Depending on land availability and farmers willingness to participate in the study, we tried to equally distribute the number of trials across the two soil types in each post. After experimental plots had been laid out, composite soil samples were taken in two depths, 0-20 cm and 20- 40 cm for chemical analysis. In each plot, the composite sample were composed by four sub-samples taken following a Y-shaped sampling frame, i.e., one located at the centre of the frame and other three at the half distance from centre of the "Y" to the end of each "Y" arms (Tittonell, 2008). The samples were air-dried, sieved through a 2-mm sieve for physical and chemical analyses.

Table 1 Soil properties for four different soil types as found in Dombe and Zembe Administrative Posts.

	Zembe		Dombe	
	Soil type 1	Soil type 2	Soil type 1	Soil type 2
N (%)	0.07	0.13	0.12	0.1
SOC (%)	1.4	1.4	1.6	1.4
pH (H_2O)	5.8	5.9	5.6	5.7
Olsen P (mg kg^{-1})	25.4	2.5	46.2	18.4
Exchangeable K (cmol$_c$ kg^{-1})	0.8	0.9	0.6	0.6
Clay (%)	24	26	24	21
Silt (%)	12	12	33	15
Soil type	Sandy clay loam	Sandy clay loam	Loam	Sandy clay loam
Soil local name	*Tchica+Djetcha*	*Tchica*	*Djiho+Djetcha*	*Djiho*
Soil classification[1]	Ferric Acrisols	Haplic Lixisols	Eutric Fluvisols	Albic Arenosols

The major difference between the soil types in each post and between posts was related to P-content.
[1] FAO-UNESCO, 1988.

Maize variety (PAN 67) and soybean variety (427/5/7) were sown in December of each year under rain-fed conditions. For maize we used inter-plant (90 cm) and intra-plant (25 cm), while for soybean inter-plant (50 cm) and intra-plant (10 cm) was adopted. Two seed per hole were sown and thinned after crop establishment to one plant per hole. Plots were kept free weeds by hand hoeing and pests (leaf miner) were controlled by chemicals.

Maize and soybean were harvested at maturity in net plots of 16.2 and 9 m^2, respectively (the two middle rows in each plot, excluding 2 border rows). Fresh yield was sun dry and recorded using a hand hanging scale. Although the experimental was designed to have sufficient farmers as replicates, in both years it was not possible to harvest all the plots as some farmers misunderstood the purpose of the experiments and harvested the crops. Therefore, six and five on-farm fields were harvested in the 2010-2011 in Dombe and Zembe, respectively. In 2011-12 it was not possible to measure the soybean yield in one of the farmer in each posts. In Dombe this was due to grasshoppers while in Zembe crops were completely damaged due to heavy rainfall and strong wind in Zembe. In addition, the cropping season 2011-12 was characterized by dry spells, especially at earlier stage of maize development cycle.

Analysis of Variance (*ANOVA*) was used to test differences between the treatments means of maize and soybean at P=0.05 using SigmaPlot version 12. We used box-and-whisker plots to show the variation. It shows five statistics – the minimum, the lower quartile, the median, the upper quartile and the maximum yield. Small circle at the upper and bottom end are outliers. The box contains the middle 50 % of data values. The line drawn across the box is the sample median for each treatment.

3. Results

3.1 Maize yields

For the cropping season 2010-11, we observed differences between mean maize yields of the five treatments in Dombe (P=0.001). The yields in the treatments NP (4785 kg ha^{-1}), NK (5070 kg ha^{-1}) and NPK (5535 kg ha^{-1}) treatments were significantly higher than in the control (3325 kg ha^{-1}) and PK (2985 kg ha^{-1}) treatments. In Zembe only the NPK treatment yielded significantly more than other treatments (P=0.022). The mean yields were: (1320 kg ha^{-1}), PK (1800 kg ha^{-1}), NP (2360 kg ha^{-1}), NK (2545 kg ha^{-1}) and NPK (3545 kg ha^{-1}). In the cropping season 2011-12, in Dombe the same treatments differed significantly, but in Zembe no differences were found. Figure 1 and 2 show the variation and the median maize yield in both posts and for both seasons.

In the cropping season 2011-12, in Dombe the same treatments differed significantly, but in Zembe no differences were found. Figure 1 and 2 show the variation and the median maize yield in both posts and for both seasons.

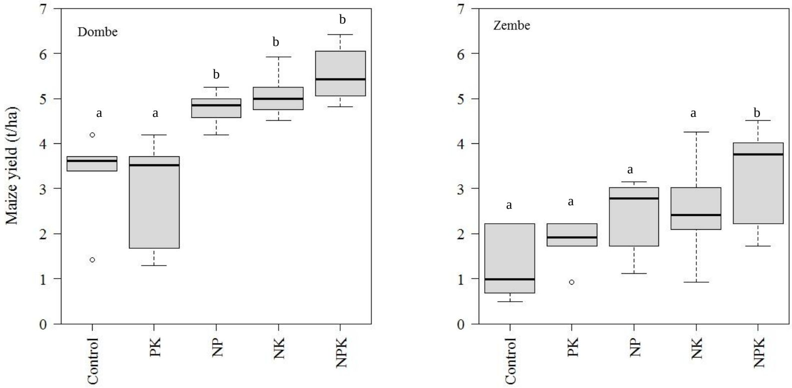

Fig. 1 Box-and-whisker plots for maize yields (kg ha^{-1}) for different treatments in cropping season 2010-11. Treatments followed by the same letter are not significantly different at P=0.05.

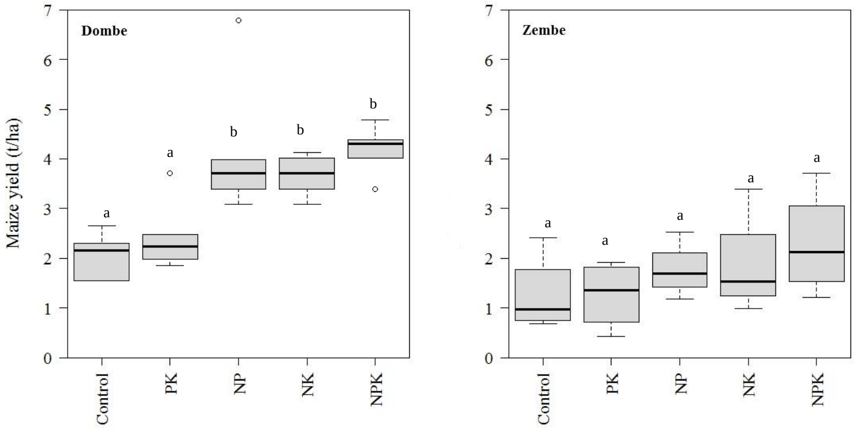

Fig. 2. Box-and-whisker plots for maize yields (kg ha^{-1}) for different treatments in cropping season 2011-12. Treatments followed by the same letter are not significantly different at P=0.05.

3.2 Soybean yield

Soybean yields across the five treatments did not differ significantly for both cropping seasons and both posts (Fig. 3 and 4). Note that the normality test in Dombe and Zembe failed (P < 0.050) including for log transformed data, therefore, ANOVA was based on rank using Kruskal-Wallis test. The soybean yields in Dombe were:

control (770 kg ha^{-1}), K (910 kg ha^{-1}), P (880 kg ha^{-1}), PK (950 kg ha^{-1}), PK+ (950 kg ha^{-1}). In Zembe the yields were: control (830 kg ha^{-1}), K (940 kg ha^{-1}), P (925 kg ha^{-1}), PK (950 kg ha^{-1}), PK+ (970 kg ha^{-1}).

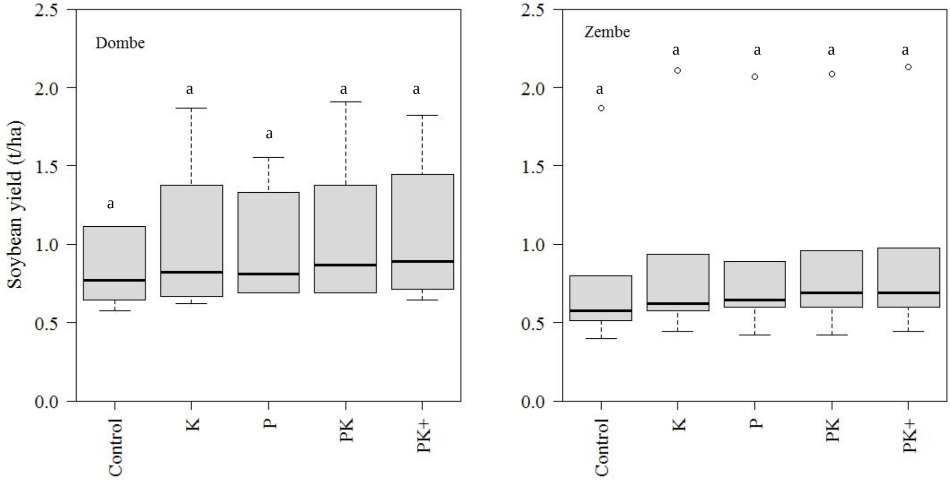

Fig. 3. Box-and-whisker plots for soybean yields (kg ha-1) for different treatments during the cropping season 2010-11. Means followed by the same letter are not significantly different at P=0.05.

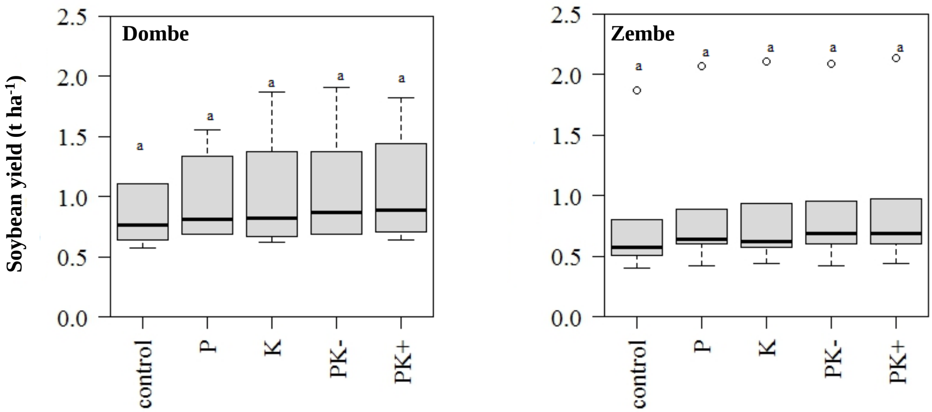

Fig. 4 Box-and-whisker plots for soybean yields (kg ha^{-1}) for different treatments during the cropping season 2011-12. Normality test failed (P=0.017), including for log transformed data, therefore, ANOVA was based on rank. Treatments followed by the same letter are not significantly different at P=0.05.

Sensitivity analysis on pigeonpea prices for large and small farms in Dombe and Zembe

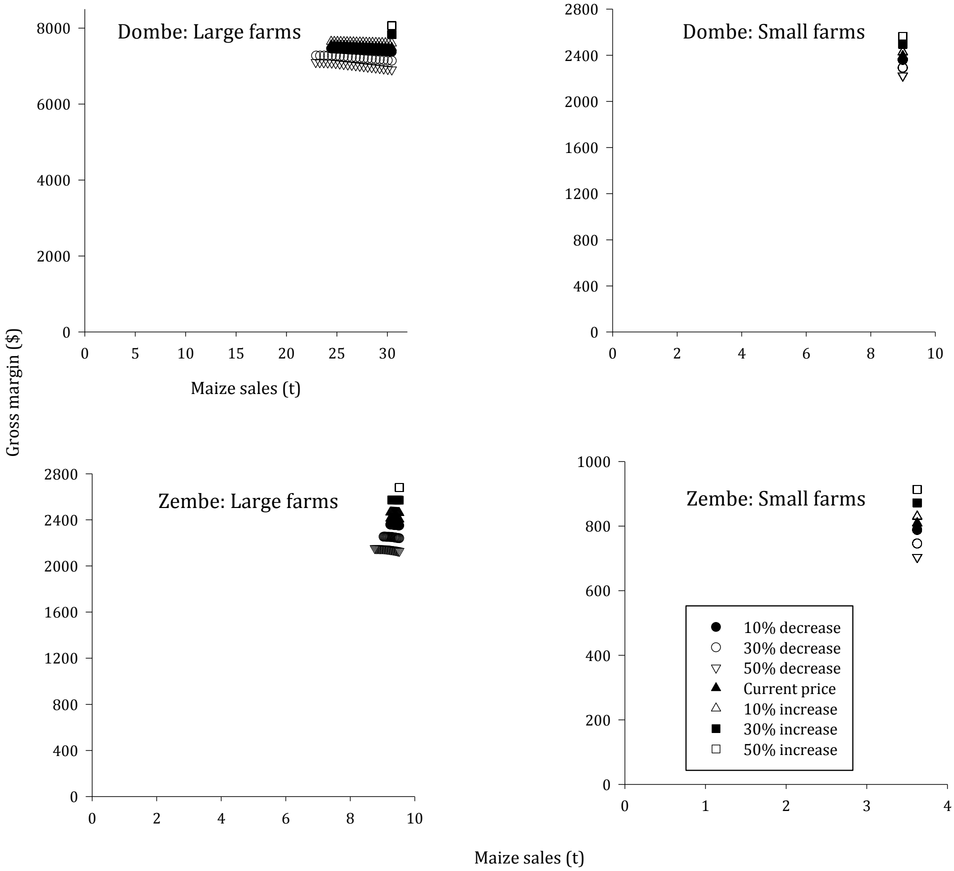

Fig 5. Sensitivity analysis on pigeonpea prices for large and small farms in Dombe and Zembe. The analysis done for the combined improvement scenario (Scenario 4)

Sensitivity on hired labour price and its impact on gross margin

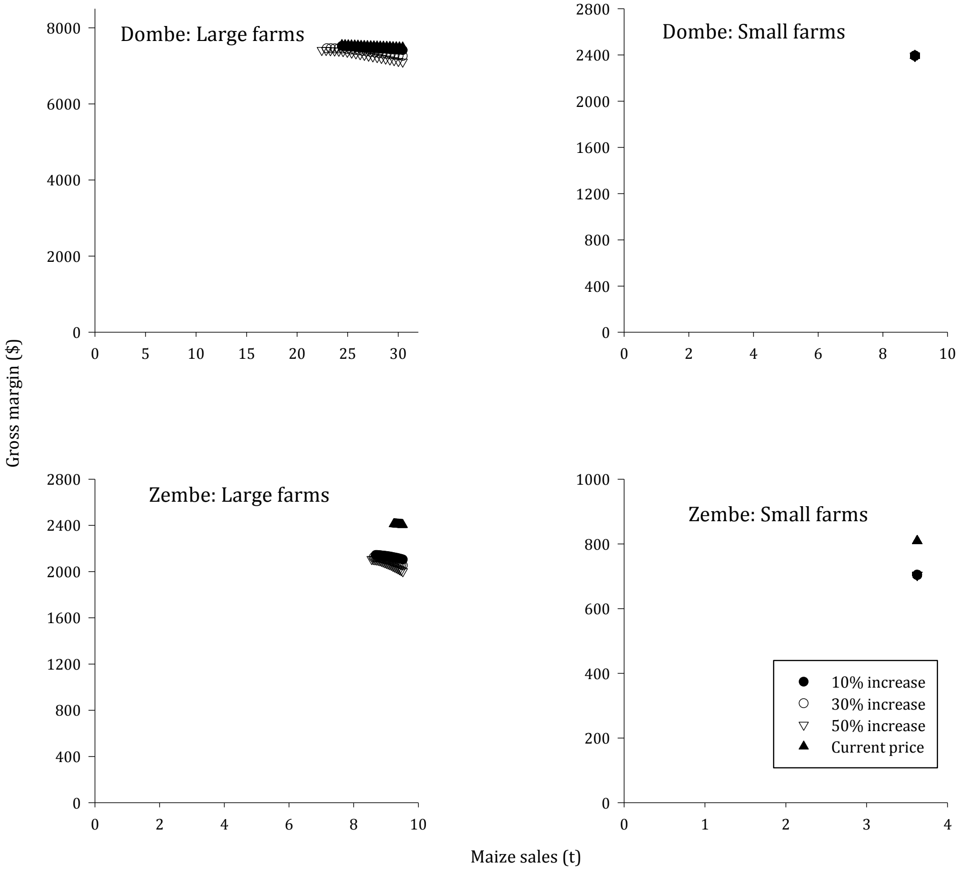

Fig 6. Sensitivity analysis on hired in labour for large and small farms in Dombe and Zembe. The analysis done for the combined improvement scenario (Scenario 4)

Appendix 3: The Windmill Approach: combining transaction cost economics and farming systems theory to analyse farmer participation in value chains

List of questions on marketing arrangements used in both posts

1. How and by whom is price determined?
2. Is there any credit provision involved between farmer and first buyer?
    a. who provides credit
    b. what is the agreement on paying interest and paying back the loan
3. What are the delivery conditions?
    a. location of delivery
    b. who takes care of transport to location of delivery
    c. who pays the transport costs
    d. type of transport method
    e. type of packaging
4. What are the agreements on quality?
    a. is there a minimum quality requirement
    b. who measures quality
    c. where is quality measured
    d. what quality standards are involved
    e. how is quality related to price
5. What other agreements between buyer and seller are part of the marketing arrangement?
    a. provision of technical assistance
    b. provision of seeds
    c. provision of fertilizers and agrochemicals
    d. other
6. Is there an expectation between transaction partners about repetition of transaction (next season)?
7. Does buyer select seller from among larger group of sellers?
8. Who are involved in the marketing arrangements?
    a. only buyer and seller
    b. third parties (state, NGO, PO)
9. To what extent is the seller-first buyer transaction related to (e.g. dependent on) a first-buyer – second-buyer transaction?

What is the final market of the products

Summary

The need to tackle poverty and hunger among rural people for whom agriculture is the mainstay of their livelihood, has dominated the research agenda in sub-Saharan African (SSA). In searching for solutions, many approaches have been tested to increase agricultural productivity of smallholder farms or to involve smallholder farms in large-scale agricultural investments such as those in commercial crops or biomass for biofuel.

In Mozambique, the government regards smallholder farmers to be important players to reduce poverty through increasing agricultural production. This commitment is reinforced in the "pro-poor" growth approach highlighted in the government's Poverty Reduction Plan (PARP) and the associated Strategic Plan for Agricultural Development (PEDSA). Apart from the goals to increase smallholder productivity and achieve food self-sufficiency, an important aspect from PEDSA is the need to transform subsistence farmers into competitive market-oriented farmers. Smallholder farms in Mozambique are highly diverse and with different levels of resources endowments. In addition, the agroecological conditions in which smallholder farms operate vary from region to region. This calls for critical analysis of the biophysical and socio-economic conditions in which small-scale farmers operate to explore opportunities for development.

In an attempt to shed light on how the livelihoods smallholder farmers can be improved and contribute to agricultural development in Mozambique, the main objectives of this study were first to understand the diversity among smallholder farms and their constraints and second to explore the opportunities for biomass production either for food, or biofuel or cash in central Mozambique. The final goal was to aid policy makers who are searching for pathways to improve the livelihoods of smallholder farmers in Mozambique. Recognizing the role of multiple players to achieve agricultural development based on smallholder farms, I applied an integrated approach that accounts for drivers at farm and national levels, and looks at off-farm opportunities, market linkages and the policy environment conducive for achieving agricultural development.

This study focuses on smallholder maize-based farming systems in two districts, Sussundenga and Gondola, in central Mozambique. The two districts are located in the Manica Plateau a region with high agricultural potential. I selected two Administrative Posts: Dombe in Sussundenga and Zembe in Gondola based on expected competition for resources

between food and cash crops and different distances to urban markets that influence the access to agricultural markets. Maize is the main food and cash crop in both posts. Sesame is grown only in Dombe whereas sunflower is grown only in Zembe.

Chapter 2 was motivated by the need for understanding the diversity among smallholder farms and their constraints to produce maize, sesame and sunflower. To this end, I used farm surveys (Dombe n=72 and n=52 in Zembe); focus group discussions (three per post) and interviews with key informants (three per post) on smallholder farmers livelihoods. Direct observations of different activities that are part of farmers' livelihood portfolios complemented the surveys and focus group discussions. Principal Component Analysis showed that access to labour and cultivated land (Fig. 2.2) were the main production factors shaping the diversity among smallholder farms in both posts. Based on these two production factors, I grouped farms in Dombe and Zembe into four farm types which I used in the subsequent chapters of the thesis. These Farm Types (FT) were the large farms only hiring in labour (FT 1); intermediate farms hiring in and out labour (FT 2); small farms sharing labour (FT 3a); small farms only hiring out labour (FT 3b). The maize and sesame yields as well as the respective labour productivities were relatively high for large farms compared with small farms. The maize yields of large farms were (2.3 t ha^{-1} in Dombe and 2.0 t ha^{-1} in Zembe). For small farms maize yields were (1.5 t ha^{-1} in Dombe and 1.1 t ha^{-1} in Zembe). No difference between farm types was observed in sunflower yields. Yet sunflower labour productivity was higher on large farms. Delayed weeding was identified as the main reason for differences in labour and land productivities between farm types. I also observed excessive alcohol consumption among small farms that could negatively affect the quality of labour. The findings from Chapter 2, indicated that opportunities for development differ among smallholder farms and that intensification and extensification options to increase production as well as off-farm jobs are valid alternatives to explore.

Building on the results from Chapter 2, and using a farm level model, Chapter 3 explored development options for large (FT 1) and small farms (FT 3b) in Dombe and Zembe in the Manica Plateau. I developed a bio-economic farm model that incorporates the main objectives of smallholder farmers and national policy goals related to the farming systems in Dombe and Zembe and I formulated intensification and extensification options for an average farm of both farm types. The resources endowments of the farmers as well as the agricultural potential have influence on development possibilities of smallholder farmers. I found that the prospects for achieving the objective of increasing income and food production are much better for large farms in Dombe compared with other farms. In Dombe, the gross margin of large farms increased from \$ 5550 to \$ 7530 per farm and maize sales from 12.4 t to 30.4 t per farm. In Zembe, the gross margin increased from \$ 1130 up to \$ 2410 per farm and maize sales from 5.1 t up to 9.5 t per farm. For small farms in Dombe, the gross margin increased from \$ 1820 to \$ 2390 per farm and maize sales from 3.0 t to 9 t per farm. In Zembe, the gross margin increases from \$ 260 to \$ 810 and maize sales from 2.0 t to 3.6 t per farm. For small farms, unless more land and labour are made available beyond the current observed, especially in Zembe, options for development may lie in earning income through permanent employment from on-farm or off-farm activities. Animal traction for land preparation and herbicides for weeding are the most profitable technologies. Intercropping of maize with pigeonpea further increase both gross margin and food production. Cultivators and fertilizers are too costly to be economically viable given current prices.

Chapter 4 assessed how food security of smallholder farms is impacted by their involvement in large scale investment of biomass production for biofuel. This chapter was motivated by lack of farm level studies that systematically address the question whether the benefits from participation in biomass production for biofuel can offset the possible negative impacts of biofuel on food security of smallholder farms, through land use change towards food crops. I studied two modes of participation in biomass production: an outgrower scheme for sunflower and a jatropha plantation offering full time employment and assessed the four dimensions of food security: availability, access, stability and utilization in smallholder farms in Central Mozambique. Through interviews with farmers (n=80) I collected data on maize sold and purchased to assess availability of food. Maize is the most important dual purpose crop; it provides both food and cash. Information on gross revenue of a farm household was used to capture impacts on cash as a key resource used by smallholders to access food. I considered both farm and off-farm sources of cash. To assess the utilization of food, I collected data on diversity of food groups consumed within a household. To analyse food stability, I calculated the revenue diversity index by adapting the Simpson diversity index equation. The results showed that the involvement of smallholder farmers with biomass production for fuel had a positive or no impact on the four dimensions

of food security at the farm level. The smallest farms (Farm types 3a and 3b) employed on plantations benefited more than larger farms (Farm type 1) and outgrowers. Positive food security impacts from working on the biofuel plantation were improvements in availability for the larger farms and improvements in access for the smaller farms. Stability and utilization were generally not impacted. Impacts on food security from the sunflower outgrower scheme were minor. While employment had positive impacts on the food security of smaller farmers, the risk of job loss as observed in the jatropha plantation cannot be underestimated.

Chapter 5 was motivated by the current shortcomings of traditional market arrangement studies that focus on a specific crop and thus on a specific value chain, and tended to emphasize the transactions costs associated to specific market arrangements. Smallholder farmers, however, cultivate multiple crops and are therefore simultaneously engaged in multiple value chains. Apart from the costs, farmers also look at the returns of engaging in a particular arrangement. Thus, the objective of this chapter was to evaluate the combined use of farming systems and Transaction Cost Economics theories in understanding the choice of various sales arrangements by the farmers. To do so, I used the farm typology developed in Chapter 2 to analyse the different market arrangements used by different farm types to sell their agricultural products. In Dombe, I interviewed 12 farmers, six itinerant buyers, one buying company, one village trader and the leaders of a cooperative. In each post, I conducted two focus group discussions composed of 4-6 farmers per group. In Zembe I interviewed 10 farmers across the farm types, and four itinerant buyers. The main issues covered during the interviews were on the marketing channels for maize, sunflower and sesame, production techniques, inputs used, yields, quantities sold per transaction, frequency of transaction, final market, selling period, distance to market, farm types, buyer characteristics, supporting organization, type of support, access to credit, role of producer organizations, and the content of the agreements between transaction parties for each farm type, and products prices. The analysis showed that a farmer decision to participate in a particular (new) value chain is determined by (a) the suitability of the new crop in the farm system (including the adaptability of the current farm system), and (b) the farmer's experiences with selling in various value chains. The Windmill diagram is the visualization of a farmer participates in multiple value chains. The diagram can be seen as a starting step towards a development of

an analytical framework that combines farming systems and transaction cost theories to understand the decision behind a participation in particular value chain as well as the sales arrangements. Like a windmill where several vanes (crops in my case) contributes to pushing the axis and rotating the millstone, a farm is engaged in various value chains each contributing to the objectives and aspirations of farmers. The key point of this approach is that farmer decisions on cropping and on sales arrangements are interdependent, and are all taken simultaneously within the farm system. Thus, the farm is the central axis of the model, while the value chains are the vanes. A key policy message is that farming systems analysis deserves more prominent place in understanding sales arrangements for agricultural products in smallholder farming settings. This is particularly relevant for the Mozambican agricultural development policy (PEDSA) objective of linking smallholder farmers into markets in sustainable manner.

In Chapter 6, I discuss the main findings from the previous chapters in relation to agricultural development policies in Mozambique (PEDSA). I explore, in a stepwise approach, agricultural development from different levels of decision making (from farmer to policy maker) and scale of analysis (from field to country level). I demonstrated that in order to explore the opportunities for smallholder development there is need to understand the diversity of farms and farmers' social and economic context. For large farms, in Central Mozambique farms with on average 2-4 ha of land, opportunities to improve their livelihoods through crop production can follow two pathways: intensification and extensification. For small farms, off-farm opportunities such as those in the biofuel investment are the best options to improve their livelihood. Given that access to markets is crucial for smallholder farms development, the current approach that focuses only on transaction costs is limited. Therefore, I have provided a framework that takes a livelihood lens for smallholder market development. This framework shows that household resources are more important than transaction costs.

Key words: *farm typology, food self-sufficiency, farm model, income, extensification, intensification, biofuel plantation, employment, outgrower schemes, sales arrangements.*

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 (6.0 ECTS)

- Biomass production by smallholder farmers in sub-Saharan Africa
- Smallholder farming systems analysis
- Sustainable livelihood approach
- Dynamics of livestock production systems under small-scale farmers conditions
- Smallholders farmers resources dynamics in sub-Saharan Africa
- Linking smallholder farmers to agricultural markets

Writing of project proposal (4.5 ECTS)

- Biomass for bio-fuel production options on family farms in Manica (Mozambique): integrated assessment of sustainability, risk and organisational configurations

Post-graduate courses (5.3 ECTS)

- Multivariate analysis PE&RC (2009)
- Impacts and Socio-economic drivers of biofuels production in Mozambique, Nijmegen, CERES summer school – Nijmengen, The Netherlands (2009)
- Tropical farming systems with livestock WIAS (2013)

Laboratory training and working visits (4.3 ECTS)

- Methods for soil and plant nutrient determination, National Institute for Agricultural Research of Mozambique (2009)
- Visit to biofuels experiment in Manica, Eduardo Mondlane University, Forestry Department, Maputo, Mozambique (2010)
-

Invited review of (unpublished) journal manuscript (2 ECTS)

- Cereal legume intercropping systems in Mozambique. Experimental Agriculture (2014)
- Using the ecosystem service approach to determine whether jatropha projects were located in the marginal lands in Ghana: implications for site selection and exit strategies. Biomass and Bionergy (2015)

Deficiency, Refresh, Brush-up courses (0 / 3 ECTS)

- Global food security, MGS (2009)

Competence strengthening / skills courses (3.1 ECTS)

- Information literacy, including endnote; WGS (2012)
- Effective behaviour in your professional surroundings, WGS (2013)
- Scientific Writing, WGS (2013)

PE&RC Annual meetings, seminars and the PE&RC weekend (1.2 ECTS)

- PE&RC Weekend last years (2009)
- PE&RC Day (2012)

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

- Meetings of PhD students: Biofuels an interdisciplinary approach (2009-2012)
- Discussions groups and meetings on biofuels issues in Mozambique (2009-2012)
- Bio-fuel meeting in The Netherlands (Fact Foundation) (2009)
- Discussion meeting with Government, private sector and education institutions on alternatives sources of biomass for biofuels. This included presentation of on-farm trials conducted with potential crops such as sweet sorghum (2009-2013)
- Discussion meeting with Principle Energy, Girassol Manica and SunBiofuels companies on smallholder farmers involvement with biomass production for biofuel (2009)

International symposia, workshops and conferences (6.9 ECTS)

- Seminário Científico sobre Bio-combustíveis, Maputo, Mozambique. (2009)
- 10th African Crop Science Society Conference. Maputo, Mozambique (2011)
- First Global Conference on Food Security, the Netherlands (2013)
- WOTRO Workshop: biofuels – opportunity or threat? (2013)

About the author

Wilson José Leonardo was born in Inhambane, Mozambique on the 3rd of September 1974. In 1990, he moved to Maputo, the capital of Mozambique to attend secondary school Francisco Manyanga. In 2001 he graduated with a Bachelor of Plant Production and Protection at the Eduardo Mondlane University, Mozambique. Upon graduating, he worked for the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) from 2001 to 2005. In 2005, he was awarded a scholarship by the Ford Foundation to pursue an MSc degree at Wageningen University which he completed in 2007 under supervision of Prof. Ken Giller. Discussions with Ken on the complexities and heterogeneities of smallholder farming systems in Sub-Saharan Africa inspired him to focus his research on the farming systems of smallholder farmers in Mozambique. In 2009, Wilson joined Wageningen University to embark on his PhD studies as a sandwich PhD candidate. Due to financial limitations at ICRISAT to accommodate a sandwich student he was forced to resign his working contract and dedicate himself full-time to his PhD research. The PhD study initially explored the opportunities and limitations of biomass for biofuel production in Mozambique. However, as soon as his research proposal was approved by Wageningen University in 2009, the interest on biomass for biofuel started to wane. Therefore, he extended the focus of his research to explore opportunities for biomass for food, biofuel or as a cash-crop amongst smallholder farms in Mozambique. In 2014 he joined the International Fertilizer Development Centre (IFDC) on a joint appointment with International Institute of Tropical Agriculture (IITA) as senior agronomist and N2Africa Country Coordinator in Mozambique. Wilson was appointed IFDC Country Representative in 2016. Wilson is married to Nércia and has two lovely children: Kedzane and Wilson Junior.

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