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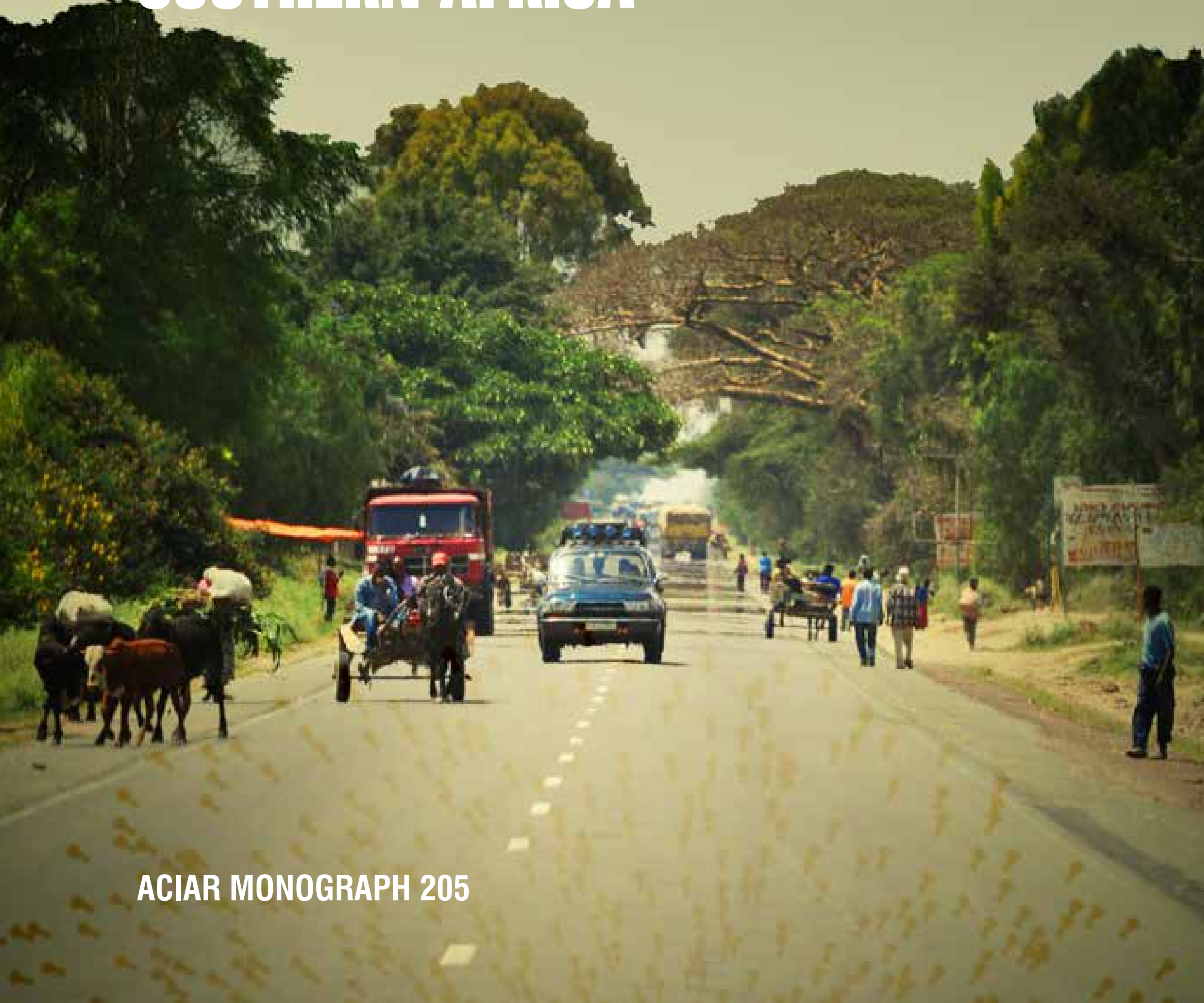
# UNDERSTANDING HOUSEHOLD DIVERSITY IN RURAL EASTERN AND SOUTHERN AFRICA



ACIAR MONOGRAPH 205

# UNDERSTANDING HOUSEHOLD DIVERSITY
## IN RURAL EASTERN AND SOUTHERN AFRICA

EDITORS
ERIN WILKUS, CASPAR ROXBURGH AND DANIEL RODRIGUEZ

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The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. ACIAR operates as part of Australia's international development cooperation program, with a mission to achieve more productive and sustainable agricultural systems, for the benefit of developing countries and Australia. It commissions collaborative research between Australian and developing-country researchers in areas where Australia has special research competence. It also administers Australia's contribution to the International Agricultural Research Centres.

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# FOREWORD

Increasing agricultural productivity, sustainability and resilience through technological innovation is a key mandate of the Australian Centre for International Agriculture Research (ACIAR). As part of the Australian Government's overseas aid program, ACIAR supports collaborative agricultural research throughout the Indo-Pacific region.

Since 1982, ACIAR has organised and funded research to inform agricultural development programs that are applied to the wide range of cultures, resources, growing conditions, political climates, food and livelihood needs of our partner countries. It is therefore fitting that ACIAR publishes this book, highlighting the role of diversity in agricultural development efforts in southern and eastern Africa.

The food and nutrition security of more than half a billion smallholder farmers in Africa depends on their capacity to scale efficient and effective innovations that increase productivity and build resilience in their food and livelihood systems. The Sustainable Intensification of Maize-Legume Systems for Food Security in Eastern and Southern Africa (SIMLESA) program, funded by ACIAR from 2010, aimed to create more productive, resilient, profitable and sustainable maize-legume farming systems to overcome food insecurity and help reverse soil fertility decline, particularly in the context of climate risk and change. The success of the program led to the implementation of a second phase of the program (2014–18) with an increased focus on upscaling sustainable intensification technologies that were initiated and tested in the first phase of the program.

This monograph, produced by the SIMLESA program, aims to identify the agroecological and socioeconomic patterns that define the diversity of opportunities to sustainably intensify eastern and southern Africa's food and livelihood systems. It describes differences and similarities within and across five countries, and the various types of disparities that contribute to generating poverty traps and opportunities for economic and social growth.

The target audience for this monograph is researchers, students and development practitioners, working in diverse settings, who wish to identify target communities for development efforts. The book is also designed for those who are more generally interested in farming systems and ways of understanding differences among people and communities.

**Andrew Campbell**
Chief Executive Officer
ACIAR

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Finally, our most sincere thanks go to the individuals and families from all the households surveyed for this work. It is humbling to be given time by those who face so many challenges and demands in their daily lives. Their resilience and optimism in the face of such uncertainty gives us all hope that we may live to see a better world, one that is finally free from poverty and hunger. We dedicate this book to them.


> "…Diversity may be the hardest thing for a society to live with, and perhaps the most dangerous thing for a society to be without…"
>
> WILLIAM SLOANE COFFIN

# INTRODUCTION

ERIN LYNN WILKUS AND CASPAR WILL ROXBURGH

# KEY POINTS

- Chronic food insecurity and poverty are high in eastern and southern Africa. These issues are expected to remain, and are especially severe in rural areas where most of the populations reside.
- Household production represents the main source of food and income for these rural households.
- Yields of maize—the region's most important food crop—remain well below estimates of what is attainable given the climate and soil conditions.
- With limited land available for expansion, sustainable intensification (i.e. growing more with the same while maintaining the resource base) provides a promising option for ensuring that production levels meet future demand.
- Adoption of sustainable intensification practices has been shown to depend heavily on the complex diversity of farming systems and household subsystems. This often leads to inequitable benefits, further alienating groups embedded in cycles of poverty.
- The diversity of household production systems makes it difficult to match feasible intensification options to farmers' circumstances.
- Methods that establish household typologies and model the diversity of household response to different intensification pathways can provide tools to develop recommendations based on farmers' options and needs.

## DEFINITIONS

**Attainable yield**—The yield that could be achieved under existing soil conditions, water availability, solar radiation and temperatures if all nutrient stresses and pest pressures were removed.

**Development pathway**—The process of farming system changes that will most likely provide the greatest advantage to a household production system, given the unique qualities and livelihood strategies of the household. Refer to Van der Ploeg et al. (2009) for a review of the development pathway concept.

**Farming system**—A population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate.

**Food security**—A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO et al. 2015).

**Household subsystem**—A decision-making unit, comprising the farm household, cropping and livestock systems, that transforms land, capital (external inputs) and labour (including genetic resources and knowledge) into useful products that can be consumed or sold.

**Household typologies**—A classification scheme that organises households based on variable household characteristics (e.g. levels of endowment).

**Livelihood strategy**—The way a household or individual matches intermittent and limited resource availability with consumption needs while allowing for uncertainties. The agroecology, markets, local infrastructure, institutions and household assets shape farmers' activities that determine livelihood strategies.

**Sustainable intensification**—Producing more food from the same area of land in a variable and changing environment, while maintaining or improving the resource base.

## 1.1 POVERTY AND FOOD INSECURITY

Eastern and southern Africa (ESA) remains an area of acute concern for poverty and food insecurity. Sustainable intensification has been promoted as a mix of innovations in agricultural technologies and management practices that can support food security and alleviate poverty. However, the benefits of sustainable intensification innovations can vary widely across households, communities, regions and countries depending on their unique needs and options. Addressing poverty and food insecurity in ESA therefore involves identifying the innovations that are more likely to benefit (and be adopted by) household producers. This starts with understanding household diversity.

Eastern and southern Africa experienced major structural transformations over the last 25 years (Reardon and Timmer 2007; Neven et al. 2009; Djurfeldt and Djurfeldt 2013). Examples of this include economic growth (Johannesson and Iryna 2010; IFAD 2016), broadened market access (Kelly et al. 2003; Reardon

2011), trade liberalisation (Minten et al. 2009) and increased access to skills and information (Donner 2004; ITU 2007; Tadesse and Bahiigwa 2015). However, food insecurity and rural poverty levels continued to increase throughout these transformations.

The 3.1% increase in Africa's middle class from 1980 to 2010 (slightly above the average population growth rate of 2.6%) provided evidence of upward mobility (Tschirley et al. 2015). Although this trend suggests an encouraging outlook (Neven et al. 2009; AfDB 2011), over the same period many ESA countries saw a rise in poverty (poverty estimates are based on the count of households with consumption or income per person below the 2011 international poverty line of US$1.90 per person per day, adjusted for purchasing power parity exchange rates) (World Bank and IMF 2013; World Bank 2016). In Kenya, poverty levels increased from 23% of the population in 1992 to 34% in 2005. In Malawi, where poverty levels were far above that in Kenya, these also increased from 64% in 1997 to 71% in 2010 (World Bank 2016). In many other countries, poverty became less prevalent with population growth. For instance, in Tanzania the proportion of people living in poverty in 2012 was nearly one-third of 1991 levels. However, as was the case in many ESA countries, due to a growing population the number of people living in extreme poverty continued to grow. By 2012, the number of Tanzanians living in extreme poverty rose by 4 million from 1991 levels. If we assume continued population growth under the same conditions, the number of people living in extreme poverty is likely to increase despite the percentage continuing to fall.

Despite trends towards urbanisation since the 1960s (World Bank 2015a), rural populations have represented the overwhelming majority of those living in ESA. These populations also have had much higher poverty levels than urban groups. In 2015, rural populations in select ESA countries (Ethiopia, Kenya, Malawi, Mozambique and Tanzania) were between a high of 84% of the population in Malawi and a low of 68% in Mozambique (World Bank 2015a). Despite growing cities, the number of people living in rural areas consistently rose to reach up to 80 million people in Ethiopia, 36.5 million in Tanzania, 34.2 million in Kenya, nearly 19 million in Mozambique and 14.4 million in Malawi by 2015 (World Bank 2015a). Poverty levels among these populations have been especially high. Overall, poverty levels in ESA reduced slightly between 1990 and 2010, showing slow progress in poverty eradication. During this period, the gap between rural and urban poverty remained constant (World Bank 2015a; IFAD 2016). In 2010, the percentage of the rural population that lived below the national poverty line was as high as 56.5% in Mozambique and 50.7% in Malawi. In the same year, poverty levels in Ethiopia were lower although still considerable at 29.6%. In 2011, 28.2% of rural residents in Tanzania lived below the national poverty line.

These high levels of poverty in turn underpin widespread food and nutrition insecurity in ESA. In particular, high numbers of undernourished people in eastern Africa relative to the rest of sub-Saharan Africa (SSA) indicate it is a high-priority subregion for nutrition efforts. Despite declines between 1990 and 2016, the number of undernourished people was higher than in any other region throughout the period (FAO et al. 2015). In both years, the undernourished population in this subregion represented nearly 60% of all undernourished people in SSA (FAO 2015). In addition, the reduction in undernourishment in eastern Africa was slower than in other regions of the world, especially East Asia and South-East Asia (FAO 2015). As with poverty levels, while the percentage of the population that was undernourished decreased in eastern Africa (from 47% to 32%), rapid population growth contributed to a 20% rise in the actual number of undernourished people. Undernourishment in the region increased from 103.9 million people in 1990 to 124.2 million in 2016 (FAO 2015). Meanwhile, undernourishment is far less acute in southern Africa. This region was home to 2% of the undernourished people in SSA in 2016, reflecting a 2.3% increase in this number since 1990 (FAO 2015). The number of undernourished people in southern Africa reached approximately 3.2 million in 2016. This growing hunger in both regions is in stark contrast to the decline in undernourishment observed in all the Food and Agricultural Organization of the United Nations (FAO) regions outside of SSA (FAO et al. 2015). Such a trend sets ESA as a priority region for poverty alleviation and efforts to enhance food security.

Levels of food security vary across countries in ESA. For instance, the 2011 Food Insecurity Index data showed that chronically food-insecure populations covered a much larger proportion of the land area in Ethiopia compared to other ESA countries (Figure 1.1). This variability across ESA countries is also evident in undernourishment levels and trends. From 1990 to 2015, Ethiopia was home to more undernourished people than any other SSA or South-East Asian country (FAOSTAT 2017). However, the trend in Ethiopia over this period was encouraging. The number of undernourished people in the country dropped from 37.3 million (75% of the population) in 1990–92 to 31.7 million (32%) in 2014–16 (estimates are based on the 3-year average). In Malawi, the number of undernourished people fell from 4.3 million (45% of the population) in 1990–92 to 3.6 million (21%) in 2014–16. In Kenya and Mozambique, numbers of undernourished people increased between the early 1990s and the mid-2010s. By 2014–16, 21% of Kenya’s population was undernourished (9.9 million) and in Mozambique 25% were undernourished (7.2 million). This variability highlights the need to address country-specific factors (World Bank 2015b; Pardey et al. 2016).

## 1.2 MAIZE PRODUCTION, CONSUMPTION AND INCOME GENERATION

From the 1990s to the early 2000s, small-scale production by household producers contributed the main share of domestic food production (Lowder et al. 2016) and supplied the largest share of food consumed (HLPE 2013) in most ESA countries. Over this period, the household plots where the majority of maize production took place decreased in size while the number of holdings increased (Lowder et al. 2016). Average plot sizes of 1.4 hectares (ha) were already a fraction of average farm size in other parts of the world. In the 1960s, the average plot size in ESA was 1,000 times smaller than the average plot size in Australia (1,844 ha) and 100 times smaller than in the USA (123 ha). In Ethiopia, the average plot decreased from 1.4 ha in 1980 to 1.0 ha in 2000 (Lowder et al. 2016). Similarly, in Malawi this fell from 1.5 ha in 1970 to 0.7 ha in 1990 (Lowder et al. 2016). In Kenya, plot size decreased more drastically from an average of 11.7 ha in 1960 to 2.5 ha in 1980 (Lowder et al. 2016). These cases, among others, have been the basis of concern over land shortages and the increasing risk of landlessness in eastern Africa (Jayne et al. 2010). Meanwhile, Tanzania showed a different pattern where plots increased in size from 1.3 ha in 1970 to reach 2.8 ha in 1990 and 2.4 ha in 2000. Collectively, these plots covered a tremendous land area. For instance, in 2001 all 11 million ha of agricultural land in Ethiopia was cultivated on plots that were 20 ha or less. Of this, over 10 million ha was on plots that were 5 ha or less (Lowder et al. 2016).

Yet average yields in ESA farms have been extremely low. Between 2008 and 2010, average maize yield in eastern Africa was 1.5 t/ha, representing a small fraction of the attainable yield of 3–4 t/ha (Fischer et al. 2014). Average yield for southern Africa (excluding South Africa) was 1.3 t/ha (FAOSTAT 2017). The difference between attainable yields and levels of production has represented a huge margin for progress in food production and an important area for investment (Jayne et al. 2010). While this margin was still large in 2010, yield trends show increases in many ESA countries since the 1990s. In Ethiopia, maize yields increased from approximately 1.5 t/ha in 1993–95 to approximately 3.6 t/ha in 2012–14.

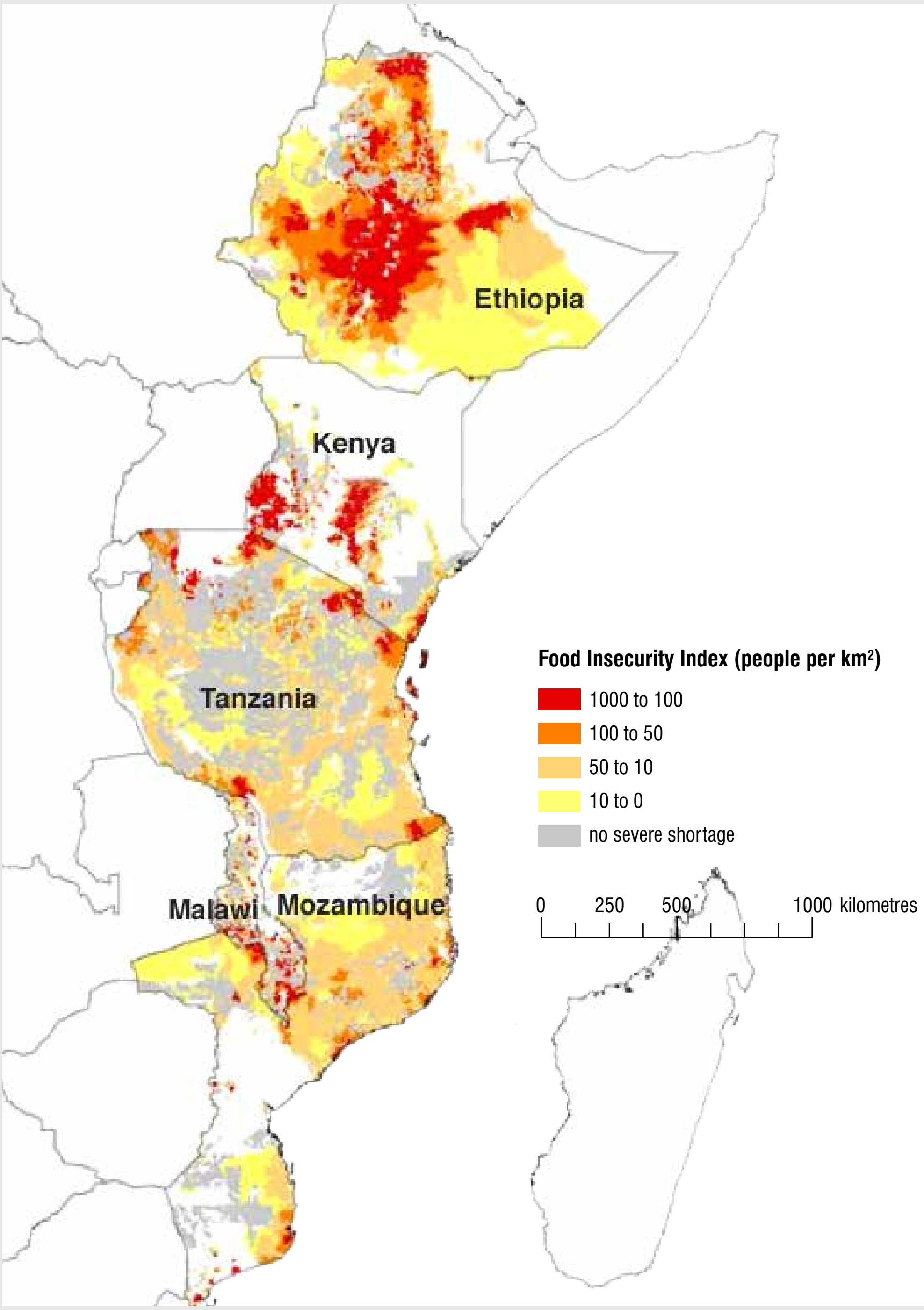



**FIGURE 1.1** Food insecurity hotspots across the five case study countries of Ethiopia, Kenya, Tanzania, Malawi and Mozambique. The Food Insecurity Index is based on 2011 levels of food affordability, availability and quality/safety.

In Kenya, maize yields made less gains. Yields in the country increased from approximately 1.4 t/ha in 1993–95 to roughly 1.9 t/ha in 2012–14. In Malawi, yields increased from 1.4 t/ha in 1993–95 to 2.2 t/ha in 2012–14. For Mozambique maize yields have been particularly low, increasing from 0.5 t/ha in 1993–95 to approximately 0.8 t/ha in 2012–14. With the exception of Ethiopia, maize yields were still far below attainable levels. The potential for productivity gains can be substantial, and offer opportunity for household producers. However, persistent production challenges remain. Between the 1990s and late 2000s, these included soil nutrient depletion (Drechsel et al. 2001; Pingali 2001; Smaling et al. 2012), limited or no use of fertilisers or inputs (Wichelns 2006) and highly variable and changing climates (Hansen et al. 2009). At low production levels in 2003, the majority of household producers in Mozambique (63%), Kenya (62%) and Ethiopia (73%) were net buyers of maize, spending 30–50% of total household expenses to supplement household yields (Jayne et al. 2006). These challenges (and the prohibitive cost of inputs to address them) were identified as major factors perpetuating chronic cycles of poverty (Tittonell and Giller 2013).

The substantial role that maize plays as a source of food and income for rural households in ESA suggests that the benefits of increased maize production could be substantial. The agriculture sector represents a major share of employment and income for rural households in ESA. In 2003, the agriculture sector supported 80% of employment in Mozambique (World Bank 2015a). This same figure was particularly high in Tanzania, where it reached 82% of employment in 2001 before declining to 74% by 2006. Similarly, in Ethiopia agriculture represented 80% of employment in 2005 and slightly less at 73% in 2013. In 2013, the agriculture sector provided 64% of the population with employment in Malawi.

In 2007, the average household from select ESA countries (Ethiopia, Kenya, Malawi, Mozambique and Tanzania) consumed approximately 200 grams (g) of maize per day, which provided 30% of daily calories and 31% of daily protein intake (Nuss and Tanumihardjo 2011). At these rates, the amount of energy that the average person consumed from maize was about 6.7 times that from meat products. Of the five selected ESA countries, maize intake levels and the contribution of maize to daily caloric intake were highest in Malawi at 359 g of maize per day and 51% of energy consumed (Nuss and Tanumihardjo 2011). This level of dependence on domestically produced maize suggests that the chronically low productivity of household producers has limited the food available for consumption and contributed to historic undernourishment in ESA. Therefore increasing production levels are likely to have a major impact on food security. In 2014, 86 surveyed stakeholders in global food security research and policy underscored this sentiment (Keating et al. 2014). They concluded that production increases would make the greatest contribution to meeting food demand (Keating et al. 2014). However, as Keating et al. (2014) point out, increasing yield is a complex undertaking: '…it is not as simple as farmers not being willing or able to adopt a set of technologies and practices. Input or output markets prices, climatic variability or other conditions may make it unattractive for farmers to make the investments or take on the risks to close the yield gap'.

## 1.3 SUSTAINABLE INTENSIFICATION: RECOMMENDATIONS AND ADOPTION PATTERNS

Between 1990 and 2014 maize production in eastern Africa increased 1.4-fold, from 13 million tonnes to 30 million tonnes (FAOSTAT 2017). These production gains have been primarily attributed to the expansion of land under cultivation, rather than intensification of production (IFAD 2016). Over this period, total land area under production in ESA increased from 9.6 million ha to 17.3 million ha—

a 0.8-fold increase. At the same time, average maize yields increased only slightly from 1.5 to 2.0 t/ha—0.3-fold increase (FAOSTAT 2017). A survey of 2,354 household grain producers from eight African countries (Ethiopia, Ghana, Kenya, Malawi, Mozambique, Nigeria, Tanzania and Zambia) showed that only a minority of households increased yields over time (Djurfeldt et al. 2008). Approximately 30% had increased yields from their first year of production (typically 1980) to 2002. The average annual rate of intensification was particularly low in the years preceding 2002, when on average only 1% of households intensified production per year. Between 2002 and 2008, the annual rate of intensification rose to 4%. In the same period, total production increases were relatively high and 69% of these gains were attributed to expansion of area. Only 14% were associated with favourable prices or terms-of-trade effects, and only 17% were associated with increased use of inputs (including labour) or technical change (Fuglie and Rada 2013). By 2008, opportunities to continue expansion were more limited. Low yields, decline in household plot size, increase in land holdings (Lowder et al. 2016) and the end of rapid land expansion (Tilman et al. 2011; Smith 2012; Vanlauwe et al. 2014) suggested such expansion was no longer a viable path to increased food production.

Intensification, as defined by the FAO Special Programme for Food Security, refers to the ‘increased physical or financial productivity of existing patterns of production; including food and cash crops, livestock and other productive activities’ (Dixon et al. 2001). From 1960 to 2000 the global land footprint grew by 11% while agricultural output grew by 153% (FAOSTAT 2017). With the exception of many ESA countries, the majority of this global production increase was attributed to intensification. For instance, yield gain in Asia was achieved primarily through widespread adoption of high-yielding varieties, fertilisers and irrigation methods (Lowell 2008). However, negative impacts of intensification in Asia included substantial groundwater depletion, soil fertility degradation and chemical run-off.

The concept of sustainable intensification was developed in response to growing concerns over these damaging effects (Pingali and Rosegrant 1994; Prabhu 2012). Sustainable intensification is the achievement of productivity gains while conserving or improving the natural resource base (Pretty 2008; Godfray et al. 2010; Tilman et al. 2011). It is a framework through which efforts to overcome poverty and hunger via reduction of yield gaps can be pursued. Production conditions in ESA (and the history of intensification achievements in other regions) stimulated efforts to promote sustainable intensification in ESA. In the early 2000s, many high-profile development efforts began promoting sustainable intensification practices. These practices included minimum tillage, crop diversification through intercropping and crop rotation, soil and water conservation practices and application of inorganic fertilisers and animal manures. Other recommendations considered utilisation of unused resources, improved labour productivity and changes in irrigation practices or pest control (Dixon et al. 2001; Keating et al. 2014). However, patterns of intensification and adoption of sustainable intensification practices have varied both across countries and among diverse sets of households (Tesfaye et al. 2015).

National level statistics indicate mixed experiences in broad adoption trends of sustainable intensification. In contrast to observations of marginal gains in yield, yearly indexes of agricultural total factor productivity (TFP)—defined as returns for a given bundle of agricultural resources, namely land, labour and capital—provide an indication of robust sustainable intensification patterns in ESA (Fuglie and Rada 2011). Fuglie and Rada (2011) found that Kenya and Tanzania both sustained steady, long-term growth in agricultural TFP from 1961 to 2008. Kenya’s agricultural TFP increased by a total of 78%. This means that a given bundle of agricultural resources produced 78% more crops and livestock in 2008 than in 1961. Tanzania saw a 48% increase over this same period. In Ethiopia, TFP fluctuated slightly around initial 1961 levels, increasing just 4% by 2008.

Variability at the household level has also determined the benefits of adopting sustainable intensification practices, with consequences for production practices and intensification outcomes. For example, in two districts of Ethiopia, the benefits of adopting specific practices (improved seeds, chemical fertiliser use and planting in rows) depended on household resources and assets. A simulation of household data from 2011 showed that adoption of these technologies had the potential to lift 'better-off poor' households out of poverty. However, the poorest households benefited less and remained impoverished after adoption of these technologies (Kotu and Admassie 2016). Similarly, Rodriguez et al. (2017) found that the poorest group of household producers in western Kenya had the most to lose (in terms of soil loss and feedstock availability) from adoption of sustainable intensification technologies (see Box 9.2). These characteristics indirectly explained differences in adoption and intensification levels among households.

A number of other case studies have also explained variability in household adoption of sustainable intensification practices through household production characteristics. Such studies tend to show that resource and production characteristics affect costs and benefits of adoption. For instance, in 2010 households in Tanzania with fertile land were more likely to adopt improved maize varieties than those with less fertile land (Beyene and Kassie 2015). Beyene and Kassie (2015) suggested that this was because returns on new maize varieties were lower (and had little advantage over older varieties) when they were cultivated in less fertile soil. This variability was also observed at broader scales, where certain household characteristics that affected adoption spanned large areas. Kassie et al. (2015) found that adoption levels of certain sustainable intensification practices (minimum tillage, improved maize varieties, crop diversification, soil and water conservation practices, inorganic fertilisers and animal manure) varied across countries in ESA. In 2010–11, the likelihood that a household adopted more than three sustainable intensification practices was about 75% in Kenya, 45% in Malawi, 15% in Ethiopia and just 5% in Tanzania. Within each country, the likelihood of adoption depended on a wide range of production dimensions. These included social capital and networks, quality of extension services, reliance on government support, incidence of pests and diseases, resource constraints, tenure security, education and market access (Kassie et al. 2015). In the case of social networks, households that were part of organised groups were more likely to adopt inputs, technologies and practices. A survey of households from eight African countries found that market factors influenced the likelihood that households intensified production (Djurfeldt and Djurfeldt 2013). Commercialised households were nearly four times more likely to intensify production than non-commercial households. In 2004–05, gender, age and education levels all influenced the likelihood of sustainable intensification practice adoption among household producers in Rwanda. Female-headed households were more likely to apply compost and green manures. Young, male and literate farmers were the only households that applied chemical fertilisers. In contrast, uneducated full-time farmers applied fallow and soil erosion control measures to maintain soil fertility (Bidogeza et al. 2009). Taken together, these case studies demonstrate the comprehensive array of household characteristics that can influence adoption of sustainable intensification practices, highlighting the complexity of efforts to establish recommendations for adoption.

Households that are less likely to benefit from intensification might seek alternative pathways out of poverty. This may involve increasing land area under cultivation or specialising in extensive grazing (extensification), diversifying production and processing activities, or exiting the agriculture sector and moving into either the non-farm economy or urban centres. Dixon et al. (2001) evaluated the potential for each of these strategies to alleviate poverty and food insecurity for different farming systems. This evaluation helped place intensification within the broader context of development (Table 1.1).

**TABLE 1.1** Relative importance of different household strategies for achieving food security. The potential benefits of each strategy are expected to increase as the shade darkens.
Table adapted from Dixon et al. (2001).

| Farming system | Intensification | Diversification | Increased farm size | Increased off-farm income | Exit from agriculture |
|---|---|---|---|---|---|
| Cereals and legumes intensification | | | | | |
| Livestock–cropping integration | | | | | |
| Irrigated farming system | | | | | |
| Extensive grazing system | | | | | |

## 1.4 UNDERSTANDING FARMING SYSTEM DIVERSITY: TYPOLOGIES AND MODELS

The diversity of farming systems is underpinned by the complex interactions of variable and interconnected farming system components that are managed for a wide range of objectives. This has represented a major challenge in identifying sustainable intensification options that support food security and livelihoods. As seen through case studies exploring sustainable intensification practice adoption, diversity at the farming system and household subsystem levels can explain patterns in household sustainable intensification practices, food security and poverty. As such, differences in sustainable intensification practice adoption across ESA countries and regions might reflect an underlying difference in the farming systems of these countries (Kassie et al. 2015). Therefore, defining and studying diversity of farming systems becomes crucial in implementing sustainable intensification. However, there is a huge variation in methods for defining and studying farming systems. For instance, the number of households considered within a farming system delineation has ranged from a few dozen households to many millions (Dixon et al. 2001). Likewise, household subsystems (i.e. the households) within the farming system can also be highly variable. The household subsystem refers to food production activities and management of multiple resources that are usually allocated to satisfy several objectives spanning alternative enterprises (Calviño and Monzon 2009; Rodriguez and Sadras 2011). The household subsystem has represented a decision-making unit comprising the farm household, cropping and livestock systems. These units transform land, capital and labour into useful products that can be consumed or sold. Sources of diversity can span all components of the farming system and household subsystem (Figure 1.2) and lead to communities of households with different constraints and opportunities, advantages and disadvantages (Tittonell et al. 2010).

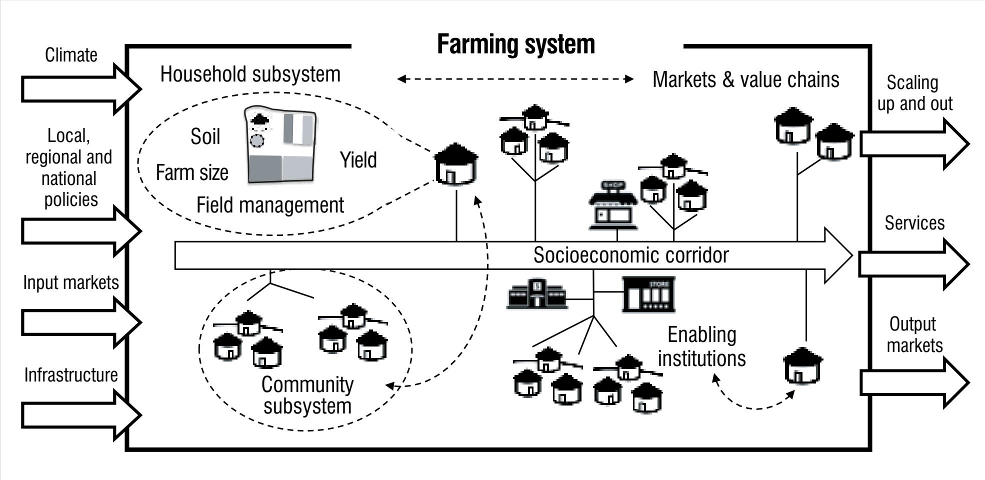
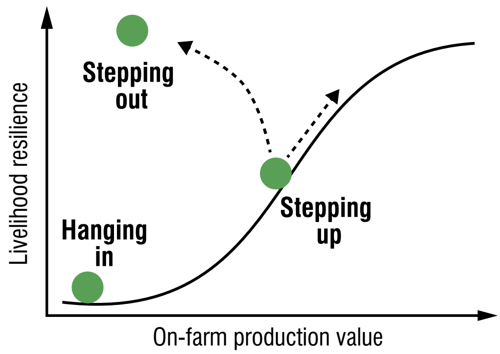



**FIGURE 1.2** Farming system schematic. Many factors can influence the farming system including climate, policies at local, regional and national levels, various characteristics of input markets and infrastructure. The household subsystem is further impacted by other households and the community subsystem at large and enabling institutions that link household producers to agriproduct value chains. Through these links to the socioeconomic corridor, the household subsystem generates agriproducts that are sold in the market, provide services to the community and environment, and generate sources of income and capital for scaling up and out.

As demonstrated in the section on sustainable intensification, the costs and benefits of adopting sustainable intensification practices can depend on sources of variability at the farming system and household subsystem levels. This results in farming systems with different livelihood strategies. Such livelihood strategies represent methods of matching intermittent and limited resource availability with consumption needs while allowing for uncertainties (Box 1.1). Variability at each level contributes to the range of household development pathways—i.e. farming system changes that are most likely to provide the greatest advantage to a household production system (Van der Ploeg et al. 2009). The challenge is to identify these pathways and form development recommendations that best support these pathways. Methods that classify households based on sources of variability and establish groups of similar households, or typologies, have therefore been developed to meet this challenge. Household models have also been used to understand the diversity of household response to adoption of sustainable intensification practices.

Different approaches have been taken to develop household typologies. Some typologies have been based on predetermined classification criteria. For instance, Pender et al. (1999) argued that three factors were most critical for determining household development pathways: agricultural potential (biophysical environment), population density and market access (socioeconomic environment). Dixon et al. (2001) classified household producers into types of farming systems based on specific differences in their natural resource base (e.g. water, land, grazing areas, slope of land, farm size) and dominant patterns of farm activities and household livelihoods (e.g. field crops, off-farm income, use of technologies).

**BOX 1.1 Example of livelihood strategies**




Simple representation of household livelihood strategies along two dimensions of profit/resilience and resources. Hanging-in households have low profits/resilience and resources. Stepping-up households tend to show high returns once a certain resource base is reached. Among stepping-up households, the relationship between resources and profits remains more constant until households reach a high resource base and profits level off.

Dorward et al. (2009) proposed a simple framework that integrates multidimensional, multilevel and dynamic understandings of poverty, of poor people's livelihoods and of their changing roles in complex agricultural systems. In their analysis they assumed that:

1. People generally aspire both to maintain their current welfare and to advance it.
2. In trying to advance their welfare, people can attempt to expand their existing activities and/or move into new activities.

Based on those propositions they identified three broad types of livelihood strategy, with three types of asset of activity contribution to those livelihood strategies:

1. Hanging in: farmers hold their assets and engage in activities to maintain their livelihood levels, under adverse socioeconomic circumstances
2. Stepping up: farmers engage in activities and reinvest in assets and their farming system to expand these activities, increase production and income and improve livelihoods
3. Stepping out: farmers engage in activities to accumulate assets which in time would allow them to move into different activities having a higher or more stable return.

Participatory work with household producers from eastern and southern Africa can profit from using such a framework as it may allow it to focus interventions that support the longer-term objectives and aspiration of the stepping-out farmers, and recognise the shorter-term needs and activities required by the hanging-in and stepping-up farmers (Dorward et al. 2009).

These criteria contributed to the generation of eight broad categories and 72 distinct types of farming systems[1] (Dixon et al. 2001).

1 Dixon et al. (2001) established the following eight broad types of farming systems based on availability of natural resources (e.g. water, land, grazing areas, climate, farm size, tenure), the dominant pattern of farm activities and household livelihoods (e.g. field crops, livestock, hunting and gathering, off-farm activities), main technologies used and intensity of production: (1) irrigated farming systems, embracing a broad range of food and cash crop production; (2) wetland rice-based farming systems, dependent on monsoon rains supplemented by irrigation; (3) rain-fed farming systems in humid areas of high resource potential, characterised by a crop activity (notably root crops, cereals, industrial tree crops [both small scale and plantation] and commercial horticulture) or mixed crop–livestock systems; (4) rain-fed farming systems in steep and highland areas, which are often mixed crop–livestock systems; (5) rain-fed farming systems in dry or cold low potential areas, with mixed crop–livestock and pastoral systems merging into sparse and often dispersed systems with very low current productivity or potential because of extreme aridity or cold; (6) dualistic (mixed large commercial or household) farming systems, across a variety of ecologies and with diverse production patterns; (7) coastal artisanal fishing, often mixed farming systems; and (8) urban-based farming systems, typically focused on horticultural and livestock production.

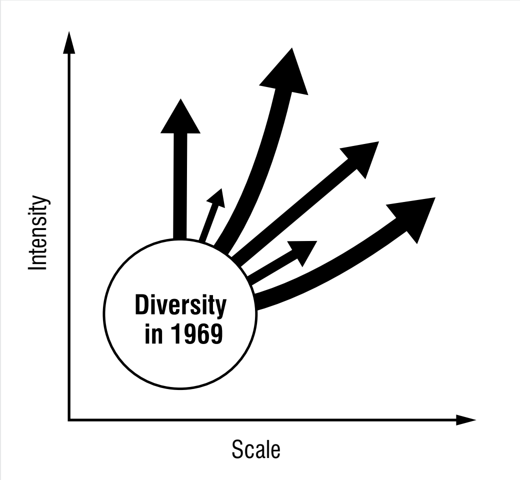



**FIGURE 1.3.** Diversity of household response. Empirical evidence of the wide range of development trajectories observed in farms in the Netherlands from 1969 to 1981.
Van der Ploeg et al. 2009

Household typologies have also been developed by applying multivariate statistical approaches to identify major sources of variability (i.e. disparities) within groups of households. These major sources of variability were then used to assign households to distinct typological groups (Tittonell et al. 2010). Household typologies, however, do not capture variability within each typological group or household characteristics that can emerge and vary over time (van Wijk 2014). A review of historical production patterns provided empirical evidence illustrating large diversity of development pathways emerging out of a similar set of households (Figure 1.3). This highlighted the importance of understanding variability over time. Dynamic whole-farm simulation models have furthermore demonstrated the wide range of impacts that can be expected from adoption of sustainable intensification practices. Typologies, together with household models, have thus been applied to better match development recommendations to the specific needs of household producers (Tittonell et al. 2009; Giller et al. 2015).

## 1.5 THIS REPORT

This report synthesises findings on the diversity of households across ESA, and the implications for research for development investments. The aim is to maximise benefits and manage trade-offs thereby increasing adoption of sustainable intensification practices by household producers. Throughout the process, this report provides a comprehensive outline for researchers aiming to study diverse communities of household producers and identifies sustainable interventions that address their unique needs and options. Chapter 2 provides a review of farming systems, their components and possible innovations in ESA. A method for deriving household typologies from household survey data is presented in Chapter 3. The country case studies (Chapters 4–8) demonstrate the application of these methods and provide examples of household typologies identified in Ethiopia, Kenya, Tanzania, Mozambique and Malawi. Such typologies are interpreted to provide recommendation domains for interventions and policies. Chapter 9 outlines how dynamic household modelling can be used in conjunction with an understanding of diversity to tease out the impacts of different intensification options on different households. Chapter 9 also presents two examples of applying a whole-farm modelling approach (in Kenya and Ethiopia) for evaluating food security, economic and environmental impacts of alternative development interventions across diverse sets of households. This is provided to demonstrate that the impacts of development interventions and associated trade-offs can vary substantially across diverse sets of households. Chapter 10 contains a broad discussion of recommendation domains identified across all five countries. Policy areas that can support the livelihoods and food security of different domains are discussed. Particular effort is made to consider how to support household groups with limited opportunities that might be further marginalised by intensification. Chapter 10 concludes with a discussion of the next steps for sustainable intensification in light of advances in digital data collection, open access and communication technology to better meet the development needs of household producers.

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# SECTION 1

# MAIZE–LEGUME FARMING SYSTEMS OF HOUSEHOLD PRODUCERS IN EASTERN AND SOUTHERN AFRICA

# AGROECOLOGIES AND FARMING SYSTEMS

CASPAR WILL ROXBURGH AND ERIN LYNN WILKUS

# KEY POINTS

- The benefits of innovations for intensification depend on agroecologies and farming system components, especially production dynamics (interactions of agroecological and household components) and institutional settings (socioeconomic components).
- Farming system components have shown high levels of variability across household production systems in ESA.
- These variable components influence household response to productive and institutional innovations resulting in a wide range of pathways for enhancing food security and livelihoods across ESA.
- Climates in ESA span warm arid and semi-arid, warm subhumid, warm humid and cool (highland) agroecological zones, each with distinct topographies and rainfall and temperature patterns.
- Soil types in ESA include ferralsols, acrisols, lixisols, arenosols and vertisols, among others. This diversity of soil types and variable soil management has explained high levels of variability in soil nutrient levels across households and within fields.
- A range of productive innovations or ‘basket of tools’ has been proposed to respond to variability in climate, soil characteristics and field and soil management practices.
- Infrastructure (telecommunication, electricity, roads), markets and enabling institutions have taken a wide range of forms across ESA.
- Household access, availability and utilisation of infrastructure, markets and enabling institutions have also varied across ESA.
- Institutional innovations have reflected variability in infrastructure and market environments, with an example of diverse fertiliser market development across ESA.

## DEFINITIONS

**Agroecological zones (AEZ)**—Geographical areas with the same agricultural production capacity based on their similar climatic, soil and vegetation characteristics. At a regional scale, AEZs are influenced by latitude, elevation and temperature, as well as rainfall amounts and distribution, soil type and vegetation. The resulting AEZ classifications for Africa have three dimensions: major climate zone (tropics or subtropics), moisture zones (water availability) and highland/lowland (warm or cool based on elevation). The simplest classification scheme divides the regions spanning African countries south of the Sahara into four zones:

1. warm arid and semi-arid tropics
2. warm subhumid tropics
3. warm humid tropics
4. cool (highland) tropics.

**Food availability**—The potential food equivalent energy (kcal) per capita per day.

**Food security**—The FAO defines food security as ‘A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life’ (FAO et al. 2015). Based on this definition, four food security dimensions can be identified as criteria for evaluating levels of food security: food availability, economic and physical access to food, food utilisation and stability over time. Food security is distinct from nutritional security in that it tends to focus on energy needs without accounting for nutritional needs (i.e. the content of the diet in relation to nutritional needs).

**Innovation**—The process by which change occurs. It may involve new ideas, new technologies or novel applications of existing technologies, new processes or institutions, or more generally, new ways of doing things in a place or by people where they have not been used before (Juma et al. 2013). This process typically involves adapting novel ideas to suit their application in a new environment while maintaining a distinct role in that environment.

**Pro-poor growth and inclusive growt**h—Pro-poor growth refers to the case when poverty is reduced substantially compared to the rate of growth of gross domestic product (GDP) per capita. This can occur when economic growth results in rising inequality in income and consumption. Inclusive growth alternatively refers to income growth that is accompanied by decreased income inequalities (Musahara 2016).

**Public–private partnership (PPP)**—A long-term contract between a private party and a government entity, for providing a public asset or service, in which the private party bears significant risk and management responsibility, and remuneration is linked to performance (Yescombe 2007). FAO proposed four foundations for successful PPPs in SSA:

1. a clear legal framework to address institutional challenges related to the dysfunction within the interparty arrangements of the PPPs and between the PPPs on one hand, and the relevant national institutions on the other

2. consistency, as well as clarity, of the policy and legal framework, to reduce uncertainty for investors
3. credible measures to address external factors such as inflation, downtime due to power failure, and downturn due to financial crisis that can negatively affected PPPs
4. a PPP unit within government, with relevant commercial and legal skills, to send a powerful signal to the private sector about the public sector's competence and seriousness of intent (FAO 2015).

**Research for development**—The undertaking of research with an explicit aim to foster humanitarian development. Often undertaken in agriculture with a view to addressing underlying problems of rural poverty and undernourishment.

**Yield gap**—The difference between the actual yield (the yield achieved by farmers) and the attainable yield (the yield limited by ecological settings such as soil and climate) (van Ittersum et al. 2013).

## 2.1 INTRODUCTION

Traditionally, the literature on sustainable intensification focused on biophysical and technological yield constraints and revenue at the plot or farm level. Only recently has research for development moved to recognising the need for more integrative systems approaches—like the farming systems framework—to address questions surrounding household production. Under the farming systems framework, farming system components and their interactions shape the opportunities and constraints for alternative intensification pathways (Giller et al. 2011). Characterising interactions across farming system components has helped to identify the properties that emerge through interactions across plot, farm, village, district, regional and national farming system levels. Understanding these interactions has been particularly challenging due to the multiple and variable nature of farming system components. Farming systems can span biophysical, technological, sociocultural, economic, institutional and political dimensions, each with specific characteristics, which can vary across farming systems (Schut et al. 2016a). Understanding existing diversity in household characteristics is a first step in understanding interactions that contribute to household production patterns and constraints. This chapter aims to provide an overview of household production systems and their diversity across ESA, with examples of context-specific innovations (productive or institutional) for achieving sustainable intensification of agriculture. Major agroecological and socioeconomic factors are described in terms of their implications for sustainable intensification. The following sections review agroecological diversity (i.e. climate and soil variability) across geographical locations, variability in field crop management, household resource endowment (e.g. individual land and labour availability and human capital) and institutional settings (e.g. infrastructure, markets and enabling institutions).

The diversity in farming systems are described in relation to two types of innovations required to achieve sustainable intensification (Schut et al. 2016b):

1. gains in sustainable productivity (Von Braun and Gatzweiler 2016)
2. strengthening of institution settings (Pretty et al. 2011; Vanlauwe et al. 2014).

Sustainable productivity innovations can refer to changes in practices, inputs or technologies that affect the production process and protect or improve the resource base. These can include adoption of high-yielding and stress-tolerant crop varieties, fertilisers and specific modifications to field management practices. Institutional innovations refer to changes in the sets of rules that determine household positions and actions. These occur through investment in (or changes to) social infrastructure, policy, partnerships, access to finance, services and markets. These types of innovations can support the range of complementary practices associated with sustainable intensification including conservation agriculture practices, or the diversification of farming systems (Dixon 2006). These innovations need to be applied in different ways to suit the specific and variable constraints and opportunities of regional and local farming systems in ESA (Robinson et al. 2015) underlying the importance of understanding farming system diversity.

## 2.2 CLIMATE

In relation to agriculture, climates of production regions have typically been classified and characterised via AEZs.[1] In SSA, four AEZs have been characterised (FAO 1994; Sebastian 2015) (Figure 2.1). All AEZs fall within the tropics (i.e. mean monthly sea-level temperature greater than 18 °C for all months) and include:

- warm arid and semi-arid tropics
- warm subhumid tropics
- warm humid tropics
- cool (highland) tropics.

Key differences between these zones relate to the moisture availability, which increases from arid to humid, as well as temperature, which decreases with elevation. The warm arid and semi-arid tropics (AEZ 1) are found in countries of both eastern and southern Africa including parts of Ethiopia, Kenya, Tanzania, Malawi and Mozambique. The semi-arid areas of this AEZ are generally considered suitable for rain-fed agriculture but have characteristically shorter and less reliable growing seasons (70–180 days) when compared with subhumid and humid regions (Sebastian 2015). The warm subhumid tropics (AEZ 2) are found in parts of Ethiopia, Tanzania, Malawi and Mozambique. These areas have growing seasons of between 180 and 270 days and tend to be more suited to intensive crop production than the semi-arid tropics (Harvest Choice 2010). The humid tropics (AEZ 3) have the longest growing seasons (more than 270 days) but are only found in limited areas of Madagascar within ESA. Cool highland tropics (AEZ 4) are found in parts of Ethiopia, Kenya and Tanzania. These have lower temperatures due to their elevation and have a range of moisture availability (arid to humid areas are aggregated in this fourth zone). Notably, agroecological conditions in Kenya can vary substantially across the country. This variation is in large part a consequence of the presence of Mount Kenya and the Nyandarua ranges which affect elevation, and thus temperature and moisture.

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1 AEZs in Africa have been classified using different criteria for different scales and locations. For example, distinctions between Zimbabwe's natural regions were developed based primarily on rainfall (Vincent and Thomas 1960) whereas Mozambique's AEZs are based on rainfall, soils and elevation (World Bank 2006a). AEZs have also been derived based on latitude, elevation, and temperature and rainfall regimes (Sebastian 2015). However, recent developments by FAO in collaboration with the International Institute for Applied Systems Analysis (IIASA) has led to the incorporation of further data (i.e. crop yields and yield gaps) into a global AEZ classification along with traditional climate and soil characteristics (IIASA/FAO 2012).

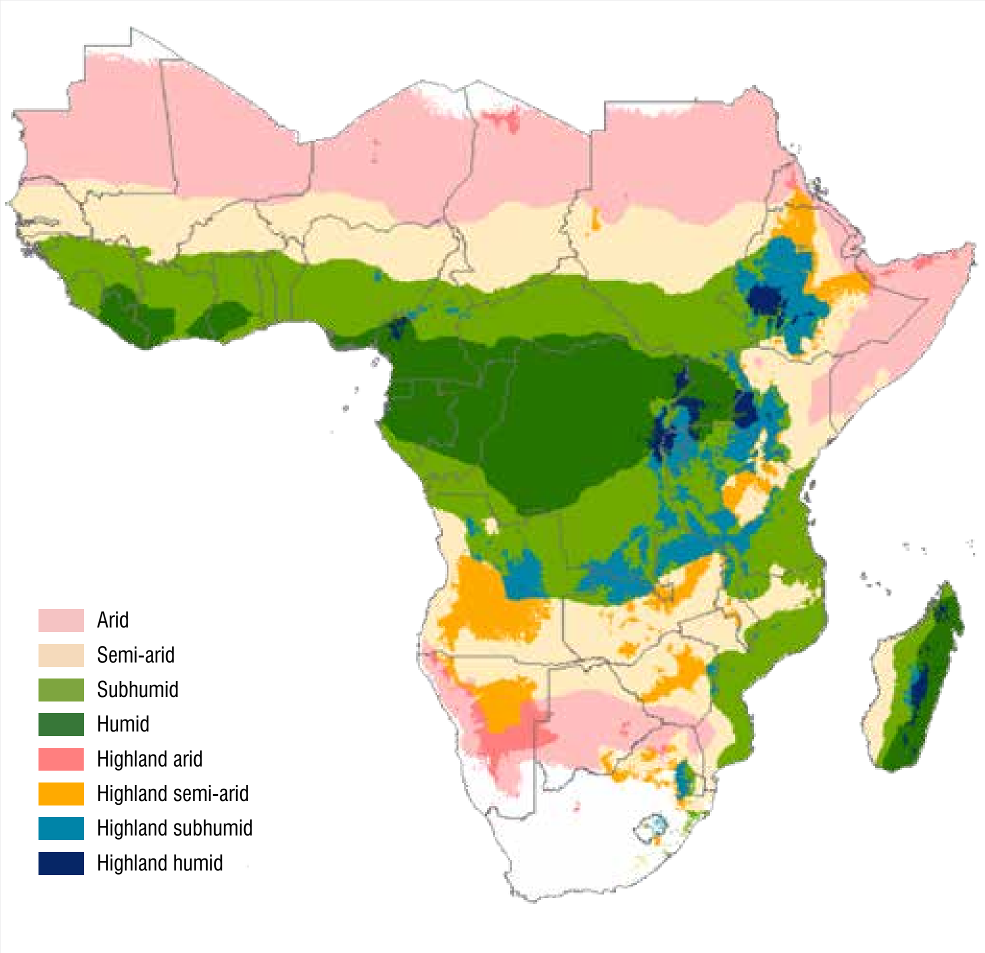



**FIGURE 2.1** Agroecological zones of Africa based on FAO/IIASA dataset
Map image sourced from Sebastian K. 2015.

Average annual rainfall in maize-producing regions of ESA is generally high with variable rainfall patterns. Bimodal rainfall patterns are found across eastern Africa in Kenya and southern Ethiopia (Diro et al. 2008). The short rains (largely, but not in all bimodal areas) are between October and December. They are highly variable and are positively correlated with the El Niño–Southern Oscillation index (ENSO) (Nicholson and Kim 1997) and sea surface temperatures in the Indian Ocean (Mutai and Ward 2000). By comparison, the long rains are more stable and occur between March and May (Nicholson and Kim 1997; Mutai and Ward 2000). In southern Africa, rainfall is unimodal, with a single rainy season over the summer months (October to April). This season has the strongest correlation with ENSO of all African rainfall patterns (Lindesay and Vogel 1990; Nicholson and Kim 1997). An analysis using global atmospheric models found that this region experienced more frequent and intense droughts as a result of climate change (Fauchereau et al. 2003). The region has also been identified as a priority area in need of maize crop adaptation to climate change (Lobell et al. 2008).

**TABLE 2.1** Climate characteristics across key sites in eastern and southern Africa
Adapted from Dimes et al. 2015.

| Country | Region | Rainfall | Climate record | Annual rainfall (mm) | Daily average temperature (°C) | Daily radiation (MJ/m$^2$) |
|---|---|---|---|---|---|---|
| **Bimodal** | | | | | | |
| Kenya | Eastern | Embu | 1983–2013 | 1,286 | 20 | 18 |
| | Western | Kakamega | 1980–2011 | 1,987 | 25 | 21 |
| | Semi-arid tropics | Katumani | 1957–1998 | 683 | 20 | 18 |
| **Unimodal** | | | | | | |
| Ethiopia | Western | Baco | 1986–2012 | 1,292 | 20 | 24 |
| | Rift Valley | Melkassa | 1977–2011 | 812 | 21 | 19 |
| | | Hawassa | 1982–2011 | 1,013 | 20 | 23 |
| Tanzania | Northern | Mbulu | 1981–2010 | 823 | 22 | 22 |
| | | Selian | 1992–2011 | 769 | 21 | 18 |
| | Eastern | Llonga | 1981–2011 | 1,013 | 25 | 17 |
| Malawi | Mid-altitude | Chitedze | 1949–2008 | 897 | 22 | 19 |
| | | Kasungu | 1947–1998 | 797 | 23 | 21 |
| | Low altitude | Chitala | 1947–1998 | 890 | 23 | 21 |
| Mozambique | Manica | Chimoio | 1969–2005 | 1,168 | 24 | 22 |
| | | Sussundenga | 1951–2011 | 1,081 | 24 | 21 |
| | Tete | Dedza (proxy for Angonia) | 1958–1998 | 950 | 20 | 19 |
| Zimbabwe | Semi-arid tropics | Bulawayo | 1939–2007 | 577 | 22 | 24 |

Rainfall patterns have played a major role in determining maize production levels in ESA, where the vast majority of maize production has been under rain-fed systems. The bimodal rainfall pattern of Kenya distinguishes the climate in this country from the majority, which experience a characteristically unimodal rainfall pattern (Table 2.1). Average in-crop rainfall can range from 395 mm in Selian, Tanzania to 858 mm in the single longer rainy seasons of Kakamega in western Kenya or even 920 mm in Chimoio, Mozambique. An evaluation of 16 maize production sites in ESA found that the coefficient of variation (CV) (%) for rainfall in 11 of the 16 sites was less than 30% (Dimes et al. 2015) (Figure 2.2). However, some areas showed much higher variability in seasonal rainfall. Rainfall over the bimodal rainy seasons in Embu, Kenya (CV = 35% and 42%) and unimodal seasons at Mbulu, Tanzania (41%), Kasungu, Malawi (37%) and Sussundenga, Mozambique (35%) suggest that frequent water deficits for maize crops can occur in these regions. Further details of the climate in countries featured as case studies are given in the relevant chapters of Section 2.

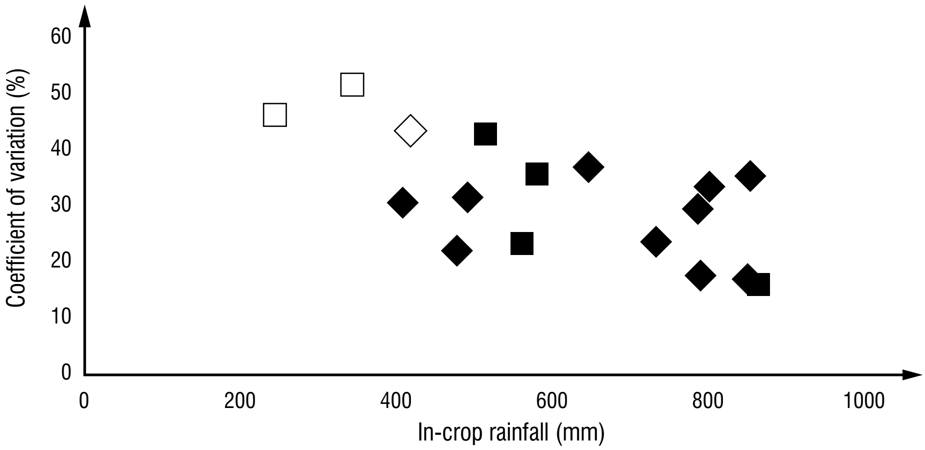



**FIGURE 2.2** Average in-crop rainfall and its coefficient of variation for the 16 site-seasons (solid symbols) examined in the study by Dimes et al. (2015); semi-arid environments (open symbols) are shown for comparisons. Bimodal (squares) and unimodal (diamonds) cropping seasons are represented.

## 2.3 SOIL

Soil is a major determinant of farming system potential (Cassman 1999), with particularly important implications in African farming systems where soil quality varies substantially across production systems (Zingore et al. 2007). The most common soils in ESA are heavier textured clay loams to light clay soils with maize rooting depths of 0.9 to 1.5 m. However, soil types vary widely across the region. Differences in historical and current geographical conditions, including age, parent material, physiography and climatic conditions, have contributed to the wide range of soil types found across ESA (Bationo et al. 2012) (Figure 2.3). The soil types (FAO classification) in ESA include:

- Ferralsols—Known as oxisols in United States Department of Agriculture (USDA) taxonomy, these soils occur mostly at low latitudes on flat, well-drained areas. They are strongly weathered (low capacity to supply plant nutrients) and contain an oxic B horizon—a 30 cm sandy loam horizon dominated by kaolinite and/or sesquioxides, clay minerals with low cation exchange capacity (van Wambeke 1974). They are widely found in Angola, Rwanda, Uganda and Madagascar.
- Lixisols—Also known as alfisols, these soils are found in south-east Africa (i.e. Mozambique, Malawi and Zimbabwe). They have a medium to high pH and low capacity for nutrient retention but due to their lower-horizon clay content have high cation saturation (Deckers 1993).
- Acrisols—Also known as ultisols in USDA taxonomy, these soils have low mineral nutrients (though less weathered than ferralsols), and have a high water-holding capacity but are prone to leaching (Bationo et al. 2012). They have a high density in the B horizon (due to clay enrichment) that can restrict root growth and soil biota (Deckers 1993). They are found in the humid regions of Tanzania (Deckers 1993).
- Arenosols—These soils cover large areas of south-western Africa (Botswana, Angola and Namibia) but are also found in eastern and south-eastern Africa, (Kenya, Tanzania Mozambique and Zimbabwe)

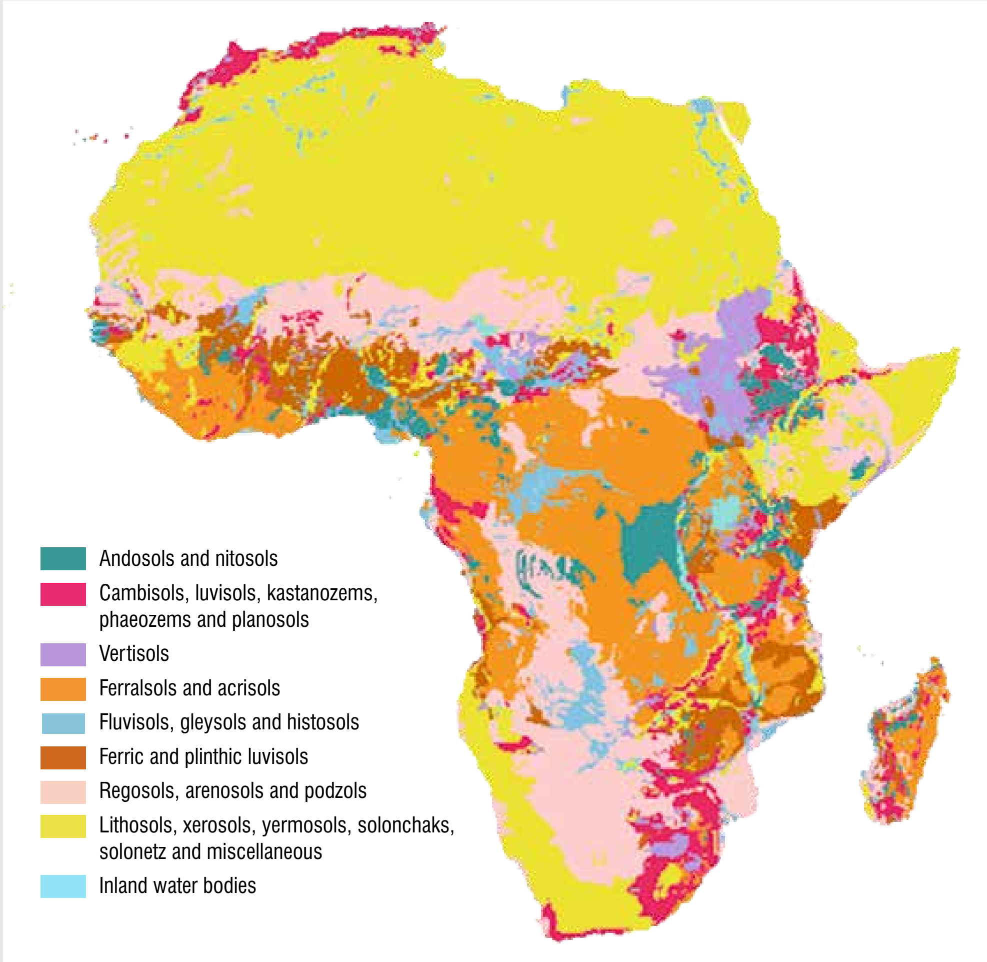



**FIGURE 2.3** Major soil types in Africa
©FAO-GIS unit, published in Bationo et al. 2012.

(Hudson 1987; Hartemink and Huting 2005). They are sands and sandy loam soils with low nutrient content and poor water-holding capacity (Jones 1984). Arenosols are subject to erosion and compaction due to their structure and are considered marginal soils for agricultural production.

- Nitosols—Regarded as highly suitable for agricultural production, nitosols do not dominate large areas of ESA but are present in Ethiopia, Kenya and Tanzania (i.e. in the Rift Valley). These soils are formed through volcanic activity. They are highly weathered but their lower horizons are fertile, rich in organic matter, have a high clay content and have excellent soil structure (Deckers 1993).
- Vertisols—These swelling (cracking) clay soils have high nutrient fertility but can be subject to low phosphorus. While they are prone to erosion and waterlogging due to their low permeability, if properly managed they can prove highly productive (due to their water-holding capacity and nutrient retention). They are mostly found in semi-arid and subhumid regions of Ethiopia and Tanzania (Deckers 1993), though they are also scattered throughout much of southern Africa (Hudson 1987).

According to Bationo et al. (2012), ferralsols and acrisols dominate the humid regions of Africa. The subhumid areas tend to have mostly ferralsols and lixisols with some acrisols, nitosols and arenosols. Lixisols dominate semi-arid areas (covering roughly 60%) along with arenosols and vertisols.

### 2.3.1 Soil types and soil management

Chemical or physical soil characteristics are among the most commonly cited production constraints for ESA (Fischer et al. 2014). As seen in the preceding list of major soil types, most soils in Africa are highly weathered and have poor fertility and/or low water-holding capacity. In 2012, only around 10% of African soils were considered 'prime land'. These were mostly in western Africa and parts of Tanzania, Mozambique, Zimbabwe, Zambia and South Africa (Bationo et al. 2012). In addition, much of ESA lies within the semi-arid tropics, which is a less productive climatic zone, and a research area that has received less attention (Hudson 1987). Extensive research for development efforts began to address this knowledge gap in the mid-1990s (Smaling 1993; Tittonell et al. 2005, 2006; Zingore et al. 2007; Twomlow et al. 2010; Giller et al. 2011; Rufino et al. 2011; Smaling et al. 2012), and have contributed to a better understanding of soil management dynamics under these conditions. Table 2.2 provides an indication of which soil types are found in each AEZ of tropical Africa, and the countries where these environments are found.

Management of these soils depends on the particular AEZ, as well as the specific field conditions (including historical and existing field and crop management practices). However, past research can provide some general information on the management of dominant soil types. Bationo et al. (2012) synthesised existing knowledge of soil management in the African context. A brief summary is provided in Table 2.3. Given that three of the four AEZs are present in a large number of countries, and that each has numerous soil types, it is clear that soil management recommendations within sustainable intensification efforts would vary considerably across ESA.

### 2.3.2 Nutrient depletion and lack of fertiliser

A further issue with soil fertility management in Africa is the historically low use of fertilisers. Stoorvogel and Smaling (1990) first brought soil nutrient depletion in SSA to wide attention by calculating nutrient balances using crop harvest and fertiliser input data. Their work, widely cited and subsequently updated (Smaling et al. 2012), maintained that without the increased use of fertilisers, African agriculture was destined for diminishing yields based purely on the further decline in already poor soil fertility. This trend in soil 'nutrient mining' has continued to the present day (Figure 2.4).

In the context of this nutrient problem, increasing fertiliser use is seen as a major intervention for sustainable intensification. The focus since the 1990s became how to increase crop nutrient inputs—particularly inorganic fertilisers—in household production systems. Calls for a Green Revolution in Africa (to provide fertiliser management assistance and mechanisation) have been made for decades (Bationo et al. 2011). The 2006 Abuja Fertilizer Summit recognised the need to increase fertiliser use in Africa and its declaration endorsed the African Green Revolution (AfDB 2017). Well-resourced international development efforts have since attempted to progress this Green Revolution (AGRA 2017) but appear to be struggling to increase fertiliser uptake (FAOSTAT 2017). Notable constraints to fertiliser use by household producers in ESA have been shown to include:

- poor underlying agronomic management (Roxburgh and Rodriguez 2016)
- problems with farmers' knowledge of fertilisers (Cavane 2007)

**TABLE 2.2** Dominant soils in the four agroecological zones of sub-Saharan Africa
Adapted from Deckers 1993.

| AEZ | Dominant soils | Less dominant soils | Countries |
|---|---|---|---|
| 1. Warm arid and semi-arid | Lixisols, arenosols, vertisols | | Djibouti, Somalia, Sudan, Ethiopia, Kenya, Tanzania, Uganda, Botswana, Namibia, Swaziland, Angola, Madagascar, Mozambique, Zambia, Zimbabwe |
| 2. Warm subhumid | Ferralsols, lixisols | Acrisols, arenosols, nitosols | Ethiopia, Tanzania, Uganda, Madagascar, Malawi, Mozambique, Zambia, Zimbabwe |
| 3. Warm humid | Ferralsols, acrisols | Arenosols, nitosols, lixisols | Madagascar |
| 4. Cool (highland) | Vertisols, nitosols | Ferralsols | Burundi, Lesotho, Rwanda, Angola, Ethiopia, Kenya, Madagascar, Tanzania |

**TABLE 2.3** List of major soil types in eastern and southern Africa and their key management challenges
Adapted from Bationo et al. 2012.

| Soil type | Management needs |
|---|---|
| Acrisols | Low capacity to adsorb macronutrient cations (e.g. potassium, calcium, magnesium) means well-timed fertiliser inputs are needed; liming needed to avoid low pH and aluminium toxicity and micronutrient deficiency |
| Arenosols | Sandy soils that require erosion and compaction management (i.e. control of traffic, tillage and retention of residues on soil surface); micronutrient fertiliser inputs needed to avoid deficiencies |
| Ferralsols | Low capacity to adsorb macronutrient cations (e.g. potassium, calcium, magnesium) means well-timed fertiliser inputs are needed; liming needed to avoid low pH and aluminium toxicity and micronutrient deficiency |
| Lixisols | Fertiliser input needed to provide nutrients as these soils have low nutrient storage capacity |
| Nitosols | Minimal specialised management needed as these volcanic soils are considered highly fertile and well suited to agricultural production; require replacement of nutrients from crop production (particularly phosphorus) to maintain soil fertility and avoid manganese toxicity |
| Vertisols | Careful timing of practices (i.e. sowing, weeding, fertilising) due to temporal changes in soil structure (shrinking/swelling); erosion management |

- low business acumen of farmers (e.g. unable to conduct cost–benefit analyses)
- poorly developed and regulated fertiliser markets (Yamano and Arai 2011a)
- low or unknown fertiliser quality (Ngetich et al. 2012)
- low-response plant genetics (i.e. use of non-hybrid/recycled seed) (Vanlauwe et al. 2011)
- recommended application rates that are inappropriate for household finances (Snapp et al. 2003; Twomlow et al. 2010; Dimes et al. 2015)
- lack of cash and credit access (Jayne et al. 2010)
- rainfall risk and risk perceptions (Meze-Hausken 2004; Cooper et al. 2008; Dimes 2011).

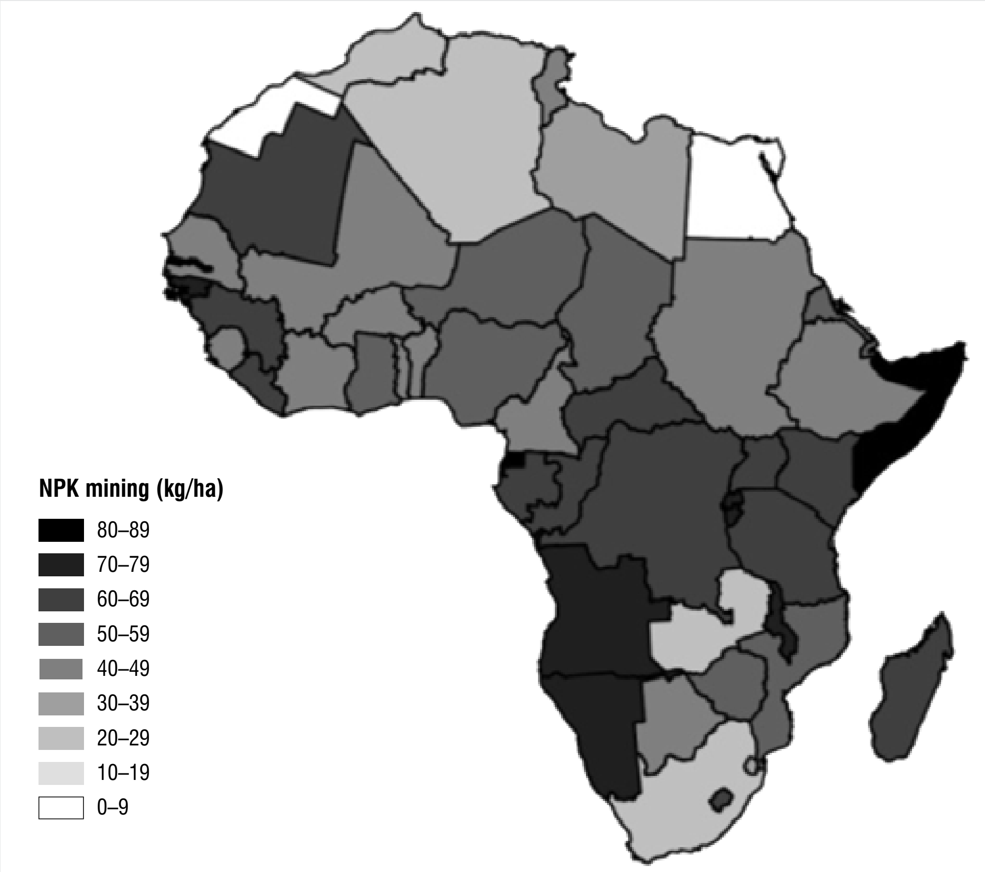



**FIGURE 2.4** Country-level nutrient mining estimates (kg NPK/ha/year) for Africa during 2002–04
Based on data from Henao and Baanante (2006); phosphate in $P_2O_5$ equivalents and potassium in $K_2O$ equivalents.

Despite great efforts to increase its use, uptake of inorganic fertiliser by ESA household producers remained low (Figure 2.5). By 2010, total average nitrogen (N) and phosphorus (as $P_2O_5$) nutrient application as fertiliser was 13 kg/ha in eastern Africa and 39 kg/ha in southern Africa (including South Africa) compared with 69 kg/ha globally (FAOSTAT 2017). Some researchers have looked to more readily available organic sources of nutrients to improve soil fertility management (Palm et al. 1997, 2001a, b; Vanlauwe et al. 1997; Vitousek et al. 2009; Place 2012). Others have aptly pointed out that such sources are:

1. too poor in quality to provide the necessary levels of nutrient inputs
2. high in labour to produce/prepare
3. already used for other farming activities (Vanlauwe and Giller 2006; Giller et al. 2009).

Likewise, poor legume yields have limited the potential contribution of N biological fixation (Giller and Cadisch 1995; Giller et al. 2009) and farmyard manure is mostly of low nutrient content (Probert et al. 1995, 2005). Section 2.5 Institutional setting and innovations offers an in-depth discussion of the institutional factors that have contributed to low fertiliser use. The interlinking and interdisciplinary nature of these constraints continue to pose a challenge to researchers and extension institutions alike.

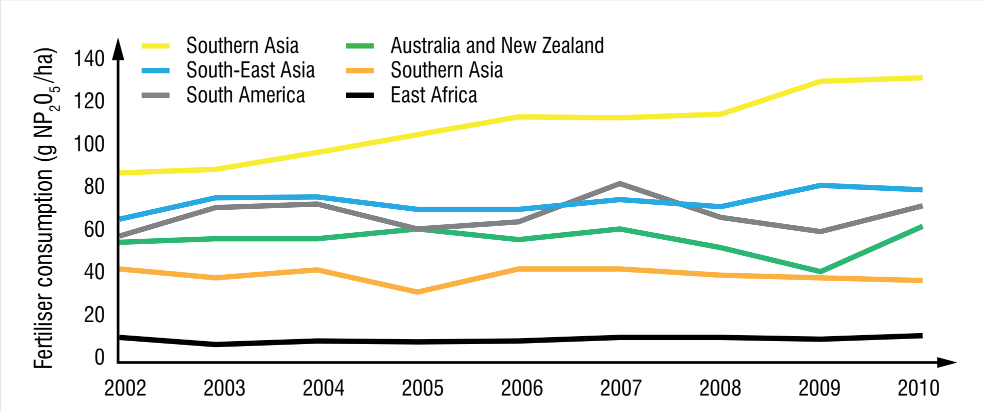



**FIGURE 2.5** Nitrogen and phosphorus addition per unit of arable land via inorganic fertilisers
Data from FAOSTAT (2017).

### 2.3.3 Within-farm diversity in soil fertility

Soil heterogeneity within and across household production systems is common in ESA as a consequence of the inherent soil–landscape variability, along with the effect of past and current land management practices (Prudencio 1993; Carter and Murwira 1995). The majority of household producers in ESA have tended to use targeted nutrient management strategies (Carter and Murwira 1995). Strong gradients of decreasing soil fertility with distance from the homestead have been observed within household farms in ESA, due to differential resource access and allocation. Tittonell et al. (2005) found that household producers managed their infields (i.e. closer to the homestead) with greater inputs due to the ease with which they can be intensively managed (i.e. more labour, more regular observation). Therefore, while this section outlines soil fertility among African households to be low and poorly managed, households with limited land and access to livestock manure will sometimes have patches of extremely fertile and responsive soils. This in turn affects the approach to field management (e.g. crop choice, weeding intensity) within a given farm. Evidence of variability in fertility across households and at the plot level suggests that both of these factors can be valuable in informing management recommendations (Tittonell et al. 2006, 2010).

## 2.4 FIELD MANAGEMENT AND PRODUCTIVITY INNOVATIONS

The field level is considered the smallest management unit where farmers make decisions that determine the success of their farming activities. Field management, in turn, feeds into the performance of the whole farm (often with associated trade-offs in other fields or activities) and ultimately of household and farming systems. Field management is another area for possible productivity innovations for sustainable intensification. It has both a spatial and temporal dimension to decision-making. While fields in commercial systems are mostly identified through fencing perimeters, these are less common among household producers in ESA, where fields are usually distinguished by the different management practices that household producers apply in a given season. As discussed earlier, soil types, proximity to the homestead or previous management history can also provide relevant criteria for establishing a field-level unit of analysis.

### 2.4.1 The 'basket of tools' approach

In relation to innovations for sustainable intensification, it can be useful to think of aspects of field management as a 'basket of tools' (Descheemaeker et al. 2016). Adjusting field management can entail various innovation options that themselves can be tailored to communities or even specific households within communities (i.e. household groups or typologies). Existing field management and the effects on crop production, household food security and income can form the basis of innovation recommendations. Moreover, pathways to intensification may involve innovations that change field management. An understanding of relationships between field management practices and other farming system components can further help to identify management practices that support specific intensification pathways of targeted households or groups of households.

The identification of 'proper' field management is both deceptively simple and unexpectedly complex. In essence, it is connected to basic principles of agronomy that are mostly well understood. From a purely biophysical perspective, it is often very easy to identify best field management, though care must be taken to account for the specific agroecological conditions of a study site/community. For example, optimal time of planting will depend on rainfall patterns and distribution, which themselves are spatially variable within larger agroecological areas (Nyagumbo et al. 2017). However, beyond the biophysical question of how to best manage a field, the socioeconomic context in which farmers operate will greatly influence their ability to adopt best practices and the overall benefits of an innovation to the household. For example, the use of additional in-crop weeding will be dependent on available labour (Leonardo et al. 2015). Other common constraints to better field management are knowledge (Dimes 2011; Kijima et al. 2011), cash and vulnerability to risk (Marra et al. 2003; Ghadim et al. 2005). Due to the influence of socioeconomic context, it is essential that research to identify best field management be conducted with community participation (Rodriguez et al. 2013). A number of different methodological approaches have been developed with this in mind, for example, the 'describe, explain, explore, design' or DEED approach (see Box 3.1). This can be extremely useful in identifying 'sociological niches' in which a tailored 'basket of options' can be strategically applied to typologies (Descheemaeker et al. 2016). Common activities to achieve a more participatory research effort include farmer workshops (Dimes et al. 2015), benchmarking studies, ex-ante analysis with crop system models exploring farmer-derived management ideas (Roxburgh and Rodriguez 2016), and on-farm experiments (Descheemaeker et al. 2016).

### 2.4.2 Farming system paradigms

Efforts to identify 'best' innovations for intensification have also drawn heavily from prevailing farming system paradigms, or models of agricultural management that are promoted for development. Examples of these paradigms include:

- the Green Revolution—the genetic, chemical and mechanical modernisation of agriculture, mainly achieved through use of improved seeds, inorganic fertilisers, chemical herbicides and pesticides, and mechanisation of labour (Lowell 2008; AfDB 2017; AGRA 2017)
- organic agriculture—the management of agricultural systems without use of chemical controls, inorganic/mineral fertiliser inputs or genetically modified seeds (Raynolds 2000; Seufert et al. 2012)
- conservation agriculture (CA)—soil conservation methods integrated into management of field crops, centred on maintenance of soil cover to reduce erosion and improvement of soil structure through increased carbon inputs and reduced tillage disturbance (Hobbs 2007; FAO 2012)

- climate-smart agriculture—the focus on ensuring flexible and adaptable field management that is resilient or responsive to climate change, developed through evidence in conjunction with relevant institutions and policies (Lipper et al. 2014).

Conservation agriculture was heavily promoted in ESA. This management system was first developed in more advanced economies as a series of field management practices to better control soil erosion and disease (Andersson and D'Souza 2014; Giller et al. 2015). It is centred on the use of crop rotations, minimal or zero tillage and the retention of crop residues for soil surface cover (FAO 2012), and has been remarkably successful in reducing soil erosion (Hobbs 2007) and increasing productivity particularly on sandier soils in drier years (Pittelkow et al. 2015a, b). The CA model influenced the field interventions that key institutions (e.g. national governments, CIMMYT) promoted in efforts to improve management of household crop fields (Andersson and D'Souza 2014). Such paradigms are important because they influenced which aspects of field management were included in research and therefore which of these are used to inform agricultural development over time.

### 2.4.3 Crop selection and rotation

The selection of a crop is one of the major decisions affecting field performance. Climate and agroecology are the major determinants of crop selection, as crop physiology limits the areas suitable for cultivation. For example, commercial coffee tree production is generally limited to certain elevations (i.e. between 900 and 1,800 m). Crop selection is often determined by cultural preferences (for food crops) and availability of markets (for cash crops). The major crops grown by household producers in ESA have included cereals, roots and tubers such as cassava and yam, maize, beans, plantains and groundnut.

Crop rotations are considered a 'pillar' of CA systems (FAO 2012). Rotation schemes can influence the contribution that production makes to the overall farming system. For instance, crop rotation has improved disease resistance, particularly for soil-borne pathogens like wheat crown rot.

Another important aspect of crop selection is the choice of variety or cultivar. This decision affects the particular genetics of the crop being produced and interacts with a range of other field-level decisions (plant arrangement, planting date, etc.). Plant breeding can be used to tailor genetics to specific agroecologies (Hammer et al. 2014) and to increase resistance to biotic and abiotic stresses (Tesfaye et al. 2006). It is estimated that maize yields could increase by 10–25% with adoption of hybrid maize varieties over open-pollinated varieties or local saved seed (Cassman 1999; Denning et al. 2009). Recent varietal dissemination and breeding efforts for ESA have placed emphasis on market- and nutrition-related, rather than purely yield-based traits (CIMMYT 2015). For instance, CIMMYT established the 2012–2017 Nutritious Maize for Ethiopia varietal development and dissemination program to identify and develop quality protein maize varieties that suit the diverse agroecologies of Ethiopia. The potential yield, marketability and nutrition improvements that can be made through maintaining or developing and adopting new varieties demonstrate that the choice of which cultivar to plant, even in restricted seed markets of ESA (see Section 2.5.3 Markets), can influence the productivity and resource use efficiency of a field.

### 2.4.4 Planting date

Planting date (or time of sowing) determines if the crop grows under the most ideal rainfall and temperature conditions for the season. Therefore it has major consequences for household performance and involves trade-offs and risks. Household models have shown that late planting can reduce yields and even explain crop failure (Makuvaro et al. 2014), while earlier planting could increase the length of the growing season (or crop exposure to rainfall) and improve yields. Household production surveys have found that most household producers delayed and/or spread out planting, leading to suboptimal planting times (Box 2.1). This has been explained by a range of factors including:

- pressures from hunger (Sacks et al. 2010)
- labour constraints or lack of draught animals (Twomlow et al. 2008; Makuvaro et al. 2014)
- risk-spreading activities, i.e. multiple planting windows to ensure a single field fares well (Cooper et al. 2008; Makuvaro et al. 2014; Rurinda et al. 2014)
- poor understanding of local rainfall distribution (Tadross et al. 2009)
- lack of knowledge of global climate patterns (e.g. ENSO) and their effects on local rainfall (Barron et al. 2003)
- the interaction between variety duration and length of growing season
- a lack of consensus on best time of planting among researchers.

**BOX 2.1 Exploring field management options through simulation modelling: planting dates under conservation agriculture**

Late planting can constrain maize productivity in rain-fed systems, and this often occurs due to labour constraints during land preparation (e.g. the clearing of weeds and preparing of planting basins). The use of improved farming systems such as CA can alter field management due to changes in soil structure as well as the labour input needed for specific tasks (e.g. planting). Nyagumbo et al. (2017) completed a simulation study determining how early planting could be performed in various household production systems of Malawi, Mozambique and Zimbabwe. The study considered conventional and various CA planting systems with and without access to draught power. Simulation results from 30 years found that the earliest possible planting dates from the perspective of labour efficiency and rainfall distribution were with CA systems using either early basin preparation (manual), or CA systems using direct seeding or Magoye ripper (mechanised). However, these earlier planting dates did not necessarily translate into the highest maize yields. This example illustrates a case where efforts to identify ideal planting dates required consideration of labour availability, rainfall patterns and field management practices.

The uncertainty of growing conditions and consequently the optimal planting date has represented an early-stage production factor that has contributed to major yield gaps. However, the benefits of early planting have to be balanced against the risk of early dry spells as well as frost risk (Pratley 2003). In many areas of ESA, optimal planting dates will vary with each season, as some early rainfall is required for planting rain-fed crops. In addition, there is growing evidence that rainfall patterns and distribution are being affected by climate change and, therefore, that planting decisions based on historical planting times may result in early or delayed planting under new climatic conditions (Thornton et al. 2010).

The lack of consensus around research approaches and interpretation of data has also limited the support received by household producers from research and extension. For instance, rainfall pattern analysis by Tadross et al. (2009) using observed meteorological data showed suitable maize planting dates in south-east Africa between mid-October and early November. However, a study by Roxburgh (2017) in the same region determined that November was the optimal planting time and this was supported by analysis using simulation modelling (Roxburgh 2017). The same study found that farmers near the city of Chimoio began planting as early as September and that this early planting resulted in lower maize yields. Further work by Nyagumbo et al. (2017) using simulation modelling concluded that January was ideal for planting in the same region. This example is indicative of the range of information being published and disseminated among researchers on the optimal time of planting. The Roxburgh (2017) study also noted that agricultural researchers typically planted their trials in November or as late as December, making it particularly challenging to translate research into practice.

### 2.4.5 Plant arrangement

Another aspect of field management that can dramatically affect crop yields is plant arrangement (i.e. density, row configuration, row spacing, basin spacing, basin spacing). Optimal plant arrangement depends on agroecology (Workayehu 2000), soil fertility (Hörbe et al. 2013), weed burden (Tollenaar et al. 1994) and plant genetics (Sangoi et al. 2002; Widdicombe and Thelen 2002; Lee and Tollenaar 2007). The relationship between plant genetics and optimal plant arrangement arises through phenotypic traits relating to crop growth, which in turn will affect maize yield through the utilisation of key resources such as soil moisture, nitrogen or radiation (Sangoi et al. 2002; Lee and Tollenaar 2007; Barbieri et al. 2008). Plant arrangement can also affect competition with weeds for these key resources. For example, increased plant densities can shade out weeds, providing a valuable strategy for suppressing weed growth (Tollenaar et al. 1994).

Various studies have shed light on the dynamics between plant density, soil conditions and management across diverse farming systems. For instance, a modelling analysis by Keating et al. (1988) found that water and nitrogen availability impacted the relationship between plant density and maize yield in semi-arid Kenya. There is some consensus, arising from studies spanning diverse farming systems, that decreasing plant densities on household plots tends to have positive impacts on yields. An ex-ante analysis in Mozambique evaluated the impact of planting density on yield and return on N fertiliser among household producers using planting densities above 7 plants/m$^2$ (Roxburgh and Rodriguez 2016), comparable to densities used in high input systems (Lee and Tollenaar 2007). Roxburgh and Rodriguez (2016) found that these high planting densities limited both crop growth and return on N fertiliser investment. Workayehu (2000) found that lower maize densities were suited to lower, more erratic, rainfall environments of southern Ethiopia, and that higher fertility was needed to ensure yield response from higher densities. The author argued that lower densities generally had a compensatory effect by increasing productivity per plant if in-crop rainfall was not limiting (Workayehu 2000). These examples from Ethiopia, Mozambique and Kenya demonstrate how lower planting density can be used to help manage limited resources. Conversely, Tittonell et al. (2008) found that farmers' fields in Kenya with high resource use (e.g. inorganic fertilisers) planted to less than 7.9 plants/m$^2$ averaged lower yields. This again demonstrates the interaction between resource (i.e. nutrient and moisture) availability and appropriate planting density. When more nutrients and/or moisture are available, planting densities are optimised at higher levels.

Finally, in addition to understanding the biophysical dimensions to plant arrangement choices, household producers may also use particular plant arrangements for cultural and socioeconomic reasons (Ziervogel 2004). They may also use a given arrangement due to its interaction with other activities, e.g. residues for animal feed (Romney et al. 2003), labour demands (Andersson and D'Souza 2014; Nyagumbo et al. 2017) or intercropping configuration (Seran and Brintha 2010). The array of issues that factor into plant spacing decisions present further challenges in identifying best plant arrangement as part of a 'basket of options' for sustainable intensification.

### 2.4.6 Fertiliser use

Due to the poor nutrient status of many soils in ESA, the application of fertilisers (particularly inorganic fertilisers) is essential to ensure good yields for household producers. As with other aspects of field management, application of fertilisers can be included in a 'basket of tools' for the sustainable intensification of household systems. As outlined above, response to fertiliser will depend on whether other aspects of management are sufficiently optimised. These include planting date (Pratley 2003), plant arrangement (Keating et al. 1988), responsive plant genetics (Hirel et al. 2011), responsive soils (Tittonell et al. 2006), control of pests and diseases (Boomsma et al. 2009; Hirel et al. 2011) and moisture availability (Cassman et al. 2002).

Nitrogen has been consistently identified as the most limiting nutrient across household production systems in ESA (Stoorvogel and Smaling 1990; Smaling 1993; Smaling et al. 2012; Bationo et al. 2012; Fischer et al. 2014). Nitrogen deficiencies mainly result from inherently poor soils and many years of continuous crop production without nutrient replenishment. Under these conditions, N fertilisers have been considered an essential input for overcoming poor productivity. However, recent reports showed that N fertilisers were prohibitively expensive for most household producers in ESA (Kelly et al. 2003; Jayne et al. 2010). The reasons for this include a range of institutional-level factors that are discussed in Section 2.5 Institutional setting and innovations. In addition, applying more fertiliser does not always result in sufficient yield increases (Dimes et al. 2015; Roxburgh and Rodriguez 2016). For instance, Dimes et al. (2015) found that returns to investment can be particularly low in ESA while the cost and risk of investment is high for households with limited resources. Therefore, identifying the conditions that increase benefits of fertilisers (N in particular) has been of great interest to researchers. In their meta-analysis of African field experiments, Vanlauwe et al. (2011) reported that N fertiliser was on average 9 kg/ha more agronomically efficient when applied on fields planted with hybrid maize varieties. The authors also reported findings that combining inorganic N with organic amendments of 'high quality', or applying fertiliser N to infields closer to the homestead, increased the agronomic use efficiency ($AE_N$) of mineral N fertilisers (Vanlauwe et al. 2011). Ladha et al. (2005) reported global $AE_N$ values of 24.2 kg gain/kg N and an African value (all crops) of 13.9 kg gain/kg N. The authors also outlined the importance of synchronising N supply with crop demand to maximise fertiliser use efficiency (Ladha et al. 2005). However, household production systems often require that benefits of management decisions are fairly predictable (i.e. benefits depend little on other production factors) before fine-tuned synchronised dynamics benefit the household (Roxburgh and Rodriguez 2016).

Aside from N, phosphorus (P) has also represented a limiting nutrient on many household plots in ESA. In addition to the lack of soil P, crop P supply via fertilisers is also constrained through soil P fixation by free iron and aluminium oxides, making the P unavailable for crop uptake (Parfitt et al. 1975). This is most common in ferralsols and acrisols (Bationo et al. 2012). Vertisols, meanwhile, are commonly deficient in P and typically require P fertilisers for optimal crop production (see Section 2.3 Soil). Issues in P fertiliser use efficiency are similar to those of N use efficiency. Again, infields (close to the homestead) are typically more responsive and have higher recovery efficiency of fertiliser P than outfields (Bationo et al. 2012). P fertiliser efficiency can also be improved through placement, i.e. applied in planting basins/hills rather than broadcast (Bationo et al. 2012).

### 2.4.7 Residue management

FAO reports retention of crop residues on fields as one of the three pillars of the conservation agriculture paradigm, based on their effect in reducing soil erosion and their soil carbon and (to a lesser degree) nitrogen contribution as they decompose on the field (FAO 2012). Crop residues have also provided soil with significant physical protection from wind and water erosion (Derpsch et al. 1986; Thierfelder and Wall 2009). The benefits of retaining crop residue have depended on factors like soil microbial metabolism, soil structure and soil nutrient cycling, and various aspects of field management (Baijukya et al. 2006). Most importantly, the immobilisation of inorganic N (from fertiliser applications) can be increased by the retention of high C:N ratio residues on low-fertility soils (Chikowo et al. 2010). This can lead to lower fertiliser $AE_N$ values on household fields (Chivenge et al. 2011; Vanlauwe et al. 2011). For high-quality residues with higher N contents and low lignin and polyphenol content, residues can be used for nutrient inputs directly on annual crops. When lignin or phenol contents are higher, it is advised that residues be combined with nutrient-rich inputs (i.e. inorganic fertilisers) to ensure proper decomposition without immobilisation of soil N or P (Palm et al. 2001b). If N content of residues is low, the resource should be either composted or simply used as a surface application for erosion control (as described in relation to CA systems).

### 2.4.8 Weed management

Weed management can be of enormous significance when discussing pathways to sustainable intensification, and there is a variety of options in the 'basket of tools' for household field management. In ESA, weed management is mostly done through ploughing fields either with tractors or (much more commonly) with animal draught power (Giller et al. 2009; Gianessi 2013; Nyagumbo et al. 2015, 2016, 2017). Alternatively, hand hoes are typically used in systems without access to animal or mechanised power (Gianessi 2013; Nyamangara et al. 2013, 2014). Households that rely on hand weeding require high levels of investment in time and labour (Rusinamhodzi 2015). Time and labour requirements can be especially high when farming systems hand weed alongside other CA practices like retention of surface residues (Muoni et al. 2013). Due to the labour intensity of manual weeding, it is typically only performed twice per crop on household fields (Tittonell et al. 2008; Roxburgh and Rodriguez 2016), compared with much higher frequency of weed control in alternative production systems or in field experiments (Thierfelder et al. 2012; Cheesman et al. 2016). Manual tillage systems are observed as having higher weed biomass than mechanised systems (Mashingaidze et al. 2012). Furthermore, weed burden in these fields is often high due to a lack of late-season or fallow weed control allowing weeds to set seed and increase the weed seed bank (Mashingaidze et al. 2012).

Weed management in household systems can be improved through a number of strategies. Increasing the frequency of in-crop weeding from (on average) twice (Tittonell et al. 2008; Roxburgh and Rodriguez 2016) to three or more times can reduce weed competition for resources (Muoni et al. 2013), though this requires increased labour input. Another productive innovation option (one that does not require additional labour) is to better target the time of weeding to optimise control (Mabasa and Nyahunzvi 1994; Mhlanga et al. 2015). Weeding during the early 'critical period' (Hall et al. 1992) can also decrease light competition (reduce shading of crop canopies) and positively impact growth and yield (Hall et al. 1992; Page et al. 2010; Cerrudo et al. 2012). Field research from southern Africa has shown earlier weeding (i.e. within 14 days of planting or when weeds reach 10 cm in height) to increase maize crop yields (Mabasa and Nyahunzvi 1994; Muoni et al. 2013; Mhlanga et al. 2015).

Another strategy for improving weed management is chemical weed control (i.e. use of herbicides). This has been shown to significantly decrease demands on labour and provide positive returns to investment when labour costs are high relative to the cost of the herbicides (Muthamia et al. 2001; Muoni et al. 2013). In addition, herbicides have reduced the negative consequences of adopting no-till practices, thereby facilitating adoption of CA and providing benefits to soil structure and biota. However, using herbicides requires sufficient market access, new knowledge (e.g. proper spraying and safety practices) as well as cash investment, meaning its adoption involves negotiating a range of factors that often constrain household producers (Muthamia et al. 2001; Muoni et al. 2013). Despite more than two decades of research investigating the viability of herbicide use on household fields (Vogel 1995), adoption remains low and manual weeding continues to be the norm (Mandumbu et al. 2011; Micheni et al. 2014). Various scholars have suggested that other aspects of field management (including planting dates, poor fertility etc.) have constrained adoption of herbicides (Dimes et al. 2015). This evidence of interdependencies in management practices and other farming system components suggests that the relative performance of a given household, its existing field management strategies, cash availability, and market integration must be taken into account in order to identify weed control practices that support intensification of household production.

The aspects of field management outlined here all fit into the 'basket of tools' for productivity innovations. However, they are substantially dependent on wider institutional settings. Often the ability or incentive for adopting improved practices will hinge on socioeconomic settings of households. In this sense, efforts seeking to improve institutional settings that affect household production are another interlinked approach to stimulating sustainable intensification.

## 2.5 INSTITUTIONAL SETTING AND INNOVATIONS

Institutional environments (infrastructure, markets, enabling institutions and PPPs) influence sustainable intensification pathways by shaping formal and informal relationships, agreements and structures. The institutional environments and changes to them, i.e. institutional innovations (Dorward 2009), have consequences for producers' access, ownership, exchange and effective utilisation of technology. Institutional innovations such as road creation or greater credit access have been treated as fundamental to promoting field-level productivity innovation and achieving sustainable intensification (Vanlauwe et al. 2014; Robinson et al. 2015). Patterns in adoption of new technologies and management strategies suggest that institutional innovations have played an increasing role in motivating productivity innovation by household producers (Von Braun and Gatzweiler 2016). In some cases, these innovations have created value for household producers by reducing transaction costs and enabling connectivity and exchange (Gatzweiler 2016). Gatzweiler (2016) highlighted the important role that institutional innovations can play in incentivising (or disincentivising) ongoing investment by household producers and other key players (Von Braun and Gatzweiler 2016). These trends suggest that technological adoption is less likely to occur or contribute to broader transitions in agricultural production without coordinated institutional innovations (Conway 2016). This has made institutional innovation an important catalyst for overcoming broader constraints limiting household sustainable intensification.

### 2.5.1 The need for institutional-level change

Institutional environments and household producers became increasingly interrelated after the market reforms of the 1980s. These reforms have had both positive and negative implications. While there are many examples of institutional innovations that have had positive impacts for household producers, the institutional environment has been considered among the primary constraints to field-level productivity increases in many parts of ESA. Moreover, sustainable intensification is constrained by different institutional factors for different stakeholders, such as NGOs, local communities, businesses and farm typology groups (Schut et al. 2016a). Gatzwieler (2016) suggests that policies have historically done little to address the unique constraints faced by household producers (including barriers to resource, asset and service access) which further marginalised them. Other studies highlight the heterogeneity among household producers, arguing that the wide range of farming system characteristics and constraints have presented additional challenges to constructing institutional-level solutions (Kuiper and Ruben 2007). Differences in constraints to intensification across stakeholders and across household producers has also explained why institutional changes have impacted groups differently, often exacerbating existing inequalities (Calderón and Servén 2008). Differences across stakeholders in their constraints to sustainable intensification underlie the need to address variability within and across groups of stakeholders.

The effectiveness of institutional innovation mechanisms for addressing poverty and inequality has therefore depended on both the institutional fit of those efforts (i.e. between policies and the social and physical assets of household producers), and the connection between these policies and targeted approaches across the regional and farm levels. Some scholars have suggested that these two goals can be achieved by improving interaction, exchange and collaboration among government officials and other stakeholders (Schut et al. 2016b). Dorward (2009) presented a framework for institutional agendas that accounts for diversity across social scales of organisation, providing a language for comparing the goals, constraints and opportunities faced by stakeholders at all of these scales (Box 2.2). Frameworks like these can be critical to the development of innovations that will benefit all players.

### 2.5.2 Infrastructure

Of the possible institutional innovations, many scholars have argued that household producers in SSA are likely to benefit most from infrastructure improvements. This is mainly based on the landlocked nature of many of these countries and remoteness from global market centres (World Bank 2007). Infrastructure in ESA in particular has been ranked far below most other regions of the world, including non-African low-income countries (Calderón and Servén 2008). Evaluations of the state of infrastructure have considered public and private investment in various components of infrastructure including buildings and power supplies (Barro 1990; Futagami et al. 1993). Similar conclusions have come from evaluating infrastructure development based on levels of investment in public capital services (Glomm and Ravikumar 1997; Turnovsky 1997), evidence of alternative tax structures (Baier and Glomm 2001) and productive current spending flows. Here we review the quantity, quality and perceptions of access to major forms of infrastructure in ESA—telecommunications, electricity and roads.

#### *Telecommunications*

Since 1980, the disparity in telecommunications infrastructure—measured as total landlines per person—between ESA and other low-income countries gradually increased (ITU 2007). However, mobile phone networks expanded rapidly in many ESA countries in the 1990s and into the 21st century. The average number of mobile phone units per 100 inhabitants in Africa reached 9.1 in 2004, with an annual growth rate between 1999 and 2004 of 59.7% (Yamano et al. 2011). Despite this evidence of rapid adoption, World Economic Forum data show that uptake of mobile technologies was below the international standard by a large margin in 2011 (World Bank and AfDB 2011). On the other hand, there are various examples of successful information and communication technology innovations, such as the rapid uptake of M-Pesa, a mobile phone-based finance service launched in Kenya in 2007 (*pesa* means money in Swahili). Developments such as these suggest that parts of ESA are responsive environments for innovations in telecommunications.

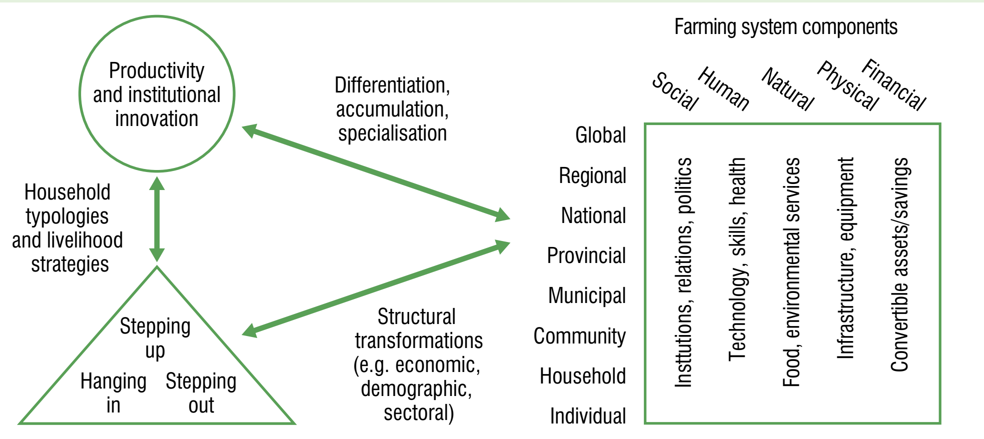
**BOX 2.2 Framework for establishing institutional agendas that address diverse constraints and opportunities of household producers**

Dorward (2009) places the role of institutional innovation within a broad policy and development framework. Here, institutional innovations and structural transformations interact with stakeholders' different livelihood strategies, assets and levels of social organisation. The policy framework begins by distinguishing household producers based on their wealth, welfare and aspirations and assigning them to three groups based on these distinguishing features:

1. hanging-in households, which are most concerned within maintaining and protecting current levels of wealth and welfare in the face of stresses and shocks
2. stepping-up households, which invest in assets to expand the scale or productivity of existing assets and activities
3. stepping-out households, which accumulate assets for investments or switches into new activities and assets.

Dorward (2009) proposes that these classifications be based on differences in five main types of assets—social, human, natural, physical and financial. Explicit identification of these three livelihood strategies can allow policy agendas to be developed based on current wealth and welfare of household producers.

The framework establishes the multiple and interrelated scales in which institutional innovations operate: global, regional, national, provincial, municipal, community, household and individual levels. The multiscale nature of this framework makes it uniquely well suited to identify the institutions and level for design and implementation that is best suited to address household constraints.




The above schematic shows how household production system components (capitals/assets) and methods for understanding and organising the diversity of household systems (livelihood strategies and transformations) are used to inform technological and institutional innovations. Adapted from Dorward 2009.

Notwithstanding major limitations, the rapid emergence of mobile phones technologies has been identified as an important positive change for agriculture in rural areas of SSA. Case studies have demonstrated that the introduction of mobile phones can improve information availability. This has reduced transportation and marketing costs, increased market participation among household producers, and stabilised and lowered food product prices and spoilage (Jensen 2007). Data from markets in Niger showed that the use of mobile phones reduced grain price dispersion by a minimum of 6.4%, reducing intraannual price variation by 12% (Aker 2008). Although these cases have been subject to scrutiny and cannot be interpreted as universal (Steyn 2016), examples like these suggest that the potential benefits of ongoing development in telecommunications can be great for household producers.

### *Electricity*

The last 25 years show an overall decline in the quality of the power sector in SSA. In 2006, the percentage of the SSA population with access to electricity was particularly low, with a median of less than 20% (OECD/IEA 2007, 2013). This was less than half that in South Asia and in other non-African low-income countries. World Bank surveys found that access rates in Mozambique and Malawi were especially low—below 10% in 2006 (Calderón and Servén 2008). Between 2000 and 2011 the absolute number of people with access to electricity increased, though two-thirds of the increases were in urban areas. This resulted in greater disparities in access to electricity between rural and urban populations, further marginalising household producers. More recent estimates by the International Energy Agency in 2011 found that Africa accounted for nearly half of the 1.3 billion people worldwide without access to electricity (OECD/IEA 2013).

Between 1980 and 2004, power generation per worker in SSA stagnated while it more than tripled in low-income economies of South Asia (Calderón and Servén 2008). SSA was the only region in the World Energy Outlook (WEO) projections for 2030 that showed an increase in the number of people without access to electricity (OECD/IEA 2013). These trends suggest that the disparity in access to electricity between households in SSA and other parts of the world will increase over time. Under the WEO projections, SSA will represent two-thirds of the global population without access to electricity by 2030 (increasing from less than half in 2011).

Even where electricity is available, it is unreliable. A power outage report from 2008 indicated frequent outages in many ESA countries (World Bank 2009). Outages were particularly high in Kenya and Ethiopia. In 2007, Kenya was reported to have 90 days of power outages, with Ethiopia suffering 80 days of outages. The number of outage days in that year was also high in Tanzania (70 days), Mozambique (60) and Zimbabwe (60). This unreliable power has significant investment and cost implications for household producers and agribusiness owners in ESA. An analysis of survey data from Uganda revealed an example where inadequate supply of electricity decreased a firm's investment in business operations (Reinikka and Svensson 1999b). More recent evidence from 2008 found that Africa (as a whole) experienced longer power outages than the rest of the world (World Bank and AfDB 2009). This report indicated that the duration of power outages in some countries averaged 12 hours and accounted for 13% of annual working hours. In contrast, approximately 1% of working hours were lost to power outages in East Asia and 7% in South Asia in the same year (World Bank and AfDB 2009). Firm surveys from 2007 found that 2% of sales were lost due to power outages in both SSA and South Asia (World Bank 2007). World Bank surveys from 2005 indicated that the frequency of outages in SSA was much higher than in East Asia (World Bank 2006c). In 2008, Africa had the second largest percentage of firms with generators (38%), suggesting businesses tended to strategise for, and absorb the costs of, unreliable power (World Bank and AfDB 2009). Clearly, successful development or upgrading of electricity infrastructure will be of substantial benefit to ESA given recent levels of supply and reliability.

### *Roads and transport*

Trends in transport networks (measured as the total road length relative to arable land surface) demonstrate either stagnation or declines in SSA over the last 25 years (Calderón and Servén 2008; World Bank and AfDB 2009). Over this same period, road networks expanded considerably in non-African low-income and South Asian countries. This has resulted in a significant gap in transportation infrastructure between SSA and these other regions. The proportion of road that is paved in SSA, and

ESA especially, increased slightly from 1990 to 2015. However, this was still considerably lower than other regions of the world. As of 2004, approximately 15% of roads in SSA were paved while this was nearly 60% in non-African low-income countries (Calderón and Servén 2008). The percentage of the rural population living within a short distance (2 km) of an all-season passable road reached the South Asian norm of 50% in only a dozen countries in Africa.

Diao and Yanoma (2003) showed that growth in many SSA agricultural sectors was constrained by high transportation or marketing costs. Transportation costs were substantial for many agribusinesses in Africa (World Bank and AfDB 2009). The World Competitiveness Report of 2009 found that transportation costs were higher within Africa than outside Africa. It was more expensive to move a shipping container within ESA (US$1,100) than the equivalent distance out of ESA (US$872 for the same container). Transportation costs were substantially lower in all other regions of the world, except eastern Europe and Central Asia. This kind of discrepancy can substantially disadvantage and disincentivise efforts to promote regional trade within eastern Africa.

Substantial price spreads between farm gates and markets among household producers in Kenya and Uganda suggest that road improvements can support increased farm-gate prices and household earnings (Yamano and Arai 2011b). Likewise, evidence from Malawi supports this approach. Diao and Yanoma (2003) evaluated the potential benefit of improving transportation infrastructure in Mozambique for agricultural growth in Malawi. Since Malawi is a landlocked country that imports and exports agricultural commodities via South Africa and Mozambique, investment in transportation infrastructure in Mozambique was expected to lower marketing costs (reduce the margins on Mozambique international trade) and benefit the agricultural sector in Malawi (Diao and Yanoma 2003). This study found that increasing total factor productivity in the Mozambique transportation sector benefited Mozambique and Malawi through increased GDP (by 6.6% and 1.8% respectively), farm incomes (6.9% and 3%) and agricultural output (5.9% and 2.6%). Consumers in both countries also benefited from reduced marketing costs where food consumption increased by 5.9% in Mozambique and 1.4% in Malawi.

These data suggest that transportation infrastructure was a major limiting factor to the business performance of the majority of rural producers. In addition, investments in infrastructure have been shown to improve business performance by freeing capital from transportation costs to increase wages of agricultural workers (Khandker et al. 2006; Mu and van de Walle 2007). Various case studies have found that investment in road infrastructure enhanced opportunities in non-agricultural activities (Escobal and Ponce 2000; Lokshin and Yemtsov 2005) and improved downstream consequences for food availability. These efforts even improved completion rates of primary school students (Mu and van de Walle 2007). This suggests that improving road infrastructure has the potential to substantially reduce market costs and increase market access with dramatic benefits for rural household producers.

The trends in telecommunications, electricity and roads suggest that infrastructure has been a limiting factor for household producers in ESA. As such, investment in road (as well as telecommunication and power) infrastructure can often overcome a range of associated constraints to agricultural and rural development.

### 2.5.3 Markets

Access to inputs that support major intensification practices, including inorganic fertiliser and improved seed, depends primarily on well-developed and functioning input markets (Yamano and Arai 2011a). It has been widely demonstrated that opportunities to purchase inputs and adopt technologies can have major implications for household production (Stifel and Minten 2008) and food security (Frelat et al. 2015). For instance, Frelat et al. (2015) found that household access to markets tended to stabilise food availability. In general, access to markets tended to decrease household dependence on any specific resource. For instance, households with access to markets required less land and livestock for ensuring food security than those without it. Access to output markets has also played a critical role in supporting high and stable economic returns to production, alleviating vulnerabilities to shocks and providing opportunities to buy and sell crops and access non-farm work (Djurfeldt and Djurfeldt 2013).

The majority of household farmers in ESA are located far from population centres and markets, which has posed a major challenge to accessing markets and their benefits. The majority of household farmers in ESA were found to be located further than four hours from a market (Smale et al. 2011). In other rural regions of the world, the majority of producers are located within two hours of a market. Only a quarter of farmers in ESA are within two hours of a market by motorised transport, compared with close to half in Asia, the Pacific and Europe (Smale et al. 2011). Furthermore, figures based on commute time by motor vehicles are likely to understate the challenges faced by household producers in ESA, few of whom have reliable access to motorised transport.

Based on this body of recent evidence, Frelat et al. (2015) suggested that improving market access and off-farm sources of income has the greatest potential to lift SSA households out of poverty and establish food security. Specific patterns in the market environment, including seasonal fluctuations in supply and demand and across locations, have major consequences for household access to markets and market information, and market prices (e.g. affordability of goods for household consumption and transaction costs of transport and intermarket commerce that drive sales prices). These consequences can shape household production orientation, level of market participation and intensification pathways (Abafita et al. 2016). (See Abafita et al. (2016) for a distinction between market participation and market orientation in their evaluation of household commercialisation processes in Ethiopia.)

### *Fertiliser markets*

The development of the fertiliser market in ESA demonstrates the challenges of establishing new markets in SSA and the factors that allow for market growth.

Despite considerable efforts in the past, fertiliser markets and accompanying industries have yet to emerge in most of SSA (Crawford et al. 2003; Poulton et al. 2006; Hernandez and Torero 2011). The most commonly cited reasons for this include lack of markets and infrastructure that provide access to fertiliser (Kelly et al. 2003; Jayne et al. 2010), a lack of access to cash or credit (Obi and Pote, 2012) and policies with poor institutional fit to incentivise private industry investment (Benson et al. 2012). Studies have identified additional factors that limit fertiliser use by household producers, including single price-setting firms that monopolise the industry and a dependence on imported fertiliser that requires multiple transactions and associated transaction costs along the value chain (Hernandez and Torero 2011). These conditions add to cash constraints and act as a disincentive for producers to increase their crop production above subsistence levels. These studies demonstrate that output markets have provided few opportunities for household producers to sell surplus yields or cash crops at prices that make for profitable commercial production.

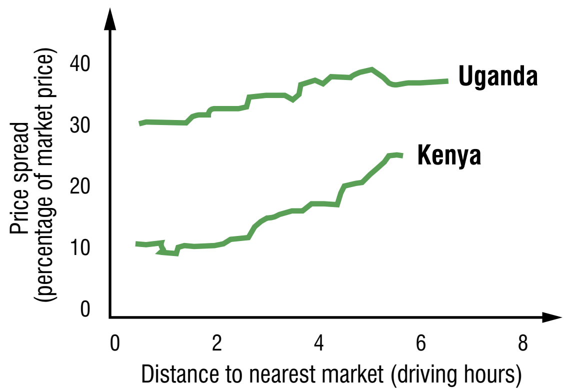
Limited access to fertiliser markets has been identified as a constraint that underlies low application of nitrogen fertilisers on household plots (Twomlow et al. 2010). However, recent trends in some parts of ESA suggest that markets are playing an increasing role in facilitating adoption of new technologies and management practices for sustainable intensification (Yamano and Arai 2011a). For instance, the number of small and medium-sized enterprises in input markets, such as for inorganic fertiliser and seed, has increased in Kenya, Uganda and Ethiopia. However, these market trends have varied across countries. Yamano and Arai (2011b) suggest that the fertiliser market in Kenya from 2004 to 2007 was more integrated than it was in Ethiopia, based on low fertiliser price variability.

Input (such as fertiliser) costs tend to increase as access to markets becomes more challenging (e.g. rugged road conditions). For instance, Gregory and Bumb (2006) demonstrated that transportation costs were positively correlated with inorganic fertiliser prices. As stated earlier, access issues can also reduce the selling prices of farm products thereby disincentivising market participation among household farmers (de Janvry et al. 1991). However, analysis by the African Development Bank indicated that transportation costs are often overemphasised as the underlying cause of high fertiliser prices, and that weak regulation and high market power concentration typically increased fertiliser retail–import price gaps (Shimeles et al. 2015). Likewise, the notion that input use is constrained simply by market development and unfavourable prices ignores more complex interactions between inputs, management and environment (Burke et al. 2017). Aside from the effect of poor market access on inputs, household farmers are also less likely to produce higher value perishable crops when transportation costs are high (Goetz 1992; Jayne 1994; Jacoby 2000). Therefore, these barriers to entry can prevent household farmers from increasing farm income via both lower adoption of technological inputs and less incentives for higher value production orientation. A case study of this effect is provided in Box 2.3.

The cost of fertiliser in ESA has been relatively high under the prevailing market conditions, creating a significant constraint to its use. The cost of fertiliser has tended to be higher in Africa compared to Europe, North America or Asia, suggesting that countries in Africa have faced unique challenges to fertiliser market development. Sanchez (2002) estimated that the cost of fertiliser in Africa was between two and six times that on the other continents. A tonne of urea cost about US$90 in Europe, US$120 in Mombasa (Kenya) and Beira (Mozambique)—both seaports—and increased to US$400 in western Kenya (700 km from Mombasa), US$500 across the border in eastern Uganda and US$770 in Malawi when transported from Beira (Sanchez 2002). Various studies have determined that fertiliser was prohibitively costly for household farmers. Affordability is especially challenging because cash flow and fertiliser demand patterns are characteristically unsynchronised where a dry season typically divides income and field preparation.

The economic returns of fertiliser use, rather than the price alone, provide a better indication of its profitability. Estimates of the maize-to-fertiliser price ratio found that the input–output ratio in Kenya increased from 2.3 in 2004 to 3.0 in 2007 (Yamano and Arai 2011a). The same price ratio in Ethiopia was comparable to that of Kenya, where the maize price was US$11 and US$13 per kg in 2004 and 2006 (about two-thirds of that in Kenya during the same periods) but fertiliser prices were also low due to government subsidies. Maize–fertiliser ratios in Uganda of 3.4 in 2003 and 4.7 in 2005 were considerably higher than in Kenya and Ethiopia. The particularly high input–output ratios in Uganda were consistent with the low fertiliser application levels observed among households at the time. A similar but more holistic input–output ratio calculation showed ratios of 2.2 and 2.9 in Kenya and 1.3–1.6 in Ethiopia where fertiliser use was high relative to other countries in ESA. In Uganda, where fertiliser use was low, these values were 4.1 and 5.0 (Yamano and Arai 2011a). In Malawi, the maize-to-fertiliser price ratio was generally below 2.0 and showed high levels of variance from 1996 to 2007. This was due to considerable maize price fluctuations within and between seasons and the steady increase in fertiliser prices (SOAS 2008). This analysis suggests that unsubsidised fertiliser was not profitable and

**BOX 2.3 Market access and price effects in Africa**




The price spread for maize is higher in Uganda than in Kenya. Price spread increases with distance from the nearest maize market.

Yamano and Arai (2011b) analysed farm–market price spread (the difference between farm-gate price and nearest market price) for maize in Kenya and Uganda. The authors found that as the distance between the maize farm and the market increased, so too did the price spread (by 2% per additional driving hour). This indicates a price reduction for more isolated farmers (i.e. 2% price reduction for every hour from the market).

Among the most remote groups, maize farmers in Kenya and Uganda near Kisumu received about the same farm-gate price, which was about 60% of the market price (as indicated by the price spread of about 40%). The absolute values of farm–market price spread were lower in Kenya than in Uganda. However, they were more sensitive to distance from the market in Kenya. The price spread increased gradually with distance to about 35% of the market price. Even in the Nairobi area, the average farm-gate price was about 20% below the market price at Nairobi. This demonstrates the loss of incentive for commercial cropping due to market isolation in ESA.

the uncertainty of returns made investment particularly risky for household producers in Malawi. This does not rule out the possibility that investment in fertiliser could increase profitability for a subset of households in ESA.

Market information provides a potential means of strategising the timing of production, purchases and sales to minimise losses. It can also allow households to sell higher and buy lower, and coordinate transportation and other market-related activities to minimise transaction costs. Market information can also encourage market price integration to establish consistent and reliable prices across space. Evidence that the majority of the urban poor typically spend a large share of their expenditure on food suggests that they are likely to benefit overall from reduced prices and volatility. Prior to recent developments in information technology, the majority of household producers in SSA faced major challenges to accessing market price information (Poulton et al. 2006). As with physical access, information access has been linked to poor infrastructure (e.g. few telecommunication towers). The majority of household producers in ESA relied on radio for their market information. High levels of illiteracy, and the rarity of smartphones, meant that text-based information via mobile technology had a limited impact in communities of household producers in ESA. However, evidence across African markets suggests a recent and dramatic change in the use of information technology (Donner 2004; ITU 2007). Studies have demonstrated the profound impacts of the rapidly diffusing mobile phone network on the marketing of agricultural products (ITU 2007; Muto and Yamano 2011).

Market services such as financial tools can be critical for allowing household production to properly interact with markets. Difficulty securing capital for investing in businesses is often one of the major obstacles to business success, suggesting limited access to capital is a likely cause of performance variability across household producers (Aldrich and Auster 1986). Numerous studies have highlighted the importance of financial management diversity among household producers when ensuring access to capital (Rutherford and Arora 2009). Although some farmers have benefited from access to financial loan services, these mechanisms have rarely represented main sources of household capital. Furthermore, it is unlikely that these financial instruments explain adoption decisions and patterns of intensification.

### 2.5.4 Enabling institutions

There are two main types of market reform efforts that most directly relate to adoption of sustainable intensification practices. The first are price-based macroeconomic instruments and supply schemes (e.g. price subsidies, price control, licensing of importers and distributors and import quotas) via government agencies, non-governmental organisations or private companies. The second are partnerships to promote inclusive market development for increased household producer market orientation and participation. Despite these two kinds of effort, most household producers have suggested that policies are more detrimental than beneficial to their intensification efforts. For instance, a survey of household producers found that they believed the ‘absence or poor functioning of institutions including policies’ was a main constraint to intensification (Gatzweiler 2016).

There are marked differences in the policies that have been passed across ESA. Their implementation and results are particularly mixed and controversial. These policy differences provide an opportunity to better understand the conditions under which specific institutional efforts have potential to make great impact. It is important to identify and critically assess the success of national policies and non-governmental programs in establishing enabling environments for both household producers and private sector investment. Here we explore this further with reference to fertiliser use among household producers.

Governments have played a substantial role throughout ESA in efforts to increase fertiliser use among household producers. Many African countries adopted state-led fertiliser distribution policies in the 1970s and 1980s. In these, governments were heavily involved in fertiliser supply schemes via public agencies (Yamano and Arai 2011a). Although substantial increases in fertiliser use and improved seeds (Eicher 1995; Byerlee 1997) took place under these policies, government agencies also accumulated substantial levels of debts, or written-off credit, that supported these subsidies.

Many governments abandoned state-led distribution policies in favour of market reform as part of the structural adjustment programs (SAP) administered by the International Monetary Fund (IMF) in the late 1980s and 1990s. SAPs established the agenda for the removal of state-subsidised programs and the shift towards market reform, liberalised economic and financial activities and privatised industries. The degree of implementation and impacts of these efforts varied considerably across countries however. Following are three case studies in enabling institutions relating to fertiliser use in Kenya, Ethiopia and Malawi.

***Fertiliser policy in Kenya***

The gradual and well-sequenced process of fertiliser market policy reform distinguished Kenya from many other ESA countries. These qualities contributed to a high and stable demand for fertiliser that spanned the transition period from the state-led distribution systems to the private market. This stable demand ensured the successful implementation of fertiliser market reform policies in the country

(Omamo and Mose 2001; Freeman and Kaguongo 2003). Household producers had started to increase fertiliser use when the Kenya Farmers Association—a parastatal organisation—applied policy instruments such as price subsidies, price control, licensing of importers and distributors, and import quotas (Freeman and Kaguongo 2003). These efforts (between 1974 and 1984) kept fertiliser prices affordable. By the mid-1980s the government encouraged private companies to enter the market (Jayne et al. 2003). Market reform efforts in Kenya also benefited from the strong cash crop sector that existed before (and during) reform efforts. The cash crop sector encouraged importers and distributors to make initial investments in facilities for importing and storing fertilisers, which reduced retail prices for household producers. Cooperatives and processing firms worked in tandem with public sector efforts. Cooperatives and processing firms incentivised household farmer investment in fertiliser by offering credits to households that produced cash crops. By 1993, the government withdrew completely from the fertiliser market and abandoned price controls.

Freeman and Omiti (2003) conclude that farmers' access to inputs improved due to the expansion of private retail networks generated via policy reforms. Recent evidence suggests that market reform policies had lasting impacts on fertiliser use. Panel data from household surveys under the Research on Poverty and Environment and Agricultural Technology (RePEAT) project from 2004 and 2007 found that di-ammonium phosphate (DAP) retail price did not depend on market access—measured as travel time to the nearest city and capital (Yamano and Arai 2011a). The authors suggest that the retail price remained the same across regions because the network of retailers was well established and integrated. Agroecological conditions also explained patterns in DAP price and application levels in Kenya, where the price increased as growing conditions improved (based on precipitation over potential evapotranspiration ratio and altitude). In other words, DAP price was high in high-potential areas presumably due to higher returns on fertiliser investment. Meanwhile, DAP application levels increased as growing conditions and production potential improved. Finally, the Yamano and Arai (2011a) study found that fertiliser application levels decreased with the DAP–crop price ratio. This indicated that household producers decreased fertiliser use as returns to investment decreased. These results suggest that fertiliser use in Kenya tended to be market-driven. In contrast, the same study found evidence to suggest that fertiliser use in Ethiopia tended to be policy-driven.

### *Fertiliser and seed policy in Ethiopia*

The history of fertiliser policies in Ethiopia is notably different from that of Kenya. It offers a counter example in policy settings which involve a much more proactive government role in fertiliser and seed supply. After the fall of the military Derg regime in 1991, the government introduced a wide range of agricultural strategies. These were aimed at intensifying cereal production under a national economic strategy known as Agriculture Development Led Industrialization (ADLI). Under ADLI, the government pursued a series of policies to promote intensification and liberalise fertiliser and seed markets (FDRE 1993, 2002, 2006). The government liberalised and demolished the monopoly on fertiliser importation and distribution that was then held by the parastatal Agricultural Inputs Supply Enterprise (AISE) (Spielman et al. 2010). However, the market reform period was volatile. It was marked by the rapid entry and exit of wholesalers and retailers that were quickly replaced by a small number of 'private' firms with strong government ties. Consequently, at the end of the 1990s the government remained heavily involved in a fertiliser credit program.

From 1994, regional governments initiated a 100% credit guarantee fertiliser supply scheme under the National Agricultural Extension Intervention Program (NAEIP). NAEIP additionally scaled up the

Participatory Demonstration and Training Extension System (PADETES), a program focused on extension, seed, fertiliser and credit services piloted by Sasakawa Global 2000 (Spielman et al. 2010). By 2004, only eight firms were active in seed production and 70% of improved maize seed production and multiplication was carried out by the state-owned Ethiopian Seed Enterprise (Alemu et al. 2007). Regulatory functions, such as varietal release reviews and seed certification, were performed by the federal government. Meanwhile, the national research system (headed by the Ethiopian Institute of Agricultural Research with other research centres and universities) developed improved varieties (Spielman et al. 2010). By 2004, the public sector still dominated seed distribution channels. In that year, 80% of improved seed sales were provided by regional extension and input supply systems. Most of these sales were paid for with credit disbursed against public guarantees (World Bank 2006b). Panel data from 2007 representing 417 households suggest that the role of government programs was still significant in supplying 64% of fertiliser (Yamano and Arai 2011a).

The long-term sustainability of the costly seed and fertiliser credit programs in Ethiopia remains unclear. There is additional concern that state-led policies have crowded out private firms (Jayne et al. 2003; Spielman et al. 2010). Only two regional holding companies and the parastatal AISE are in control of all fertiliser imports and distribution. Since 2007, all fertiliser imports have been controlled by AISE and cooperatives. The quality of this state-led fertiliser distribution is also questionable, specifically with regard to the suitability of fertiliser packages to household production systems and the timeliness of delivery. For example, the state-led policies have tended to distribute standard packages across vastly diverse farming systems, resulting in suboptimal use of inputs by many household producers. A study cited by Spielman et al. (2010) found that half of farmers surveyed received fertiliser after planting. Numerous studies have found shortcomings in the quality and timeliness of seed deliveries, including late deliveries that result in suboptimal planting times or distributions of varieties that did not suit household conditions (Sahlu and Kahsay 2002).

Despite growing concerns over the effectiveness of government policies in promoting fertiliser use, evidence from 2007 suggests that state-led policies were major determinants of household fertiliser use. In contrast to Kenya, panel data from the RePEAT project found policy-related factors explained patterns in inorganic fertiliser (DAP) prices and application rates in Ethiopia (Yamano and Arai 2011a). Driving time to the nearest urban centre had a positive effect on the DAP price (Yamano and Arai 2011a). The authors explain this finding based on price-setting policies in the country, where government-supported fertiliser agencies set the base price constant across regions, but add transportation charges to the costs incurred by farmers at the local level. In contrast to Kenya, DAP application was higher in low-potential areas (Yamano and Arai 2011a). The authors suggest that these findings reflect government policies designed to encourage farmers to use fertiliser in areas where they would otherwise have low incentive to do so. Finally, Yamano and Arai (2011a) found that one effect of these centralised price controls was that fertiliser application levels increased as returns to investment decreased. This is based on government-supported agencies setting the fertiliser prices lower where farmers have lower returns, in an effort to ensure affordability.

### *Fertiliser policy in Malawi*

From the mid-1970s to the early 1990s, the Government of Malawi financed a universal fertiliser subsidy program, along with subsidised household credit and controlled maize prices. The system began to break down in the late 1980s, and subsidies were discontinued by the mid-1990s. Despite the significant financial burden of these subsidies, the government continued to play a role in fertiliser provision in the late 1990s. In an effort to offset declining maize productivity and a food and political crisis, in 1998 the new democratic government introduced the US$23.5 million Starter Pack Program (Harrigan 2003). From 1998 to 2000, the program imported, subsidised and distributed starter packs of improved seed and fertiliser to all households that cultivated at least 0.1 ha of staple foods. In response to donor pressure (mainly from the World Bank) to establish a more targeted approach, the program narrowed its distribution to more targeted groups of households from 2000 to 2005.

However, continued high levels of food insecurity led to significant political pressure for larger subsidies. This was eventually realised with the implementation in 2005–06 of a large-scale, voucher-based program known as the Malawi Agricultural Input Subsidy Programme—subsequently renamed the Farm Input Subsidy Programme (FISP) (Dorward and Chirwa 2011; Chibwana et al. 2012). FISP deviated in two significant ways from the previous program. First, its scale, which increased from around 50,000 tonnes of fertiliser in 2004–05 to 130,000 tonnes in 2005–06. Second, the new program allowed cash redemption of vouchers as well as tobacco inputs. The vouchers were meant to target 50% of farmers, who would receive fertilisers for maize production, with further vouchers for tobacco fertilisers and for improved maize seeds.

In their assessment of the efficacy of the program's targeting, Dorward and Chirwa (2011) found that efforts were focused on full-time male-headed households with relatively more land and resources. This was consistent with evidence that better-off households used the subsidies more than the most at-risk households (Ricker-Gilbert et al. 2009). These findings indicate that the program had the greatest impact on better-off households, while neglecting the needs of those most at risk. This is in line with evidence that programs stimulating productivity innovations are more likely to benefit those with greater landholdings (i.e. more production potential) than others, reinforcing existing inequalities in ownership (Kuiper and Ruben 2007). Furthermore, the targeting criteria used for distributing vouchers were inconsistent across localities. This inconsistency was explained by vagueness in guideline definitions of target beneficiaries (Dorward and Chirwa 2011).

The program was successful in raising maize productivity (SOAS 2008) and increasing food self-sufficiency (Dorward and Chirwa 2011). However, households that participated tended to simplify their crop rotations in response to the program. More land was allocated to maize and tobacco at the expense of other crops such as groundnut, soybean and bean (Chibwana et al. 2012). These adverse effects led to efforts to promote integrated soil fertility management practices (e.g. organic fertilisers, reduced or no-till conservation agriculture). The FISP also included subsidised legume seeds in an effort to address these concerns, though to limited effect (Dorward et al. 2010). In addition to these concerns, the substantial costs associated with FISP implementation accounted for approximately 74% of the agricultural budget and 16% of the national budget in 2008–09. The benefits of FISP investments have therefore been scrutinised against the perceived forgone benefits of alternative investments.

### 2.5.5 Sharing the benefits

As seen in the examples from Kenya, Ethiopia and Malawi, price-based instruments and market developments have tended to benefit some households over others. Variability in household asset endowments have explained inequitable outcomes of policy efforts, reinforcing income inequality. For instance, policies focused on improving agricultural technologies are more likely to benefit land-based households over those without land, exacerbating existing inequalities in asset ownership. Similarly, programs that reduce price bands (e.g. infrastructure investment and development) are more likely to reach net-buying and net-selling households while excluding those with limited market access (Kuiper and Ruben

2007). Kuiper and Ruben (2007) simulated the impact of a policy that promoted fertiliser by lowering prices on household producers in Ethiopia. The policy nearly doubled fertiliser use from 36% to 68% of households, however these efforts did not reach the poorest households, resulting in increased within-village income inequality. This was explained by the prohibitive cost of fertiliser use for poorest households.

The need for more targeted development efforts that ensured benefits for the poorest members of society motivated a new policy agenda focused on inclusive growth (McKague and Siddiquee 2014; IFAD 2016a). These efforts prioritised inclusive growth rather than pro-poor growth. Pro-poor growth refers to the case when poverty is reduced substantially compared to the rate of growth of GDP per capita. However, this can result in rising inequality in income and consumption. Alternatively, inclusive growth refers to income growth that is accompanied by decreased income inequalities (Musahara 2016). Thus, inclusive development encompasses improvements in distribution of wellbeing, accompanied by overall growth or increased wellbeing across the country. This is an especially relevant development indicator in the context of many ESA countries. In this region, the rapid rise in the middle class starting in the 1980s was accompanied by growing inequalities (JICA 2013; Musahara 2016).[2] For instance, the average Gini score (measuring inequality) from 2003 to 2012 ranged from 33.6 in Ethiopia to 47.7 in Kenya, indicating high levels of inequality (Malik 2014). These trends prompted efforts to ensure that marginal groups were included in ongoing development of the agricultural sector.

Over the last two decades, several initiatives under the framework of inclusive development have been implemented at African continental and subregional levels. These were designed to ensure that household producers benefited from agricultural development and emerging markets. Inclusive development goals played an increasing and more explicit role in goal setting at the continental level. The importance of this inclusive development was first alluded to in the Comprehensive Africa Agricultural Development Programme (CAADP). This was Africa's policy framework under the New Partnership for Africa Development (NEPAD), during the 2003 African Union (AU) summit in Maputo, Mozambique.[3] The stated vision of CAADP is 'Agricultural transformation, wealth creation, food security and nutrition, economic growth and prosperity *for all*' (emphasis added) (FAO 2002). In June of 2014, CAADP reiterated the need to ensure prosperity for all in the Malabo Declaration of 'accelerated agricultural growth and transformation for *shared prosperity* and improved livelihoods' by 2025 (emphasis added). However, such declarations do not always lead to impact. A recent assessment spanning 46 countries from 2001 to 2014 concluded that CAADP had had an insignificant effect on household incomes (Benin 2016).

In 2015, the AU established a clear commitment to inclusive development. In Agenda 2063 of the AU Framework Documents, the AU placed the need to 'plan for a prosperous region based on inclusive and sustainable development' as the primary aspiration for 2063 (AU 2015). In addition to CAADP (2003) and the Maputo Declaration (2003), the Sirte Declaration (2004), Abuja Food Security Summit Declaration (2006) and Malabo Declaration on Accelerated Agricultural Growth and Transformation offered a strong basis for Agenda 2063. The first stated objective in the 'Decisions and Declarations, an Implementation Strategy and Roadmap' of the Malabo Declaration is 'transformed agriculture and sustained inclusive growth'. Here we explore the implementation of this inclusive growth agenda through the use of PPPs and inclusive businesses.

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2 Since the 1980s, Africa's middle class increased threefold, reaching nearly 350 million in 2010 (34% of the population)—up from about 126 million or 27% in 1980. It is projected to reach 1.1 billion (42%) in 2060 (AfDB 2011).

3 NEPAD, first established in 2001, adopted into the African Union (AU) in 2002 and then reincorporated into the AU as the NEPAD Planning and Coordinating Agency in 2010, was made responsible for managing and implementing continent-wide development programs and projects (FAO 2002).

***Public–private partnerships***

The beginning of the 21st century saw a resurgence of interest in private investment in infrastructure. This was again seen as a potential mechanism for raising productivity, enhancing food security and lifting rural people out of poverty. Kularatne (2008) explored the effect of infrastructure investment on GDP and found evidence that it impacted GDP indirectly through its effect on private investment more generally. Similar findings were reported in previous studies (Perkins et al. 2005). A shift towards private investment strategies has also gained popularity for its potential to create jobs outside of farming (e.g. in both the service and production sectors). This, in turn, stimulates broader rural development. Private investment in agriculture is often considered undesirable based on the associated risks. PPPs have therefore been treated as an important institutional mechanism for increasing such investments. This allows stakeholders to share risks and address other constraints in pursuit of sustainable agricultural development. As an example, Box 2.4 describes a PPP called Grow Africa that aimed to increase private sector investment in agriculture and accelerate the execution and impact of investment commitments.

The United Nations Development Programme promoted PPPs based, in part, on the expectation that they support market environments that 'include the poor on the demand side as clients and customers, and on the supply side as employers, producers and business owners' (Gradl et al. 2010). A potential shortfall of PPPs lies in the focus that many of these efforts put on advanced technology projects. Consequently, large enterprises have been better positioned to benefit from PPPs than small firms and household farmers. The significant role of government in establishing PPPs also has the potential to distort their inclusiveness for household farmers, and lead to rent-seeking behaviour by large-scale companies. Examples of inclusive business models, where private sector firms incorporate diverse types of beneficial schemes, provide examples where the public sector plays a more limited role (WBCSD 2016).

Alternative business models (i.e. farmer groups and contract farming) have been shown to benefit household producers in ESA. Contract farming has been more common in value chains for high-value crops, particularly those with large export markets such as coffee, tea and flowers (Barrett et al. 2012). Other notable examples include horticulture (Neven et al. 2009; Rao and Qaim 2011) and dairy (IFAD 2016a). However, inclusive business models have been less common for low-value staple crops such as maize. Notable exceptions include the Cereal Growers Association in Kenya and Tanzania, Farmer Concern International in Kenya and Uganda, the Rural Urban Development Initiative in Tanzania and the Agricultural Development Trust (AGMARK) in Kenya and Uganda (USAID 2011). Several inclusive business models have targeted markets for farm inputs including the Real IPM Company that marketed a small seed treatment pack, and Farm Input Promotion-Africa, a not-for-profit company that marketed small, low-cost packs of seed and fertilisers (Hall et al. 2010).

Orr and Mwema (2013) evaluated the effect of three inclusive business models in eastern Africa, two in Kenya and one in Uganda. The authors found that although a warehouse receipt system in Kenya was profitable to household producers, it showed low uptake by maize growers. In a contract sorghum grower model (also in Kenya), the majority of producers belonged to all-female groups, suggesting success in increasing involvement of a marginalised group. The business scheme was also profitable for household producers, intermediaries and buyers with potential for growth. In the Ugandan example, approximately half of the households were women. This again suggests that the business model was successful at increasing involvement of a marginalised group. The project was also profitable for household producers and buyers.

**BOX 2.4 Grow Africa and Southern Agricultural Growth Corridor of Tanzania**

The Grow Africa partnership was funded jointly by the AU, NEPAD and the World Economic Forum in 2011. Its mandate was to increase private sector investment in agriculture, and accelerate the execution and impact of investment commitments. Grow Africa was responsible for facilitating collaboration among governments, agricultural companies and household farmers to lower costs and risks of investment in agriculture. In 2015, Grow Africa was working with 200 companies to implement investments totalling US$10 billion (Cartridge 2015). It played a significant role in including isolated communities in agribusiness value chains. For example, Grow Africa was responsible for establishing the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) Centre. Initiated in 2010, the SAGCOT Centre was designed to showcase investment opportunities in the region which covers approximately one-third of mainland Tanzania. SAGCOT provided infrastructure that linked small-scale farmers to regional and international agribusiness value chains. It represented the first PPP of this scale in Tanzania's agricultural history. However, these new kinds of inclusive-growth PPPs are not immune from the same challenges and criticisms of previous institutional-level efforts. Nijbroek and Andelman (2016) evaluated the intensification potential for these regions and found that they had limited potential relative to other areas of Tanzania. For instance, the authors found that half of the targeted areas were totally or partially unsuitable for intensification. Few ex-ante assessments of SAGCOT have been conducted. One study found that household welfare increased when household producers were from SAGCOT target areas. However, their analysis suggested that land-rich outgrowers benefited more from SAGCOT investments than land-poor households (Herrmann 2017).

## 2.6 CONCLUDING REMARKS

Farming systems in ESA are extremely diverse in terms of their biophysical environment, socioeconomic conditions and policy settings. This multifaceted diversity confounds our understanding of the constraints facing households. A lack of understanding leads to poorly developed interventions, policy proposals and development efforts. Such efforts have often failed to effectively impact poverty or undernourishment, as seen by the macro-level statistics presented. This chapter outlined diversity among households of ESA in their agroecology. We then provided a discussion of diversity in relation to two forms of innovations for sustainable intensification: productive innovations (discussed largely in terms of field-level management) and institutional innovations. This exploration demonstrated the sheer complexity of constraints and challenges to intensification of household producers. The following chapters begin to provide a methodology for quantifying and analysing this diversity, with a view to informing better targeted development options.

This chapter demonstrates that single development approaches to diverse sets of households can disproportionally impact certain demographic groups and either alleviate or exacerbate inequalities among households. Therefore, it is critical that any efforts to deliver sustainable intensification be formed with an understanding of that diversity in a holistic manner. This means accounting for the diversity of both biophysical and socioeconomic factors, as well as the wider institutional settings.

In the following chapters, we begin to marry the DEED approach (Box 3.1) to studying diversity, with the framework of Dorward et al. (2009) in understanding aspirations and livelihood states of household producers. We apply this to an analysis of diversity through developing local farm typologies, in a similar manner to Tittonell et al. (2010) but applied to a wider range of potential innovations, i.e. those outlined by Schut et al. (2016a).

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# HOUSEHOLD TYPOLOGIES:
## METHODS FOR IDENTIFYING TARGET COMMUNITIES

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# KEY POINTS

- Methods for establishing household typologies have a range of approaches to selecting household classification criteria.
- Classification criteria have emerged out of theoretical principles of development, efforts to establish standardised approaches for characterisation, and in response to a growing body of empirical evidence.
- Multivariate analysis methods—principal component analysis (PCA) and cluster analysis—have allowed for a standardised analysis method that identifies empirically based classification criteria.
- The empirical nature of this approach has provided flexibility for wide application across different farming system contexts while also offering a standardised method to support comparative studies.
- The approach taken to characterise the households described in the SIMLESA case studies involved:
  - surveys of randomly selected households, stratified across major agroecological and social regions
  - summary statistics for regional comparisons within countries
  - cluster households within regions of each country based on factors identified in PCA:
    - PCA within regions to identify region-specific classification criteria
    - cluster analysis of households within regions to assign more homogeneous groups based on major sources of variability
    - summary statistics to characterise distinct clusters, identify production advantages and disadvantages and describe livelihood strategies of household groups.

## DEFINITIONS

**Cluster analysis**—A type of multivariate analysis that groups (or clusters) single observations (in the case of this report, households) into a set where they are more similar to each other than they are to other groups (or clusters). In essence, cluster analysis is used to help define subgroups within a population on the assumption that there are a number of distinct unknown subgroups whose differences will be meaningful in understanding group diversity and its consequences. In this report, cluster analysis is used to identify household typologies.

**Dendrogram**—A widely used method for visualising the distance level at which observations or clusters are combined. Dendrograms are useful when determining the number of clusters to keep in a hierarchical approach (which does not predetermine the number of clusters).

**Eigenvalues**—An important output from PCA analysis (see below), eigenvalues describe the proportion of total observed variability that is represented in a given principal component (PC). In the case of this report, they are used to determine whether a given PC is to be retained for further analysis. Eigenvalues less than 1 (i.e. explaining less than 10% of overall dataset variability) are dropped from further analysis.

**Euclidean distance**—In hierarchical cluster analysis, a metric for determining the 'distance' between two observations is required to form clusters based on their proximity (i.e. similarity). The Euclidean distance is a measure of geometric distance in multidimensional space between two objects (i.e. households) for a given observed variable. It is the most commonly used distance metric, and uses the average of all points (in our case, households) in a cluster to measure distances between clusters.

**Farming style**—The mode by which a production system orders a coherent repertoire that guides practical actions and informs farmers' judgements (Van der Ploeg et al. 2009).

**Hierarchical clustering analysis**—A type of cluster analysis that begins with each observation (in our case, household) belonging to its own cluster. Clusters are subsequently joined through minimal distance to each other until only one cluster remains. This type of cluster analysis allows for greater exploration of the data as it does not require a predetermined number of clusters to be formed.

**Principal component (PC) loadings**—Values describing the correlation between a given observed variable (e.g. farm size) and an artificial PC variable created through principal component analysis. These PC loadings are calculated the same as Pearson's correlation coefficient and are similar to $R^2$ values for linear correlations. The observed variable with the highest PC loading is used to represent a given PC variable in subsequent analysis (in the case of this report, cluster analysis).

**Principal component analysis (PCA)**—A type of multivariate analysis used (in the case of this book) to reduce the number of variables needed to represent the overall variability observed. The analysis examines relationships within a group of variables to identify the underlying structure of the data. The technique combines observed variables into a smaller set of artificial variables called 'principal components'. This is based on combining variables with collinearity. The new

PC variables then undergo regression analysis to determine orthogonal (non-correlated) lines of best fit to generate eigenvalues. Eigenvalues provide an estimation of the total observed variability explained though a given PC variable. A single observed variable (i.e. the one most high correlated with the PC in question) can then be used as a proxy to represent that variability (i.e. eigenvalue) in subsequent analysis.

**Ward's minimum variance**—An agglomerative clustering algorithm that approaches clustering as a kind of analysis of variance. It is suited to numerical data (i.e. as with PCA) and is useful as an explorative method to clustering. It minimises the variability within clusters, making it suitable for identifying more homogeneous groups.

## 3.1 INTRODUCTION

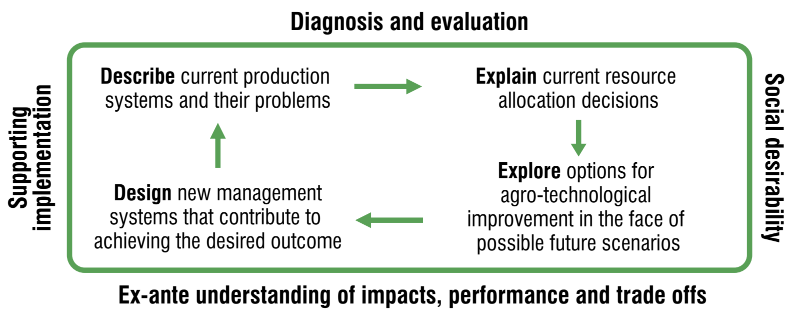
As Chapter 2 has shown, each component of the farming system can vary considerably across households, communities, agroecological regions and countries, as well as over time. One way of understanding this diversity has been to organise households into distinct groups with similar opportunities and constraints (typification). Households that fall within the same group are expected to respond similarly to development recommendations on the basis of those shared characteristics. The process of establishing household typologies is a first step within a broader agricultural development effort to promote context-specific pathways (Box 3.1). Efforts to classify households into typology groups were therefore developed to address the distinct decision-making challenges of different types of households (Reardon and Vosti 1995).

Farming system typologies have been constructed using various approaches that reflect a range of data collection methods, classification criteria and analysis approaches. This chapter reviews these methods with specific reference to the approach behind the SIMLESA case studies that follow in Section 2.

Classification schemes for understanding household diversity began as early as the 1940s when household production systems were most typically classified based on the region in which they were found (Hofstee 1946; Van der Ploeg et al. 2009). Interest in understanding other sources of household production variability gained traction with recognition that agricultural development processes varied *within* regions. The wide range of possible sources of variability became increasingly apparent as the body of research on farming system diversity expanded, broadening the timeframes and regions under study. With diversity studies covering a broad range of contexts, many scholars emphasised the need for context-specific classification criteria and argued that inconsistencies across diversity studies were necessary (Mądry et al. 2013). Giller et al. (2011) argued against the use of identical classification criteria across drastically different farming systems. To illustrate this argument, they compared the humid forest of Cameroon, where households shifted cultivation with perennial crops, to crop–livestock farming systems in the semi-arid savanna of Mali and Zimbabwe. At the same time, predominant development paradigms shifted. Empirical evidence of spatial and temporal changes to farming systems stimulated the revaluation of assumptions behind data collection. The same trends led to revaluation of classification criteria and interpretation, leading to the generation of new classification methods and organisational schemes (Box 3.2).

This range of approaches to diversity studies has posed a challenge when comparing their outcomes. It has also complicated efforts to establish standardised approaches to developing household typologies. The methods that were selected for the SIMLESA case studies emerged out of debates in these areas. This brief review of the development of classification methods provides rationale for the SIMLESA methods that are then discussed in greater detail.

## BOX 3.1 Understanding household diversity in the context of agricultural development: the DEED framework




A flowchart of the DEED approach (adapted from Tittonell et al. 2009).

The DEED methodological framework was first popularised by Giller et al. (2011) as a method for studying the complexity and diversity of farming communities for development, testing and improvement of innovations for development. The framework consists of four discrete steps: describe, explain, explore and design (DEED). Each step involves various types of data collection, analysis and interpretation.

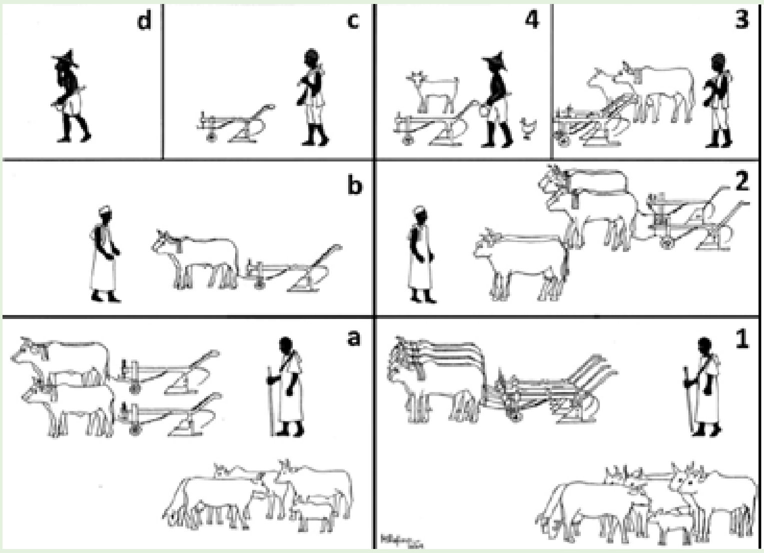
Establishing household typologies is one method that can be used in the first steps of describing and explaining the system. Describing the system refers to the process of evaluating existing farming system conditions and identifying challenges or obstacles to reaching desired outcomes.

Explaining the system refers to understanding the patterns of resource allocation and their consequences. Examples of tools for describing production systems and their challenges include surveys, econometrics, resource allocation maps, visioning exercises, ex-ante modelling and farm interviews together with typologies. After the describe step, explaining can include modelling exercises at the field, farm and landscape levels, data mining, multivariate methods and econometrics. At this step, problem trees can also identify major contributing factors and establish logic behind theories of change. Similar analytical tools can be applied at the explain and explore steps.

The explore step refers to evaluating options for improvement under future scenarios. Methods for exploring include participatory activities and modelling. These can explore potential impacts of future agricultural developments and assess the social desirability (or feasibility) of current or alternative farming system scenarios.

The design step refers to the process of designing new management systems that contribute to achieving desired outcomes. The explore and design steps can involve ex-ante impact assessments of performance and trade-offs. Multi-agent models and innovation systems are also uniquely suited to assist in design.

**BOX 3.2 Changes of farming system typologies over time**




A cartoon representation of two sets of farm typologies developed in 1988 (IER 1988, left) and 2007 (Sanogo et al. 2010, right) to describe the diversity of livestock producers in Koutialala, Mali. (Figure from Giller et al. 2011.)

The typologies of livestock producers in Mali have changed over time, reflecting differences in the range and variability of farming system characteristics. A comparison between typologies from 1988 and 2007 shows that classification criteria changed to reflect the degree and types of disparities that existed among the community at the time.

From 1988 to 2007, overall livestock ownership levels increased. This changed the threshold numbers for classifying groups of households. In 1988, the household with the largest herds had more than 10 units of livestock.

By 2007, this threshold level increased to 20 units of livestock. In addition, ownership of small ruminants and chickens was introduced as a new household classification criterion (typology '4' in cartoon).

## 3.2 THEORY AND CONCEPTS OF HOUSEHOLD CLASSIFICATION SCHEMES

Some of the earliest examples of classification schemes applied a-priori classification criteria based on modernisation models of European agricultural development. This resulted in a focus on structural differences like farm size (land or labour) and productivity (output per unit area). The household typologies that emerged out of this period were classified in terms of their 'distance' from the 'optimum' farm size–productivity relationship (Van der Ploeg et al. 2009). Examples included, 'traditional', 'non-professional', 'residual' or 'leavers'. This placed the diverse set of household typologies on a single agricultural development trajectory based on the assumption that agriculture development was a linear process—specifically, that farm size (based on land and labour) increased with productivity (output per unit area). Household resource endowment has also been widely used to classify households into groups like 'poor', 'mid-class' and 'wealthy'. An underlying assumption of these schemes was that households could reach certain welfare thresholds at which point they pursued stable or predictable livelihood strategies (Dixon et al. 2001).

By the late 1980s, new typologies arose in response to growing evidence that structural characteristics like farm size and productivity were poorer predictors of livelihood strategies than assumed under modernisation theory. The alternative Dutch and French concept of farming styles took a more functional and whole-farm approach. Farming styles discuss the farming system in terms of a 'mode of ordering: a coherent repertoire that guides practical actions and informs farmers' judgements' (Van der Ploeg et al. 2009). This concept shifted interest towards functional classification schemes. Functional typologies have considered different scales of the farming system, with some examples focused entirely on field-level diversity and others that extend beyond the household. For instance, Tittonell et al. (2005b) characterised plots rather than households in western Kenya to understand farming system diversity at the field level. They identified five different field types based on production activities, resource allocation and management practices: home gardens, grazing fields, close fields, mid-distance fields and remote fields. The farming style concept additionally suggested that farming systems were influenced by factors beyond the field with a mix of interacting components that spanned field and household operations.

This concept of the farming style emerged as the global share of household producers engaged in 'other gainful activities' started increasing.[1] This prompted interest in the diversity of household economic operations and transitions out of agriculture. Household income levels, income sources and cost–benefit relationships became common a-priori criteria for classifying households. As an example, Tittonell et al. (2005b) classified household producers in Kenya based on their main source of income, generating a 'self-subsistence-oriented' typology and a 'market-oriented' typology. Classification criteria related to market linkages, and social and institutional factors also emerged, extending the scope of classification criteria beyond the household subsystem. For instance, Gómez and Ricketts (2013) proposed a novel food value chain–based typology (modern, traditional, modern-to-traditional and traditional-to-modern). On the basis of these distinguishing characteristics, the authors were able to consider nutrition-related consequences for each typology group. Gillespie and Kadiyala (2005) highlighted social and institutional factors in their typological study. Such factors included variability in household sensitivity to agricultural policy and prices, the allocation of additional income generated from agricultural activities, as well as the increasing feminisation of the agricultural labour force.

Growing concern over land degradation, such as soil erosion and nutrient depletion, contributed to another set of classification approaches focused on environmental sustainability (Pender et al. 1999). Household resources and resource use patterns became common classification criteria as they were considered to be indicators of sustainability. For instance, Tittonell (2014) argued for the importance of classifying households by patterns in natural, financial and human resource growth (and contraction). He claimed that these patterns predicted household vulnerability to shocks and poverty traps.

By the early 2010s, the majority of typologies applied a combination of classification criteria that reflected this history of diversity studies. These criteria spanned three broad dimensions:

1. household subsystem structural components (e.g. land area, field-level characteristics, resource endowment)
2. economic status and activities (e.g. household income-generating activities)
3. resource sustainability (limited natural, financial and human).

1 The global share of households benefiting from other gainful activities grew from 39% in 1979 to 41% in 1989 and 49% in 2000 (Van der Ploeg et al. 2009).

**TABLE 3.1** Data collected using the survey instrument

| Farming system component | Examples |
|---|---|
| **Climate** | |
| Biophysical constraints and risks | The presence or absence and level of importance of drought, flood, pests, diseases and soil fertility constraints disaggregated for each SIMLESA crop |
| Season duration | Length of the season, total rainfall, rainfall and temperature patterns (averages, extremes and variability) |
| **Input markets** | |
| Crop production inputs | Availability, timeliness, prices and quantity of agronomic inputs (e.g. improved seed, fertiliser) disaggregated for each SIMLESA crop |
| Livestock production inputs | The number and cost of livestock purchased within the survey year; livestock production costs including fodder, labour, veterinary care, artificial insemination, etc. |
| Household consumption | Consumption levels (kg), source (market-purchased, own-produced) and frequency of consumption of foods items (e.g. staples, vegetables, meat and other animal products), non-food items (clothing, kerosene, school fees, etc.) |
| Market access | Market information and source of information |
| **Household subsystem** | |
| Household demographics | Age, gender, marital status, occupation, labour contribution |
| Household assets | Type of housing and roofing material, type of toilet, means of transport, production equipment and type of land tenure (rented, owned) |
| Production knowledge and adoption | Years growing maize and various legumes, crop variety knowledge, sources of information and seed, seed quality, adoption and disadoption |
| Plot characteristics | Plot size, intercropping and crop rotation specifications, plot area, soil characteristics (slope, depth, soil type) |
| Field management | Residue management and tillage, input use, weed control |
| Coping strategies | Strategies for addressing risk factors including drought, pests/diseases, price fluctuations (e.g. sell livestock, eat less, pull children out of school) |
| Yield-related outcomes | Maize and legume variety performance including agronomic (grain and cob size, disease and pest tolerance, etc.), cooking and utilisation (storability, cooking time, taste, nutritional value), total volume harvested |
| Utilisation of crop residues | Total production of crop residues (kg) and percentage allocated to various purposes including fuel as firewood, fertiliser when left on land, feed for livestock, use as construction material or income source as a sold good |
| Grain storage | Type of maize and legume storage structure, duration of storage, amount (kg) stored and amount lost to storage, quality loss during storage (yes/no) and percentage, types of pests found in storage and types of applied storage management practices |
| Livestock production | Type and number of livestock (e.g. indigenous milking cows, cross-bred cows, mature goats) |

| Farming system component | Examples |
|---|---|
| Food availability | On a scale of constant food shortage to constant food surplus, utilisation of on-farm crop yields |
| **Community subsystem level** | |
| Membership in formal and informal institutions | Production and marketing cooperatives and farmers' associations, social networks (e.g. indices for trust with community members such as number of years living in the community, number and types of transactional and supportive relationships with individuals) |
| **Socioeconomic corridor** | |
| Markets and service access | Distance to the nearest market, the quality of the road to the nearest market and transport costs, distance to the nearest source of seed, fertiliser, herbicides and pesticides, agricultural extension office and health centre |
| **Value chain** | |
| Upstream and downstream value chain actors | Number and type of buyers (e.g. broker, farmer group, wholesaler, individual consumer) disaggregated by crop |
| **Enabling institutions** | |
| Access to financial capital, information and institutions | The type, number and sources of loans applied for and received (e.g. loans for seed, fertiliser, investment in seed drill) |
| Access to extension services and trainings | Type/focus of extension services (e.g. crop varieties, integrated pest management, soil and water, weather forecasts, livestock, family health) and their main source (e.g. government, non-profit NGOs, private companies, mobile phone) |
| **Output markets** | |
| Seasonal maize sales | Marketability (demand), output price, price, quality, disaggregated by season |
| Livestock value | Value of livestock, quantity sold within the survey year |
| Livestock products | Daily average, total quantity and value of milk |
| Alternative sources of income | Non-farm agribusiness (grain milling, trading etc.), pension, sale of goods produced on-farm or harvested (e.g. firewood and crop residues) |

The increasingly complex treatment of household production systems required diversity studies to accommodate a much broader suite of farming system characteristics. Various theories of development were put forth to establish priorities when selecting variables for classifications. These were largely informed by emerging development patterns and goals (e.g. food security). For instance, the World Bank (2007) suggested that diversity in four main farming system dimensions was critical to understand household development processes. These dimensions were:

1. food production for household income generation
2. reduction in real food price associated with increased agricultural output
3. empowerment of women as instrumental agents to support household food security and health outcomes
4. the indirect relationship between increasing agricultural productivity and nutrition outcomes via contribution to national income and macroeconomic growth.

Hoddinott (2012) suggested typologies based on six development pathway elements involving changes in:

1. household income
2. crops, farm practices and markets
3. crop varieties and production methods
4. use of time
5. savings
6. intrahousehold resource allocation.

Other approaches to selecting classification criteria have been based on evidence from farm and village walks (Afroz et al. 2016) and feedback from participatory modelling exercises (Rodriguez et al. 2013). As an example, Afroz et al. (2016) collected data for classifying household farmers through group discussions and informal conversations. The authors conducted key informant interviews, collecting personal narratives and recording direct observations over a period of 2–3 months annually for two years. Tittonell et al. (2005a, b) used a participatory exercise with households from western Kenya. The authors found that the variables that households considered most relevant for classification (indicators of 'wealth' and 'farm management') varied across communities. For instance, the importance of access to information, education levels, family size and type of housing varied across districts and localities (Tittonell et al. 2005a).

Multivariate analysis of a wide range of farming system variables provides an alternative approach to selecting classification criteria directly. Rather than applying a-priori variables based on various theories of development, statistical methods like PCA followed by cluster analysis offer analytical tools for identifying and classifying households by major sources of variability. PCA identifies latent variables that explain the majority of variance among households. PCA has therefore been a common method for identifying classification criteria that reflect the major disparities of the community. Cluster analysis is typically used to classify households after identifying the classification criteria. The empirical nature of this approach has provided flexibility for application across different farming system contexts, while also offering a standardised method to support comparative studies. At the same time, the analysis still draws from development theory to inform the data considered for collection and interpretation of results. Households from the following SIMLESA case study chapters (Chapters 4–8) were classified through this method. The household survey used for data collection and subsequent identification of latent variables and household classification is described in the sections that follow.

## 3.3 DATA COLLECTION AND ANALYSIS TOOLS

### 3.3.1 The household survey instrument

The survey instrument captured data related to farming system characteristics (Figure 1.2) falling under climate, input markets, household subsystem, community subsystem, socioeconomic corridor, value chain, enabling institutions and output market categories (Table 3.1). Most of the questions were designed to capture the state of the farming system from 2010–11, generating a ‘snapshot in time’ of household performance. The generic survey was adapted to fit country-specific farming system components and metrics, while maintaining the consistency required for comparable evaluations of the five SIMLESA countries. Household data were collected by trained enumerators using a structured questionnaire under the supervision of socioeconomists. Teams of enumerators were trained in household survey techniques to establish reliable and consistent data collection procedures. Enumerators identified and selected household heads or (in their absence) senior household members well versed in farming activities as survey respondents.

### 3.3.2 Household selection

The first step in establishing the SIMLESA project household typologies was to generate a set of empirical data from household surveys. Household selection began with purposive sampling based on criteria set by the scope and question of the study (see previous section). First-stage household selection criteria were based on maize production potential and the agroecological conditions. To capture diversity in the structural factors that could influence livelihood strategies, household selection was stratified across agroecologies and socioeconomic units (villages, parishes, markets). Identifying the scale that was selected for stratification depended on an initial understanding of patterns of diversity across a landscape of farming systems. Community- or village-level stratification is generally regarded as a useful scale of discrimination for identifying structural factors that influence the choice of certain livelihood strategies (Kruseman et al. 2006). Distinction at the community level should, however, be based on the understanding that diversity is greater between villages than among households (Bigman and Fofack 2000). Stratification across agroecological zones was primary for the SIMLESA study because the project encompassed households spanning diverse agroecological conditions that were expected to impact the low-input farming system under evaluation. Stratified purposeful sampling at the first stage of household selection limited selection bias, allowing for a large sample of households. It also ensured that the set of households included in the study had maize production potential and spanned at least two contrasting sets of agroecological conditions.

This selection process led to the identification of households spanning multiple levels and types of governance systems (e.g. districts, tribes, farmers associations). In order to evaluate differences across communities, a subset of households from each group (stratified across communities) was then randomly selected to ensure that distinct communities were represented. At this stage, the households represented villages with vastly different population sizes. To address this, the final step for the SIMLESA project involved proportionate household sampling so that the final number of households from each village was proportional to the village size.

Box 3.3 describes the household sampling methods used in each SIMLESA case study country.

**BOX 3.3 Household sampling methods used in the SIMLESA country case studies**

Initial criteria for selecting survey households depend on the scope of the study. Household sampling for the SIMLESA country case studies spanned Ethiopia, Kenya, Tanzania, Malawi and Mozambique. As part of a program focused on maize-based farming systems, maize production and agroecology were used as primary criteria in selecting districts and villages. To establish a representative sample, households were then randomly selected across communities and at numbers proportional to the number of households in the area.

In Ethiopia, households were selected from the Southern Nations, Nationalities, and Peoples' Region (SNNPR) region and western parts of Oromiya, where maize–legume-based farming systems are most common. In the first stage of household selection, nine districts (five from Oromiya, three from SNNPR and one from Benishangul) were purposely selected: Bako Tibe, Gubuesyo, Shala, Dudga, Adami Tullu, Mesrak Badawacho, Meskan, Hawassa Zuria and Pawe. Seven of these districts (Shala, Dudga, Adami Tullu, Mesrak Badawacho, Meskan and Hawassa Zuria) were located in a low-potential agroecological zone, with characteristically low and erratic rainfall; while the remaining districts fell under a high-potential zone with adequate rainfall. In the second stage a total sample of 69 farmer associations was selected randomly with population proportional to size of the association (i.e. proportionate sampling). A total of 896 households were selected to be interviewed; of these about 11.25% were female-headed.

In Kenya, a three-stage sampling procedure was used to select study households from western and eastern Kenya. First, the districts were purposely selected followed by a second round of randomised household selection within administrative divisions. Of the selected divisions, lists of villages were created from which 88 villages were sampled. This was proportionate to the number of villages in the division. For the sampled villages, a random sample of households was selected proportional to the number of households in the villages. A total of 613 households were sampled; 494 were male-headed and 119 were female-headed.

In Tanzania, the survey targeted two districts in the eastern zone: Kilosa and Mvomero. In the northern zone, the study covered the Mbulu and Karatu districts. Mbulu and Karatu districts are classified as high-potential areas, while Mvomero and Kilosa are classified low-potential.

For the Malawi country case study, households from the Central and Southern regions were selected. In the Central region the districts surveyed were Lilongwe, Kasungu, Mchinji, Tcheu and Salima, while in the Southern region only Balaka district was surveyed. Purposive sampling considering maize production potential and agroecological conditions was then used in combination with stratified sampling to arrive at six districts: five in the Central region (Lilongwe, Kasungu, Mchinji, Salima and Ntcheu) and Balaka in the south. Three districts in the Central region (Lilongwe, Kasungu and Mchinji) fall under a high-potential area while the remaining two (Salima and Ntcheu) and Balaka in the Southern region fall under a low-potential area. Multistage random sampling combined with probability to proportional size sampling methods were then used to get 64 extension planning areas (EPAs), 89 sections and 235 villages. The same procedure was again used to get 891 households from the 235 villages; about 16% of these were female-headed.

A combination of purposive and stratified sampling methods was also applied in Mozambique to select households spanning four districts (Sussundenga, Manica, Gorongosa and Angonia) and 154 villages. Two of the districts (Sussundenga and Manica) are situated in the province of Manica, while Gorongosa and Angonia are found in the provinces of Sofala and Tete, respectively. A multistage random sampling procedure was used to select households from a list prepared from each district. Based on the selected villages, proportionate household sampling was used to identify the households that were interviewed. A total of 510 households were targeted for the survey, of which 348 were male-headed, i.e. about 68.2% of the sampled population.

## 3.4 HOUSEHOLD DATA ANALYSIS: IDENTIFYING HOUSEHOLD TYPOLOGIES

This section outlines the methods that were used to carry out the case studies presented in the following chapters. Examples are provided when outlining each step of the analysis to help demonstrate the approach taken. This review therefore offers a practical guide for carrying out similar analyses on other datasets. All analyses can be accomplished through the use of appropriate packages using the open-source and freely available R statistical working environment (R Development Core Team 2011). The R-based code that was developed to run the analysis described is available as detailed in the appendix of this publication.

### 3.4.1 Regional comparisons within countries

Following survey administration and data collection, multivariate and data mining techniques were applied to compare agroecological regions. Summary statistics and plots of frequency distributions were used to evaluate the diversity present in the raw household data. The comparisons began with a set of primary household characteristics that were of interest. These are enumerated in Table 3.2 and include major assets or productive resources (e.g. land-to-labour ratios, numbers of cattle owned), economic outcomes and activities (e.g. household total annual income, proportion of annual income from farming, total annual household expenditure, total annual expenditure on food). Box plots were used to display and evaluate regional differences. Comparisons that showed evidence of regional differences were reported in each case study.

**TABLE 3.2** Variables subject to descriptive and exploratory analysis to inform variable selection for cluster analysis

| Variable | Units | Description |
|---|---|---|
| Size of household | man equivalents (ME) or adult equivalents (AE) | Calculated from household demographics (number, age and gender), reflects the availability of labour from within the household |
| Age | years | Age of the household head, reflects the position of the household along the farm development cycle |
| Education | years | Formal education followed by the household head, reflects the household's ability to access information |
| Productive assets | 1000 relevant currency | Value of all material assets used for farm production, reflects household wealth and the degree of investments in farm production |
| Household assets | 1000 relevant currency | Value of all major household furniture, reflects the wealth of a household |
| Farm size | hectares (ha) | Area of land owned by the household |
| Cultivated area | hectares (ha) | Total area cultivated by the household |
| Maize area | hectares (ha) | Area under maize cultivation |
| Sheep and goats | head | Total number of sheep and goats owned by the household |
| Cattle | total livestock units (TLU) | Size of the cattle herd owned by the household, calculated by assigning different weights to the types of animals |

After the regional comparisons, variables that reflected key indicators of farm development were selected and included in a PCA. The aim of this PCA was to narrow the total number of variables (by eliminating co-variables that were heavily correlated) and identify major sources of disparity within regions. These sources served as classification criteria for assigning households to typology groups (via cluster analysis).

### 3.4.2 Principal component analysis to select classification criteria

Principal component analysis was performed locally for each site (i.e. within each country) using normalised varimax rotation (Kaiser 1958)—see Box 3.4 for discussion. The variables that were included in the PCAs were country-specific, based on an initial exploration of data (see previous section on regional comparisons). Specifically, this represented variability among key indicators (e.g. representing productive assets, socioeconomic factors, market connectivity, farm investment and income). For PCAs, 9 variables were included in Kenya, 19 in Mozambique, 22 in Malawi, 21 in Ethiopia and 17 in Tanzania. Outputs from the PCA included eigenvalues and PC loadings. Eigenvalues were used to determine the number of PCs retained, based on eigenvalues that were greater than 1 (Walker and Madden 2005; Osborne and Costello 2009). PC loadings were used to identify a single variable (i.e. with the highest loading) to represent retained PCs and thus allow data reduction (Walker and Madden 2005). This process produced variables that were strongly correlated within the PC (i.e. high loadings for the same PC). These variables were omitted from the subsequent cluster analysis to avoid extreme multi-collinearity and singularity. Some of variables that were excluded at this stage were later considered in characterising clusters of households.

**BOX 3.4 Principal component analysis for data reduction, and the surrounding debate**

Principal component analysis is one of the most popular methods for survey data reduction. It is a kind of regression analysis that helps identify collinearity of variables, thereby allowing for a reduction of variables used to represent diversity of a dataset (Walker and Madden 2005). PCA is often confused with factor analysis (particularly exploratory factor analysis) though the two are distinct in a number of ways (Fabrigar et al. 1999; Walker and Madden 2005; Osborne and Costello 2009). Three aspects of PCA often cause controversy when applied to survey data: whether required assumptions are met, the type of rotation used, and the criteria for retaining PCs. Assumptions of PCA include:

- data are normally distributed
- data are continuous numeric only
- no specification error (i.e. no irrelevant variables)
- sufficient sample size (at least 100 observations and at least five observations per variable).

Beyond satisfying the above, factors can be orthogonally rotated prior to extraction in order to improve parsimony (i.e. reduce number of variables with high loadings in a single PC). This is best achieved through varimax rotation (Kaiser 1958). However, some statisticians argue that this method is simplistically chosen over others and not always as appropriate as ‘oblique’ (e.g. ‘quartimin’) rotation (Fabrigar et al. 1999).

Finally, the number of PCs retained for further analysis is often a matter of dispute. Most typically, studies have retained all components with eigenvalues above 1, though some statisticians have criticised this approach, advocating instead for the use of scree plots to define a ‘bend or break point’ where eigenvalues decrease at a lesser rate (Walker and Madden 2005; Osborne and Costello 2009). Once the principal components being retained have been identified, they can themselves be represented by highly correlated observed variables. A widely accepted and common practice has been to simply use a single observed variable with the highest loading for each PC. This results in a reduced list of observed variables for subsequent analysis.

Figure 3.1 and Table 3.3 provide an example of PCA results from two regions included in the Kenya case study. In the example, variables representing the first five components were used in subsequent cluster analysis. PCA of the household data (analysed separately for western and eastern Kenya) indicated that the first two PCs accounted for a large proportion of the dataset variability (35% and 22% for western and eastern Kenya respectively). Additional PCs accounted for a decreasing (but still significant) share of the total variability (Figure 3.1). In order to ensure a greater capacity for household characterisation, all five PCs were retained for subsequent cluster analysis in the Kenya case study. Each PC was represented by the single variable with the highest loading value (Table 3.3). Table 3.3 provides the list of the first five factors (and loading values) that were retained in this process. In both regions, land area (farm size and cultivated area) accounted for (i.e. had the highest loadings) in the first PC, which represented the largest amount of dataset variability. Aside from land area, both sites had PCs with highest loading values for household size (i.e. man-equivalents) and the number of sheep and goats owned. In western Kenya, other PCs were highly correlated with education and household assets, while for eastern Kenya other PCs were related to maize area and cattle owned (Table 3.3). These variables were subsequently used to assign households to typology groups in cluster analysis.

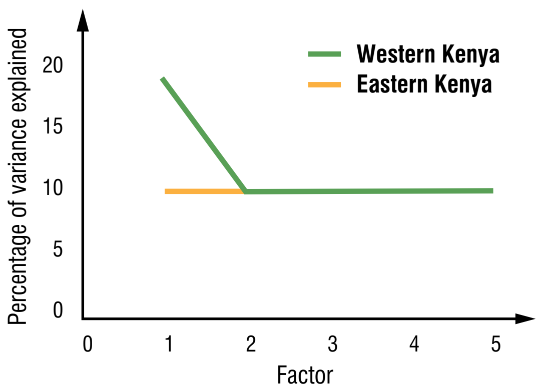



**FIGURE 3.1** Percentage of variance (derived from PC eigenvalues) explained with each of the first five PCs (factors) for eastern and western Kenya.

**TABLE 3.3** PC loadings for observed variables and eigenvalues for the first five principal components in western and eastern Kenya

| Site/variable | PC 1 | PC 2 | PC 3 | PC 4 | PC 5 |
|---|---|---|---|---|---|
| **Western Kenya** | | | | | |
| **PC loadings** | | | | | |
| Man equivalents | | | | –0.23 | 0.98 |
| Age (years) | 0.11 | | | | 0.12 |
| Education (years) | | | | 0.97 | |
| Productive assets (KSh) | | | | | |
| Household assets (KSh) | | 0.98 | | | |
| Farm size (ha) | 0.93 | | 0.15 | | |
| Cultivated area (ha) | 0.43 | 0.22 | 0.14 | | |
| Maize area (ha) | | | | | |
| Sheep or goats (head) | | | 0.11 | | |
| Cattle (TLU) | 0.14 | | 0.97 | | |
| **Eigenvalues** | 1.091 | 1.028 | 1.010 | 1.009 | 1.007 |
| **Eastern Kenya** | | | | | |
| **PC loadings** | | | | | |
| Man equivalents | 0.98 | | | | |
| Age (years) | | | –0.19 | | |
| Education (years) | | | 0.98 | | |
| Productive assets (KSh) | | | | 0.22 | 0.12 |
| Household assets (KSh) | | | | 0.96 | |
| Farm size (ha) | 0.14 | | | 0.12 | 0.11 |
| Cultivated area (ha) | | | | | |
| Maize area (ha) | | | | | |
| Sheep or goats (head) | | 0.99 | | | 0.11 |
| Cattle (TLU) | | 0.12 | | | 0.97 |
| **Eigenvalues** | 1.004 | 1.003 | 1.001 | 1.001 | 0.100 |

### 3.4.3 Cluster analysis for household group assignments

Cluster analysis applied the variables that were identified in the PCA as classification criteria for assigning households to more homogeneous groups. The variables retained through PCA (described above) were used in a hierarchical clustering analysis employing Ward's minimum variance linkage method (Murtagh and Legendre 2014). The case studies applied the Euclidean distance method to calculate the distance matrix prior to clustering (Gong and Richman 1995; Mimmack et al. 2001). Ward's minimum variance method is an agglomerative clustering algorithm that approaches clustering as a kind of analysis of variance. It is suited to numerical data (i.e. as with PCA) and was selected for its utility as an explorative method to clustering. This type of cluster analysis (i.e. hierarchical) allows for greater exploration of the data as it does not require a predetermined number of clusters to be formed, and begins with each observation (in our case, household) belonging to its own cluster. Clusters are subsequently joined through minimal distance to each other until only one cluster remains. The number of clusters in the case studies was determined by visual inspection of the dendrograms (Figure 3.2). The number of clusters per site was based on a preference for 2–4 clusters per site, aiming for relatively similar number of households per cluster. Clusters equated as functional household typologies (farm types) in our analysis. This method generated groups of households with the highest levels of similarity along the subset of farming system dimensions that accounted for the majority of variance in the region. By organising households in this way, the typologies (i.e. household groups) highlighted regional disparities.

The typology groups were subsequently characterised through a comparison of medians of:

1. all variables from the local PCA analysis
2. selected 'key' variables included for all sites/countries.

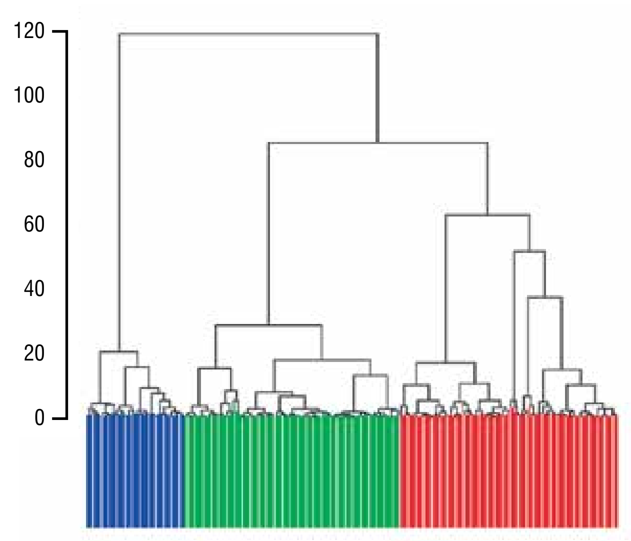



**FIGURE 3.2** Dendrogram output of Ward's hierarchical cluster analysis of household data in eastern Kenya using Euclidean distance as a similarity measure; three clusters delineated by colour.

### 3.4.4 Comparing household typologies at the national level: livelihoods and options

After local cluster analysis was completed for each region (in each country), the resulting typologies were compared and contrasted at the national level using heatmaps of key variables (Table 3.4). Variables used to compare typologies at the national level included those relating to:

1. food security—defined in our analysis as indicators of household food availability (Frelat et al. 2015)
2. socioeconomic indicators
3. economic outcomes.

Typologies were grouped based on their relative values of these key variables using the following guidelines.

- Food-secure/insecure households were separated by relative indices of food availability with consumption equivalent being the most important factor.
- Based on *relative* education, typologies were labelled ‘less educated’ or ‘educated’.
- Typologies were considered ‘off-farm workers’ if median off-farm income was relatively high while income from crops or other farming was relatively low.
- Typologies were considered ‘market-oriented’ farmers if they had relatively high incomes from farming activities.
- Typologies were called ‘diversified’ if their relative income was comparable among multiple sources.
- Typologies were considered ‘high income’ if median total annual income was in the top half of the observed range for the country, otherwise they were labelled as ‘low income’.

Similar typology groups were identified and labelled into livelihood groups based on the above classifications and these were used to inform discussion on the nature of livelihoods (Dorward et al. 2009) and options in each country.

**TABLE 3.4** Details of variables used in national-level analysis of household typologies in order to identify livelihoods and options

| Variable group | Variables included | Units |
|---|---|---|
| Food security (green) | Land owned | ha |
| | Livestock owned | total livestock units |
| | Consumption equivalent | kcal/adult equivalent/year |
| Socioeconomic factors (red) | Education | years of schooling for household head |
| | Distance to markets | minutes walking to seed or main market |
| | Proportion of women | percentage of households with female heads |

| | | |
|---|---|---|
| Economic outcomes (blue) | Income from crop sales | annual net income from crops |
| | Income from off-farm work | annual net income from off-farm work |
| | Income from non-crop farm sales | annual net income from non-crop farming |
| | Total household income | annual net income from all sources |

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# SECTION 2

## CASE STUDIES

# ETHIOPIA

ERIN LYNN WILKUS, CASPAR WILL ROXBURGH, PASWEL MARENYA, MOTI JALETA, ADAM BEKELE AND MENALE KASSIE

# KEY POINTS

- The 721 households included in this case study spanned four agroecologies in Ethiopia: the Central Rift Valley, subhumid, humid and semi-arid regions.
- The productive assets, constraints and market orientation of households varied across agroecologies.
  - Households from the humid region had more productive assets with larger land area under cultivation, and more labour and livestock than households from the other agroecological regions.
  - Households from the Central Rift Valley and the semi-arid regions faced the greatest challenges to production (smaller farm plots) and sales (located further from markets).
  - Household from the Central Rift Valley depended less on income from agricultural activities and more on off-farm income compared to households from the other regions.
- Local disparities in household asset values were found in all four regions. Other sources of variability were region specific.
- Households fell into two to five distinct groups (i.e. typologies) within each agroecological region based on characteristics that reflected local disparities.
- Seven livelihood strategies, based on food availability, social mobility and market orientation, were represented among farmer groups in Ethiopia:
  - groups with high food availability:
    - socially mobile, commercial farmers (1%)
    - socially mobile, off-farm workers (22%)
    - socially immobile, off-farm workers (16%)
    - socially immobile, low-income households (24%)
  - groups with low food availability:
    - socially immobile, low-income households (27%)
    - socially mobile, low-income households (9%)
    - socially mobile, off-farm workers (1%).
- Households that were best positioned for intensification of on-farm production:
  - had human and financial capacity advantages to intensify field management activities and invest in productivity-enhancing technologies
  - would likely benefit from access to agricultural inputs.
- The most at-risk, food-insecure groups would likely benefit from access to land and new markets for young and educated job seekers and old households.

## 4.1 COUNTRY OVERVIEW

Ethiopia is on the Horn of Africa, and landlocked by Eritrea to the north, Djibouti to the north-east, Somalia to the east, Kenya to the south and South Sudan and Sudan to the west. In 2016, Ethiopia was home to approximately 89.8 million people (Schwab 2017). It was ranked 109 of the 138 countries evaluated by the World Economic Forum in 2016–17 based on the Global Competitiveness Index (Schwab 2017). This ranking reflects the high number of households that could not meet their basic needs in 2016. The country ranked particularly low in factors related to poverty and food insecurity, including infrastructure, health and primary education. A major challenge in addressing these issues has been reaching the 81% of the population that lives in rural areas of the country, who are mainly household producers (World Bank 2015). Agricultural production statistics from 2010 found that household producers accounted for approximately 95% of agricultural GDP (Chanyalew et al. 2010). Various agroecological and socioeconomic factors have presented challenges to production and food security, many of which are found in the Central Rift Valley, semi-arid, subhumid and humid regions, areas where this case study is focused (Figure 4.1). The Central Rift Valley and the semi-arid region are broadly classified as low agroecological potential regions, and the humid and subhumid regions are considered high agroecological potential regions.

The Central Rift Valley region is a closed river basin in central Ethiopia. In a survey of >10,000 households, average (2004–09) yield gap estimates for maize in the Central Rift Valley ranged between 4.2 and 9.2 t/ha (Getnet et al. 2015). In 2014, food security in many areas of this basin was considered stressed or in a state of crisis (WFP 2014). The households that represent the Central Rift Valley in the case study presented here were in the Adami Tullu woreda (district) of Oromiya and the Meskan woreda of SNNPR, about 168 and 133 km south of Addis Ababa, respectively. The most recent census from 2007 estimated the population of the Adami Tullu woreda at 141,405 with 85% living in rural areas (IHSN 2007). Water and pasture shortages in Adami Tullu, which occurred with high frequency over the last decade, have been linked with major losses in crop production and livestock for household producers in this region (WFP 2014). The total population of Meskan woreda in 2011 was estimated at around 174,647, of which 92% were engaged in agriculture and 71% felt seasonally food-insecure (Duguma 2015). Duguma (2015) provided evidence that major production challenges in Meskan increased household dependence on market exchange of livestock and off-farm activities. These challenges included erratic rainfall with delayed onset, early cessation or insufficient quantity or distribution of *belg* (the short rainy season in the spring) or *kiremit* (or *meher*, the long rainy season in the summer) (Duguma 2015).

The semi-arid region is located south of the Central Rift Valley region. The households that represent the semi-arid region in this case study were in the Shala woreda of the Oromiya Region and the Awasa Zuria and Mesrak Badawacho woreda of SNNPR. The 2007 national census estimated the population of Shala at 149,804 with 87% residing in rural areas (IHSN 2007). The 2007 national census estimated the population of Awasa Zuria at 124,472 with all living in rural areas and the Misrak Badawacho population at 142,823 with 89% residing in rural areas (IHSN 2007).

Conversion of most of the land from forest and grazing to cropland has left little room for further agricultural expansion in the Central Rift Valley and semi-arid regions (Getnet et al. 2015). Approximately 40,000 hectares of land in the Awasa Zuria woreda was converted from forest to farmland between 1972 and 2000, leaving just 2.8% of land forested (Dessie and Kleman 2007). Under these conditions, intensification of production systems provides a promising avenue for exploring food security and poverty eradication strategies.

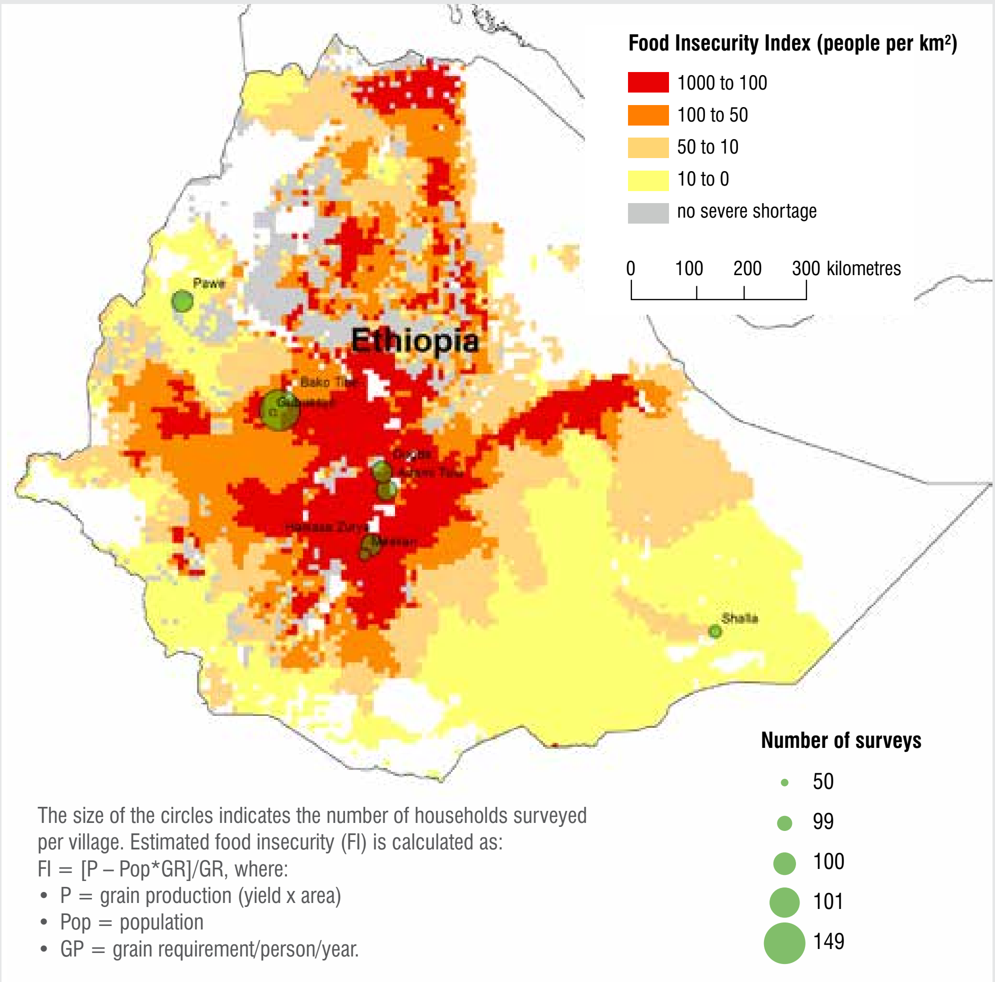


**FIGURE 4.1** The distribution of the surveyed farms in Ethiopia (n = 721) on a map showing the frequency of food insecurity (FFI)

Potgieter et al. 2013.

The high-potential subhumid and humid regions of Ethiopia are located further north-west. Households that were surveyed from the subhumid region were located further north than the other households, in the Pawe woreda of Benishangul-Gumuz. The 2007 national census estimated the population of Pawe woreda at 45,552 with 78% living in rural areas (IHSN 2007). Although agroecological conditions for the Pawe woreda suggest that the region has high production potential, average maize yield estimates for the subhumid region were between 2.0 and 2.5 t/ha in 2010, substantially lower than the estimated attainable yield of 3–4 t/ha (Fischer et al. 2014). Furthermore, severe yield losses from late-onset rains in 2010 demonstrated the vulnerability of household producers to climate stresses in this part of the country (Zappacosta et al. 2010). Households that were surveyed from the high-potential humid region resided about 200 km west of Addis Ababa in the Bako Tibe and Gobu Seyo woredas of Oromiya. The 2007 national census estimated the population of Bako Tibe and Gubuesyo at 123,031 (81% rural) and 41,012 (88% rural) respectively (IHSN 2007). In 2014, approximately 48% of households in Bako Tibe were food-insecure (with food security defined as 2,100 kcal available per adult equivalent per day) (Jirane 2015). The most recent available estimates from 2011 were that 37% of households were food-insecure in Gobu Seyo (Keneni 2011).

## 4.2 REGIONAL DIFFERENCES

Most households from the Central Rift Valley and the semi-arid region had comparable farm sizes, consumption equivalents, and access to similar levels of labour (Figure 4.2). Central Rift Valley and semi-arid households had small farms and large families relative to most households from the subhumid and humid regions. Consequently, households in the Central Rift Valley and semi-arid regions had low land:labour ratios relative to those in the subhumid and humid regions. Most Central Rift Valley and semi-arid households had to walk further to access output markets than those from the subhumid and humid regions. This suggests that Central Rift Valley and semi-arid households faced greater challenges to selling commodities produced on-farm than most households from the other groups.

Although most Central Rift Valley and semi-arid households had comparable farm sizes, those in the semi-arid region had more land area with fertile soil and more livestock. Perhaps due to the relatively small land area under cultivation and fraction of fertile soil, off-farm activities contributed more to total household income in the Central Rift Valley compared to all other regions. In contrast, income generated through farming was the only source of income for most households in the humid and subhumid regions, and contributed just under 90% of total incomes to most semi-arid households. This suggests that agricultural activities were less critical to the livelihood strategies of most households from the Central Rift Valley compared to most households from the semi-arid, subhumid and humid regions.

Key productive resources (i.e. land and labour) were higher in the more productive regions. Most households in the subhumid areas had large farms and small families relative to most households in the other regions. However, these households had access to less labour, and consequently higher land:labour ratios than the other regions. Households in the humid region also had large farms relative to the Central Rift Valley and semi-arid households; however, in contrast to the subhumid region, most households in the humid region had access to more labour and therefore land:labour ratios comparable to most households in the Central Rift Valley and semi-arid regions. Households in the humid region also had more fertile soil than those in the Central Rift Valley, semi-arid region and especially the subhumid region (where households reported no fertile soil). Finally, households in the humid region had more livestock and estimated their total asset value above the estimates of most households in the other areas.

Overall, households in the Central Rift Valley and the semi-arid regions faced greater challenges to production (smaller farm plots) and sales (located further from markets) of household crops compared to households in the subhumid and humid regions. Agricultural activities contributed less to household incomes in the Central Rift Valley than the other regions. Labour was more limiting in the subhumid regions than other regions. The humid region had the most desirable mix of productive assets with more land (including fertile land), labour and livestock and desirable land:labour ratios of all the regions.

## 4.3 HOUSEHOLD TYPOLOGIES

Households within each of the four regions were classified into groups based on characteristics that accounted for the largest disparities (i.e. variance) in the region. Household asset value disparities were

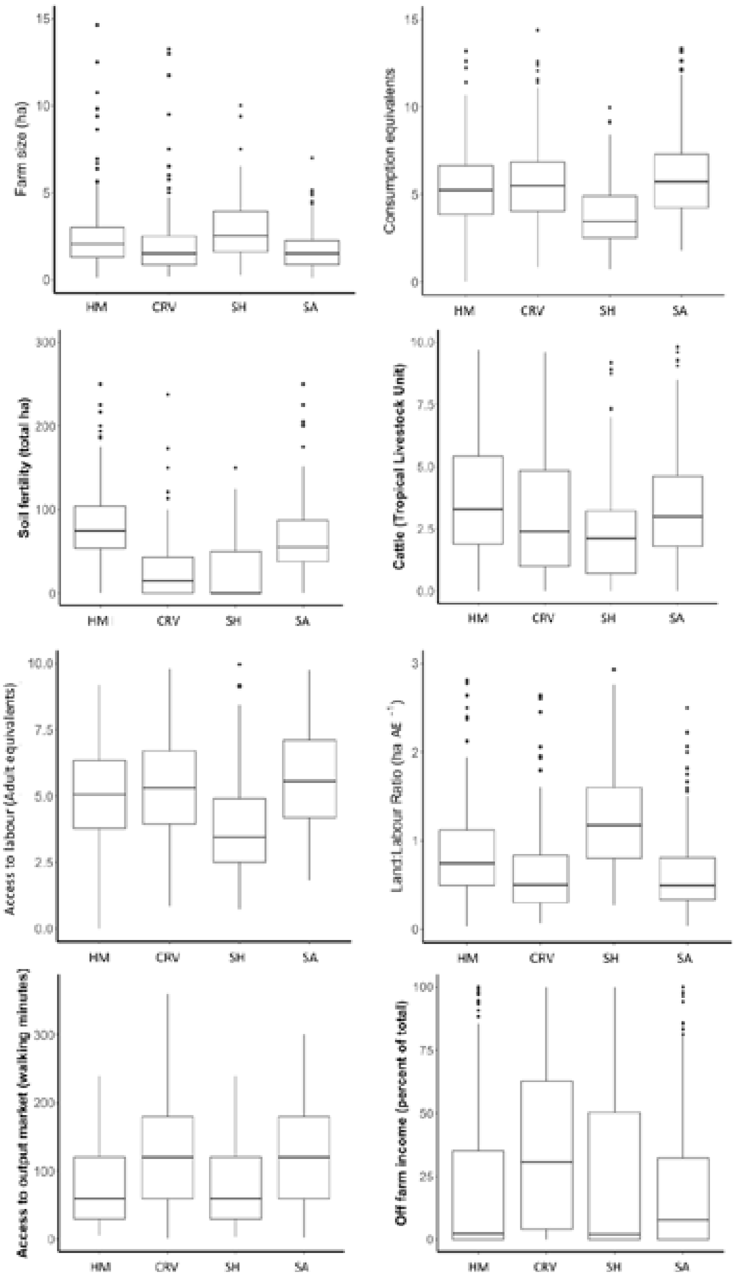


**FIGURE 4.2** Regional comparisons of farming system characteristics. Median farm size (ha), consumption equivalents, access to labour, land:labour ratios, land area with fertile soil, cattle (TLU), access to output markets (walking minutes) and off-farm income across household producers in the humid (HM), Central Rift Valley (CRV), subhumid (SH) and semi-arid (SA) regions of Ethiopia. Box = 25th and 75th percentiles; bars = minimum and maximum values.

identified in all four regions. Aside from total asset value, major sources of variability among households depended on the region. Household groups in all four regions were therefore established based on household asset values and local sources of variability.

### 4.3.1 Central Rift Valley

Major disparities in the Central Rift Valley were in household asset value, experience growing maize and access to markets and water. Households from this region fell into two groups (CRV1 and CRV2) based on these characteristics. Most CRV2 households had more livestock and valued their total asset value above that of CRV1 households (Table 4.1). CRV2 households were also more likely to have a female head of household. Nearly half of the CRV2 households had female heads of household while none of the CRV1 households were female-headed. Evidence that the high asset group was more likely to have a female household head might indicate that female household heads were more likely to save money and keep livestock. Saving patterns might also however be a reflection of lower levels of participation in the marketplace, as these households were located further from markets than CRV1 households. Most CRV1 households also had more experience growing maize and easier access to water (based on walking distance to the nearest water source). CRV1 households also had slightly higher total household incomes than most CRV2 households.

**TABLE 4.1** Cluster medians (and standard deviations) for the cluster variables (shaded) and independent household characteristics in the Central Rift Valley of Ethiopia (n = 208)

| Cluster variables | Frequencies (%) or cluster medians (standard deviations) | | |
|---|---|---|---|
| | CRV1 | CRV2 | *P*-value[a] |
| | 66% | 34% | |
| Total assets value (birr) | 840.5 (2,822.8) | 1,103.0 (23,895.5) | 0.000*** |
| Total livestock units (TLU) | 2.7 (8.7) | 4.7 (34.0) | 0.000*** |
| Experience growing maize (years) | 20.0 (13.5) | 17.5 (10.6) | 0.000*** |
| Man equivalents | 2.6 (1.5) | 2.8 (1.7) | 0.48 |
| Technology factor | 29.0 (18.6) | 29.0 (18.7) | 0.77 |
| Distance to water (walking minutes) | 10.0 (16.6) | 15.0 (32.1) | 0.000*** |
| Distance to seed markets (walking minutes) | 30.0 (29.9) | 60.0 (75.5) | 0.000*** |
| Female-headed (%) | 0 | 46 | 0.000*** |
| Age (years) | 40.0 (13.9) | 40.0 (10.4) | 0.104 |
| Education (years) | 3.0 (3.3) | 2.0 (3.6) | 0.639 |
| Household income (birr) | 6,510.0 (10,118.9) | 6,307.5 (33,966.48) | 0.035* |
| % income from crops sales | 37.0 (30.2) | 41.9 (30.7) | 0.998 |
| % off-farm income | 32.7 (33.0) | 20.6 (34.7) | 0.909 |
| % income from 'other' | 14.4 (26.5) | 13.3 (27.2) | 0.888 |

[a] ANOVA test (*, **, *** for *P*-value <0.05, 0.01 and <0.001 respectively)

### 4.3.2 Subhumid region

The major disparities in the subhumid region were in household access to labour, education levels, access to markets, and drought histories. Households from this region fell into four groups (SH1, SH2, SH3, SH4) based on these characteristics. SH2 was the high-income cluster in the subhumid region. SH2 households estimated their total asset value and household income at least 10 times above the estimates of most households from the other groups (Table 4.2). SH2 households also had access to more labour (represented as man-equivalents) than others although this group did not have the highest education level. SH1 households also valued their total household assets above SH3 and SH4, however this value was still far below that of SH2 households.

**TABLE 4.2** Cluster medians (and standard deviations) for the cluster variables (shaded) and independent household characteristics in the subhumid region of Ethiopia (Benishangul-Gumuz and Benshangul, n = 100)

| Cluster variables | Frequencies (%) or cluster medians (standard deviations) | | | | |
|---|---|---|---|---|---|
| | SH1 | SH2 | SH3 | SH4 | *P*-value[a] |
| | 33% | 10% | 49% | 8% | |
| Total assets value (birr) | 1,740.0 (1,600.7) | 13,608.5 (3,571.2) | 1,100.0 (2,103.2) | 1,123.5 (909.4) | 0.000*** |
| Drought frequency | 0.0 (0.29) | 0.0 (0.85) | 0.0 (0.67) | 0.0 (0.0) | 0.06* |
| Experience growing maize (years) | 14.0 (9.1) | 11.5 (4.8) | 19.0 (10.0) | 7.0 (3.3) | 0.000*** |
| Education (years) | 0.0 (1.9) | 2.5 (3.6) | 0.0 (1.5) | 9.0 (8.9) | 0.000*** |
| Man equivalents | 2.0 (0.9) | 3.2 (0.9) | 1.9 (1.3) | 1.8 (0.5) | 0.034** |
| Distance to fertiliser markets (walking minutes) | 60.0 (82.4) | 60.0 (47.5) | 45.0 (58.1) | 25.0 (17.1) | 0.016** |
| Distance to household plots (walking minutes) | 30.0 (23.1) | 20.3 (14.2) | 18.3 (12.3) | 14.5 (5.9) | 0.002*** |
| Distance to output markets (walking minutes) | 120.0 (46.2) | 105.0 (47.9) | 45.0 (35.0) | 17.5 (16.1) | 0.002*** |
| Female-headed (%) | 21 | 0 | 18 | 25 | 0.218 |
| Age (years) | 38.0 (12.0) | 39.0 (6.1) | 47.0 (14.2) | 28.0 (4.6) | 0.000*** |
| Household income (birr) | 6,635.0 (11,401.4) | 20,290.5 (12,930.9) | 4,050.0 (13,092.4) | 5,207.0 (5,720.4) | 0.002*** |
| % income from crops sales | 76.8 (35.1) | 86.2 (30.2) | 69.4 (37.1) | 53.9 (41.0) | 0.503 |
| % off-farm income | 0.0 (33.9) | 0.0 (16.8) | 14.3 (37.2) | 16.8 (43.2) | 0.299 |
| % income from 'other' | 0.0 (18.1) | 13.2 (29.0) | 0.0 (18.8) | 0.0 (27.0) | 0.671 |

[a] ANOVA test (*, **, *** for *P*- value <0.05, 0.01 and <0.001 respectively)

SH3 and SH4 households had greater ease of access to fertiliser markets, household plots and output markets than most SH2 and SH1 households. Most SH4 households were positioned closer, and had greater ease of access, to these components of the socioeconomic corridor than most SH3 households. SH4 households had less experience growing maize and younger and more educated household heads than most households from the other groups. In contrast, most SH3 households were more experienced growing maize and had older household heads than most households from the other groups.

### 4.3.3 Humid region

Major disparities in the humid region were in household assets and productive resources, access to market and technology adoption levels. Households from this region fell into two groups (HM1 and HM2) based on these characteristics. Most HM2 households valued their total assets above HM1 households. HM2 households also had older household heads and greater ease of access to seed markets (Table 4.3). HM1 households were more likely to have fertile soil on their plots and lower food consumption per capita (consumption equivalent) than HM2 households.

**TABLE 4.3** Cluster medians (and standard deviations) for the cluster variables (shaded) and independent household characteristics in the humid region of Ethiopia (Bako Tibe and Gobu Sayu, n = 199)

| Cluster variables | Frequencies (%) or cluster medians (standard deviations) | | |
|---|---|---|---|
| | HM1 | HM2 | *P*-value[a] |
| | 42% | 58% | |
| Total assets value (birr) | 2,181.0 (2199.6) | 2,599.0 (8369.0) | 0.006** |
| Number of goats/sheep | 0.0 (1.1) | 0.0 (4.1) | 0.015** |
| Fraction of good fertility soils | 0.11 (0.3) | 0.0 (0.1) | 0.004*** |
| Age | 30.0 (8.6) | 42.0 (13.4) | 0.000*** |
| Consumption equivalents (CE) | 4.3 (1.5) | 6.0 (2.2) | 0.000*** |
| Technology factor | 29.0 (11.5) | 29.0 (12.1) | 0.000*** |
| Distance to household plots (walking minutes) | 8.0 (5.9) | 6.5 (10.0) | 0.165 |
| Distance to seed markets (walking minutes) | 40.0 (23.6) | 30.0 (19.5) | 0.000*** |
| Female-headed (%) | 8 | 6 | 0.543 |
| Education (years) | 3.0 (3.1) | 4.0 (3.5) | 0.151 |
| Household income (birr) | 4,969.5 (11524.0) | 6,720.0 (11487.8) | 0.201 |
| % income from crops sales | 50.7 (30.1) | 48.2 (30.4) | 0.825 |
| % off-farm income | 0.8 (25.5) | 42 (28.4) | 0.300 |
| % income from 'other' | 24.3 (28.6) | 18.8 (27.4) | 0.440 |

[a] ANOVA test (*, **, *** for *P*- value <0.05, 0.01 and <0.001 respectively)

### 4.3.4 Semi-arid region

Major disparities in the semi-arid region were in household livestock ownership, education levels (years of formal education and access to extension services), access to markets and drought histories. Households from this region were classified into five distinct groups based on these characteristics. Total asset value of households was highest in SA4 followed by SA1, SA2, SA3 and SA5. Most SA4 households had larger farms, more livestock and higher household income levels relative to the other groups (Table 4.4). SA4 and SA1 households had higher education levels than the other household groups. SA1 households had small farms relative to the other groups. Most SA3 households were more likely to experience a drought than those from the other groups. SA5 households estimated the total value of household assets below all other groups. SA5 households were also located more than two hours further away from seed markets than other household groups.

**TABLE 4.4** Cluster medians (and standard deviations) for the cluster variables (shaded) and independent household characteristics in the semi-arid region of Ethiopia (Hawassa Zuria, Misrak Badawacho and Shala, n = 214)

| Cluster variables | Frequencies (%) or cluster medians (standard deviations) | | | | | |
|---|---|---|---|---|---|---|
| | SA1 | SA2 | SA3 | SA4 | SA5 | *P*-value[a] |
| | 31% | 20% | 29% | 9% | 11% | |
| Total assets value (birr) | 2,294.0 (2,187.4) | 820.0 (2,501.3) | 715.0 (1,478.1) | 4,768.0 (11,054.4) | 427.0 (930.7) | 0.000*** |
| Farm area (ha) | 1.2 (0.8) | 1.3 (1.1) | 1.6 (1.0) | 3.6 (1.6) | 1.9 (0.7) | 0.000*** |
| Total livestock units (TLU) | 3.1 (12.1) | 3.3 (4.2) | 3.1 (31.5) | 11.0 (122.8) | 3.7 (30.9) | 0.000*** |
| Number of goats/sheep | 1.0 (3.0) | 0.0 (2.5) | 0.0 (3.2) | 0.0 (3.0) | 1.0 (8.6) | 0.06 |
| Drought frequency | 2.0 (1.2) | 2.0 (1.2) | 4.0 (1.5) | 2.0 (1.2) | 3.0 (0.9) | 0.000*** |
| Education (years) | 7.0 (3.1) | 0.0 (2.7) | 0.0 (2.5) | 5.0 (3.9) | 0.0 (2.0) | 0.000*** |
| Distance to extension services (walking minutes) | 20.0 (14.1) | 20.0 (37.0) | 20.0 (12.8) | 15.5 (16.1) | 15.0 (16.0) | 0.005** |
| Distance to seed markets (walking minutes) | 30.0 (55.5) | 30.0 (38.0) | 30.0 (31.3) | 40.0 (43.1) | 180.0 (76.0) | 0.000*** |
| Sampled population (%) | 31 | 20 | 29 | 9 | 11 | – |
| Female-headed (%) | 2 | 9 | 6 | 0 | 9 | 0.167 |
| Household income (birr) | 7,500.0 (10,363.7) | 5,680.0 (6,708.7) | 4,208.5 (6,952.0) | 18,660.0 (4,2271.5) | 62,97.5 (5,002.2) | 0.000*** |
| % income from crops sales | 72.9 (32.4) | 62.1 (31.0) | 66.4 (32.4) | 61.7 (27.2) | 76.1 (23.4) | 0.498 |
| % off-farm income | 4.5 (26.6) | 13.9 (28.7) | 9.4 (28.4) | 12.5 (24.6) | 4.6 (0.14) | 0.250 |
| % income from ‘other’ | 10.5 (24.7) | 1.5 (23.0) | 4.8 (24.1) | 13.3 (18.1) | 9.6 (19.9) | 0.958 |

[a] ANOVA test (*, **, *** for *P*-value <0.05, 0.01 and <0.001 respectively)

The farming system characteristics of SA2 households were comparable to other farmer groups (especially SA1 and SA3). Most SA2 households valued total household assets relatively low and at levels comparable to SA3 households. SA2 households had relatively small land areas—similar in size to SA1 households. They owned relatively few livestock (similar to the numbers found among most SA1 and SA3 households) and lived relatively far away from extension services but close to seed markets.

## 4.4 LIVELIHOODS ACROSS ETHIOPIA

Seven livelihood strategies were represented among the 13 farmer groups in Ethiopia. Food availability (based on land area, livestock and consumption equivalents) was relatively high in seven of the typology groups and low in the remaining six groups (Figure 4.3). Overall, groups with high levels of food availability had more land area under cultivation and consumption equivalents than groups with low levels of food availability. In the groups with high levels of food availability, the contribution of the components of food availability varied. Four of the groups with high food availability had large livestock herd sizes (SH2, SA4, CRV2 and HM2). Alternatively, the SA2 group had larger land area under cultivation and higher consumption equivalents but owned less livestock than the other groups.

Social mobility (based on education, proximity to markets and the probability of having a male head of household) varied among groups with high food availability. Three groups (SH2, SA4 and CRV1) were socially mobile, with a high probability of having a male head of household and moderate levels of education relative to the other farmer groups. However, all three groups were located far away from markets. The remaining four groups with high food availability were socially immobile. Of the socially immobile groups, HM2 was the only group with one well-established component of social mobility, namely education level (Figure 4.3). This variability in social mobility among groups with high food availability illustrates the range of social mobility components that can underlie food availability.

In addition to social mobility levels, market orientation (based on crop, off-farm and other farm income sources and levels of income generated through these activities) varied among the groups with high food availability. These groups included socially mobile commercial farmers (1%), socially mobile off-farm workers (22%), socially immobile off-farm workers (16%) and socially immobile low-income households (24%). The three highest income generating groups—the group of socially mobile commercial farmers (SH2) and two of the groups of socially mobile off-farm workers (SA4, CRV1)—were also more likely to have a male head of household than any other group in Ethiopia. SA4 households stood out among the groups of off-farm workers given their range of income sources. In contrast to CRV1 and HM2 which generated very little income outside off-farm work, SA4 households did generate income from crops and other farm activities in addition to generating particularly high levels of off-farm income. The remaining groups with high food availability had low incomes from either off-farm work or diverse sources. The different market-orientation types and range of income generation sources among groups with high levels of food availability demonstrates the range of economic conditions that can underlie food availability.

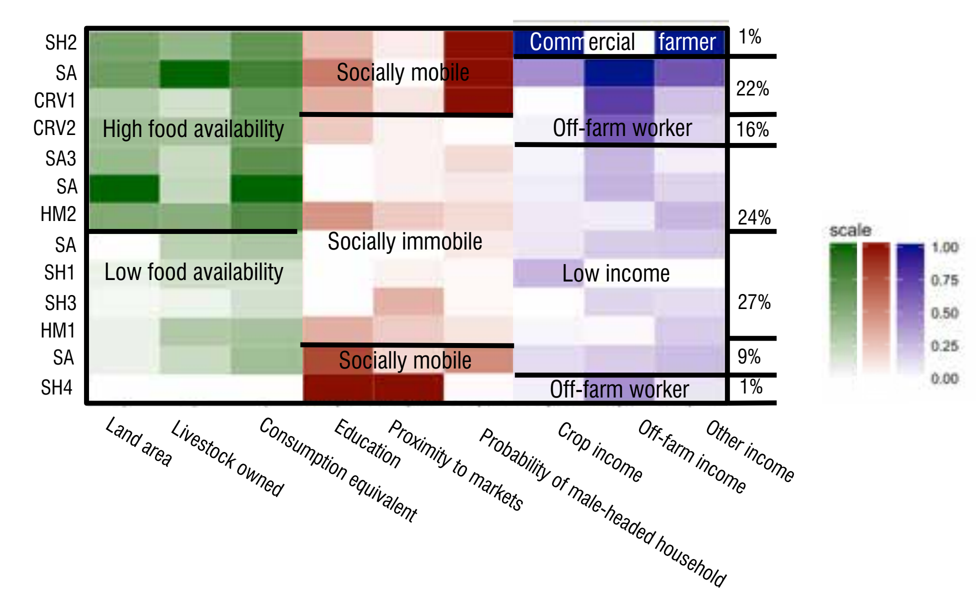


**FIGURE 4.3** Heatmap displaying relative values (based on cluster median) of farmer group characteristics and livelihood strategies from households in the humid (HM1, HM2), Central Rift Valley (CRV1, CRV2), subhumid (SH1, SH2, SH3, SH4) and semi-arid (SA1, SA2, SA3, SA4, SA5) agroecological regions of Ethiopia. The intensity of each coloured cell indicates the value of the farm system variable for a farmer group relative to the other farmer groups. Three types of farming system variables were used to characterise livelihood strategies: food availability levels (green), social mobility factors (red) and economic outcomes (blue). Food security variables were the median values for land area, total livestock units (TLU) and consumption equivalents (CE) within each group. The social mobility factors were median education level (years of formal education), distance to main markets (walking minutes) and the proportion of female-headed households within the group. Economic outcomes were median income levels from crop sales, off-farm activities, and other (non-crop) farm sales. The percentage of households represented within each livelihood strategy is indicated on the right-hand side of the livelihood description.

Food availability was low in the remaining six groups. Social mobility varied among the groups with low food availability, with four socially immobile (SA5, SH1, SH3 and HM1) and two socially mobile (SA1 and SH4) groups. The two socially mobile groups both had high education levels, that were even higher than the socially mobile groups with high food availability. However, SA1 households were more likely to have a male head of household than SH4 households. SH4 households were alternatively located closer to markets than SA1 households. Regarding market orientation, all of the groups with low food availability, except for SH4, were composed of low-income households. SH4 was the only group of off-farm workers.

## 4.5 HOUSEHOLD DEVELOPMENT OPTIONS

Differences across farmer groups in each agroecological region and the range of livelihoods across the country highlight competitive advantages and opportunities at the local and national levels that can direct household development agendas. Livelihood strategies and qualities that distinguish typologies at a local level suggest that some households were well positioned to transition out of farming, while others may be suited to invest in productivity innovations—i.e. what Dorward et al. (2009) refer to as stepping out and stepping up, respectively. Other groups could achieve food security but had certain qualities that presented barriers to investment in development—i.e. hanging-in households. The challenges faced by households from food-insecure groups reflected a unique set of needs and priorities that are discussed separately.

### 4.5.1 Stepping out

A subset of farmer groups had particularly high off-farm incomes indicating that these groups were best positioned within the country to transition out of farming. This included both groups from the Central Rift Valley (CRV1 and CRV2), one group from the semi-arid region (SA4) and one group from the subhumid region (SH4). Both groups from the Central Rift Valley had particularly high off-farm incomes relative to groups from the other regions. At a local level, CRV2 households were more productive and profitable crop producers. CRV2 households were also located further from markets than CRV1 households. CRV2 households therefore faced greater challenges to finding alternative sources of income and had more to lose from transitioning out of agriculture than CRV1 households. This local-level assessment suggests that efforts to support the transition out of agriculture among groups from the Central Rift Valley should account for the unique challenges faced by CRV2 households, e.g. those related to market access and income losses from decreased crop sales.

SA4 households had high incomes and education levels relative to the other groups in the semi-arid region. The regional advantages that SA4 households had in financial and human capital made them well positioned to establish off-farm enterprises within and beyond the region. Although food availability and income levels among SH4 households was low, this group also had characteristics that gave households a local advantage in establishing off-farm work. SH4 households had much to gain from abandoning household production. Specifically, SH4 households were younger and more educated than the other groups in the region and the country. They were therefore competitive candidates for skilled work positions in the region. Opportunities for SH4 households depend on the feasibility of entrepreneurial endeavours and the availability of rural non-farm work. Examples might include local government jobs, teaching primary school, entry level jobs or specialised work based on the individual. SH4 households were located close to output markets so they were also well positioned to enhance food security by purchasing food with income made through off-farm activities.

### 4.5.2 Stepping up

SH2 households were best positioned to invest in productivity innovations. Most SH2 households estimated their total income at around 10 times estimates from the other groups in the subhumid region (Table 4.2) and the country (Figure 4.3). Crop sales contributed approximately 86% to those incomes. Most SH2 households also had access to more labour than other groups in the subhumid region, which gave this group an additional advantage for increased production. These qualities suggest that SH2 groups had the human and financial capacity to intensify field management activities and invest in productivity-enhancing technologies. These households would likely benefit from access to more land and agricultural inputs (fertilisers, improved seed).

### 4.5.3 Hanging in

At the national level, food availability was high among SA3, SA2 and HM2 groups. These groups were composed mainly of diversified farmers with low incomes that tended to be well established. However, these groups faced certain constraints that might have limited their economic performance. Relative to the other group from the humid region, HM2 households had higher consumption per capita and were located closer to seed markets, indicating a higher level of connectivity to the socioeconomic corridor. Similarly, the SA2 group was located close to seed markets relative to other groups within the semi-arid region. This level of connectivity was the only observed advantage that SA2 household had over other groups in the semi-arid region, indicating that connectivity to markets might have been a critical component of ensuring food availability among households in this group.

Despite the relative advantages of these groups, SA2, SA3 and HM2 groups faced unique production constraints. The older age of HM2 household heads relative to the other groups in the region could have contributed to production (i.e. labour) limitations. Consequently, households might have produced at levels necessary but not beyond what was required for household consumption. SA3 and SA2 groups valued their total household assets below most households in the semi-arid region. With few liquid assets, households within these groups might be both risk-averse and/or unable to invest in major productivity innovation technologies or management practices. The SA3 group was also more likely to experience drought than any other in the semi-arid region. Most of these hanging-in households also faced challenges to gaining knowledge of opportunities to enhance productivity. For instance, the SA2 group was located relatively far from extension services. Furthermore, SA2 and SA3 represented the only groups with high food availability in the country that had no formal education. The variety of constraints faced by these groups demonstrates that efforts to support them must account for group-specific production constraints at the local level.

### 4.5.4 Risk of food insecurity

The most at-risk, food-insecure groups faced substantial challenges to reducing or eliminating that risk. These challenges largely related to having few productive resources and/or opportunities to acquire those resources. At-risk groups spanned agroecological regions. The groups included two from the semi-arid region (SA5 and SA1), three from the subhumid region (SH1, SH3 and SH4) and one from the humid region (HM1).

SA5 households estimated their total asset value below others in the semi-arid region and were located more than two hours further away from seed markets. Meanwhile, SA1 households had the smallest land area available to them for cultivation of all semi-arid groups, presenting a unique disadvantage. Similar to SA5 households, HM1 households also valued their total assets below others in their region and were located relatively far from household plots and seed markets. These disadvantages could have been major factors limiting household food security in these groups.

SH1, SH3 and SH4 households valued their assets below other groups within the subhumid region (Table 4.2). In contrast to groups from the semi-arid and humid regions, SH3 and SH4 households were particularly well connected to the socioeconomic corridor. SH4 households were located closer to markets than all the groups in their region. Although these groups were well connected, other unique SH4 household characteristics may have constrained their ability to exploit local markets. For instance, SH4 households were younger and more educated that other groups in their region. These qualities might have limited their opportunities to acquire productive assets and gain experience growing maize. With less farming experience and resources, SH4 households might have had fewer employment options in the rural economy.

Most of the older SH3 households faced a very different set of challenges to the younger SH4 households. Limited labour capacity among these households may have limited production. With this as a limiting factor, access to the socioeconomic corridor might have provided little benefit to SH3 households. SH1 households were located further from the market than SH3 and SH4 households. SH1 households were located just as far from markets as SH1 households and also valued their total assets above SH3 and SH4 households. In contrast to SH2 household, SH1 households were not particularly inexperienced or old. It is likely that isolation from the market more directly limited household food security among SH1 households than SH2 households. The diversity of challenges among food-insecure groups highlights the importance of understanding the diversity of households within a region and even within groups that have low food availability. The groups with low food availability would likely benefit from different developments. These could include access to land (SA1) and new markets (SA5, HM1 and SH1), especially for young and educated (SH4) and old (SH3) households.

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# KENYA

CASPAR WILL ROXBURGH, ERIN LYNN WILKUS, PASWEL MARENYA, MOTI JALETA AND MARTINS ODENDO

# KEY POINTS

- The 613 households included in this case study spanned areas of high and low agricultural productive potential in eastern and western Kenya.
- Households from eastern Kenya were wealthier (in both total incomes and assets) than those in western Kenya, despite lower rainfall, possibly due to greater specialisation in dairy production and richer soils.
- Local disparities in household land area under cultivation, access to labour, household sizes, livestock ownership levels and household asset values were found in both eastern and western Kenya.
- Households fell into three groups in the east and three groups in the west based on differences in characteristics that reflected local disparities.
- The wealthiest households in eastern Kenya were overwhelmingly male-headed, while the poorest households in western Kenya were more female-headed, indicating clear gender disparities.
- Four livelihood strategies were represented among the farmer groups in Kenya,
  - socially mobile, commercial farming households with high food availability and high income (39%)
  - socially mobile, diversified households with low food availability and low income (31%)
  - socially mobile households working off-farm with low food availability and low income (20%)
  - socially immobile, subsistence households with low food availability and low income (10%).
- Households with high food availability in western Kenya had relatively high income from livestock dairy production and off-farm work, while those in eastern Kenya were more evenly split between crop, livestock and off-farm production activities.
- High food availability, high-income households were positioned to benefit from transformational technology or access to new markets.
- Households with low food availability and low incomes in both regions were mostly younger and relied on a diversified livelihood strategy (i.e. both on- and off-farm income) in eastern Kenya, and were less commercially focused in western Kenya.
- Households most at risk of food insecurity would likely benefit from opportunities to increase their resource base or their production intensity of maize, the staple food.

## 5.1 COUNTRY OVERVIEW

Kenya is an eastern African country located in the eastern African Rift Valley, extending to the Indian Ocean in the south-east and Lake Victoria in the south-west. Its Nyandarua Mountains, as well as Mount Kenya, lead to a wide range of elevations and therefore climatic zones. The country has approximately 46 million people (KNBS 2009), and despite being a focal point for international development efforts since its independence (Arnold 2005) it continues to suffer poor economic conditions and low human development. For instance, Kenyan GDP in 2015 was only US$63 billion. In 2005, 49% of the rural population lived below the national poverty line (World Bank 2017). Kenya was ranked 96 of 137 countries in terms of social and physical development by the World Economic Forum, though the report did note that its rankings were high relative to other countries in SSA (Schwab 2016). For areas of agricultural significance, the country can be loosely divided into the western region and Rift Valley and the more marginal eastern and northern regions (Grace et al. 2014). The western and Rift Valley region is broadly classified as a high agroecological potential region and the eastern and northern regions are considered low agroecological potential regions. Households from this case study represent Embu and Meru counties in the eastern region (314 in total) and Bungoma and Siaya counties in the western region (299 in total) (Figure 5.1).

Food insecurity in both eastern and western Kenya suggests there are contributing factors beyond agricultural potential criteria (Figure 5.1). For specific examples of management, socioeconomic and market or policy constraints, see Chapter 2.

***Western Kenya***

In the western region the long rainy season typically starts in mid-February and ends in mid-August (FEWS 2017). Both Siaya and Bungoma counties receive bimodal rainfall with long rains falling between March and June with peaks in April and May, and short rains between August and November (Mugalavai et al. 2008).

Siaya County has altitude ranging from 1,400 to 1,140 m above sea level (masl). Ecologically, much of the land area in Siaya district falls in the lower midland agroecological zone (Jaetzold et al. 2006a) and has a humid climate (Bryan et al. 2013). Annual rainfall is between 1,100 and 2,700 mm (Bryan et al. 2013) and temperature ranges between 15 °C and 30 °C (County Government of Siaya 2017). Census data from 2009 reported 199,034 households were located in the county with a total population of 842,304 (KNBS 2009). Of these, less than 10,000 people had completed college. Census data also indicated that 173,574 people reported being self-employed in small-scale agriculture.

Bungoma County borders Uganda in the west and is located mainly within lower and upper midland zones. In 2009, the national census reported the county had 270,824 households and a population of 1.4 million people (KNBS 2009). Just under 23,000 people had completed college according to census data. Altitude ranges from 1,200 to 1,800 masl, and average temperatures range from 16 °C to 30 °C with a county average of 23 °C. Between 1983 and 2010, annual rainfall in the county ranged from 1,300 to 2,500 mm (Oloo 2013). Bungoma County has well-drained and fertile soils but management of crops and livestock is poor. Key crops in the region include maize, sunflower, sugarcane, coffee, tobacco, potatoes, beans and bananas (Oloo 2013). About 52% of the working population is engaged in agriculture and this provides on average 60% of household income. In 2005, it was estimated that 60% of the Bungoma population was living below the poverty line (Government of Kenya 2005).

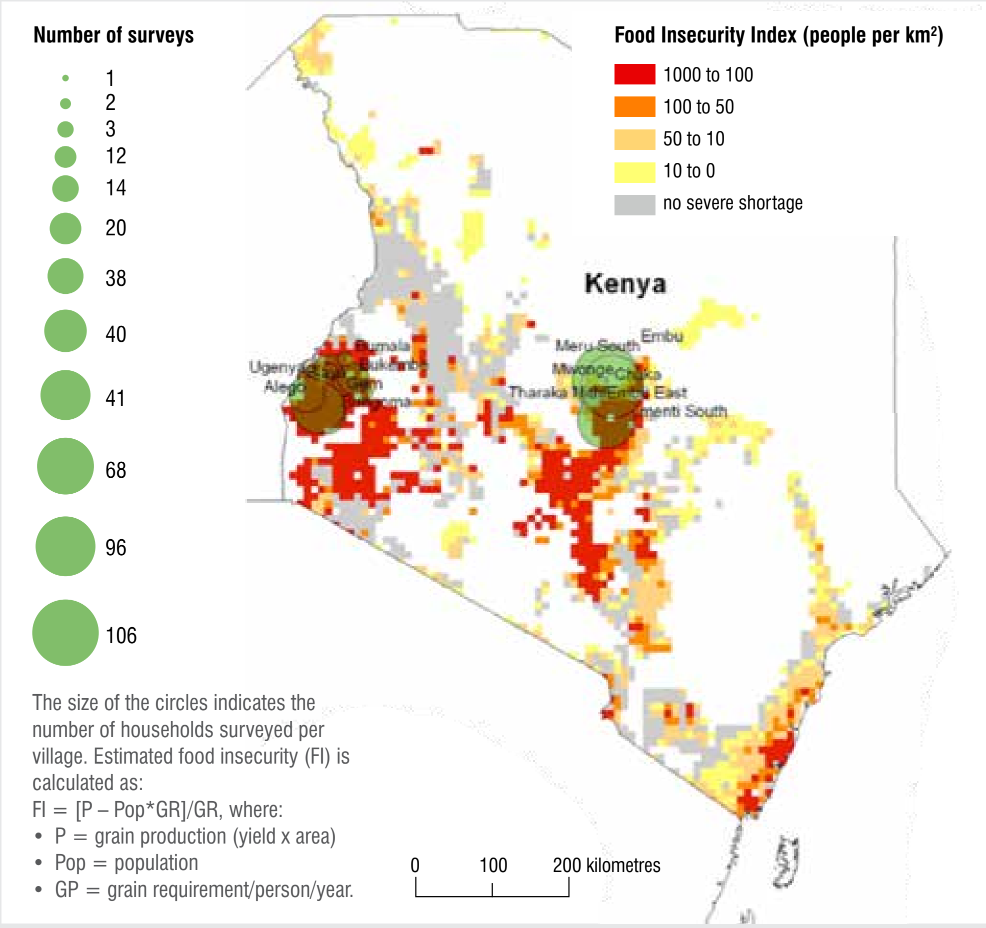


**FIGURE 5.1** The distribution of the surveyed farms in eastern and western Kenya (n = 613), on a map showing the frequency of food insecurity (FFI)

Potgieter et al. 2013.

### *Eastern Kenya*

In the eastern part of Kenya, Embu and Meru counties fall in the moist mid-altitude and moist transitional zone, as defined by Hassan (1998). Altitude ranges widely and rainfall is bimodal and variable (Jaetzold et al. 2006b). The area has a diversity of agroecological conditions. The eastern region has five major soil types: nitosols, andosols, vertisols, ferralsols and cambisols. The soils and agroecology of the area are greatly influenced by the presence of Mount Kenya and the Nyandarua ranges (Jaetzold et al. 2006b).

Embu is a primarily subhumid region with relatively good market access and fertile soils (Verkaart et al. 2017). Farms are said to be relatively well commercialised and the average farm holding is approximately 0.8 ha, though previous surveys found average cultivated area was only 0.64 ha (Verkaart et al. 2017). National census data from 2009 indicate 131,683 households are based in Embu with a total population of 516,212 (KNBS 2009). In the same year, over 107,000 people in the county reported their employment in small-scale agriculture (KNBS 2009).

Meru County is also considered a high-potential area for agricultural production, though it has enormous agroecological variability due to differences in elevation around Mount Kenya. Altitude ranges from 300 to 5,200 masl, though most crop production occurs in areas between 750 and 2,000 masl (Jaetzold et al. 2006b). Rainfall can vary from under 400 mm to 2,500 mm (Hakizimana et al. 2017). The Meru County local government reported the local literacy rate at 53% in 2012 (County Government of Meru 2017). National census data from 2009 indicate Meru County was home to 319,616 households and 1.4 million people (KNBS 2009). More than 261,000 residents are self-employed in small-scale agriculture (KNBS 2009).

## 5.2 REGIONAL DIFFERENCES

Differences between regions were apparent in crop yields, livestock ownership and management, and household incomes (sources and amounts). While the observed range of maize yields was similar in both regions, the top half of yields in western Kenya was higher than in the east (Figure 5.2a). Conversely, bean yields were notably higher in eastern Kenya (Figure 5.2b). Outliers with higher yield for both crops appeared to be similar in each region (Figures 5.2a and b). While median cattle ownership was roughly the same in each region, households in western Kenya had a more positively skewed distribution, meaning those with high numbers of cattle in western counties had relatively more than those in the east (Figure 5.2c). However, households in eastern Kenya had much higher incomes from their animal product sales than those in the west (Figure 5.2d). This is likely due to the more widespread improved animal breeds in eastern Kenya (Kebebe et al. 2017). Households in eastern Kenya derived more of their total incomes from household production than those in western Kenya (Figure 5.2e), and had higher total incomes overall (Figure 5.2f).

## 5.3 HOUSEHOLD TYPOLOGIES

Households in western and eastern Kenya were classified into groups based on the characteristics that accounted for the largest disparities (i.e. variance) in the region. Disparities in household land area under cultivation, access to labour, family size, livestock ownership level and household asset value were found in both eastern and western Kenya. Other major sources of variability among households depended on the region.

Households in the western region fell into three groups (W1, W2 and W3). Major disparities that were unique to western Kenya were in household education level and total asset value. W2 and W3 cultivated similar sized plots and had similar family sizes, but W2 households were younger and more educated, and estimated their total asset value at twice that of W3 households (Table 5.1). W1 households appeared to be the most resource endowed and wealthiest households in western Kenya. They had far more land, larger families, more sheep and goats, greater estimated total assets and higher incomes than the other two groups (Table 5.1).

In eastern Kenya, households also fell into three groups (E1, E2 and E3). Major disparities that were unique to eastern Kenya were in the number of cattle owned and land area under maize cultivation. E1 and E2 households had different resource endowment levels (Table 5.1). E2 households had more land, labour and cattle than E1 households, and these higher levels were associated with higher median incomes (Table 5.1). E1 households represented the majority (60%) of sampled households in the region so the relative poverty levels of these households was widespread. They were younger and more likely to have female heads of households.

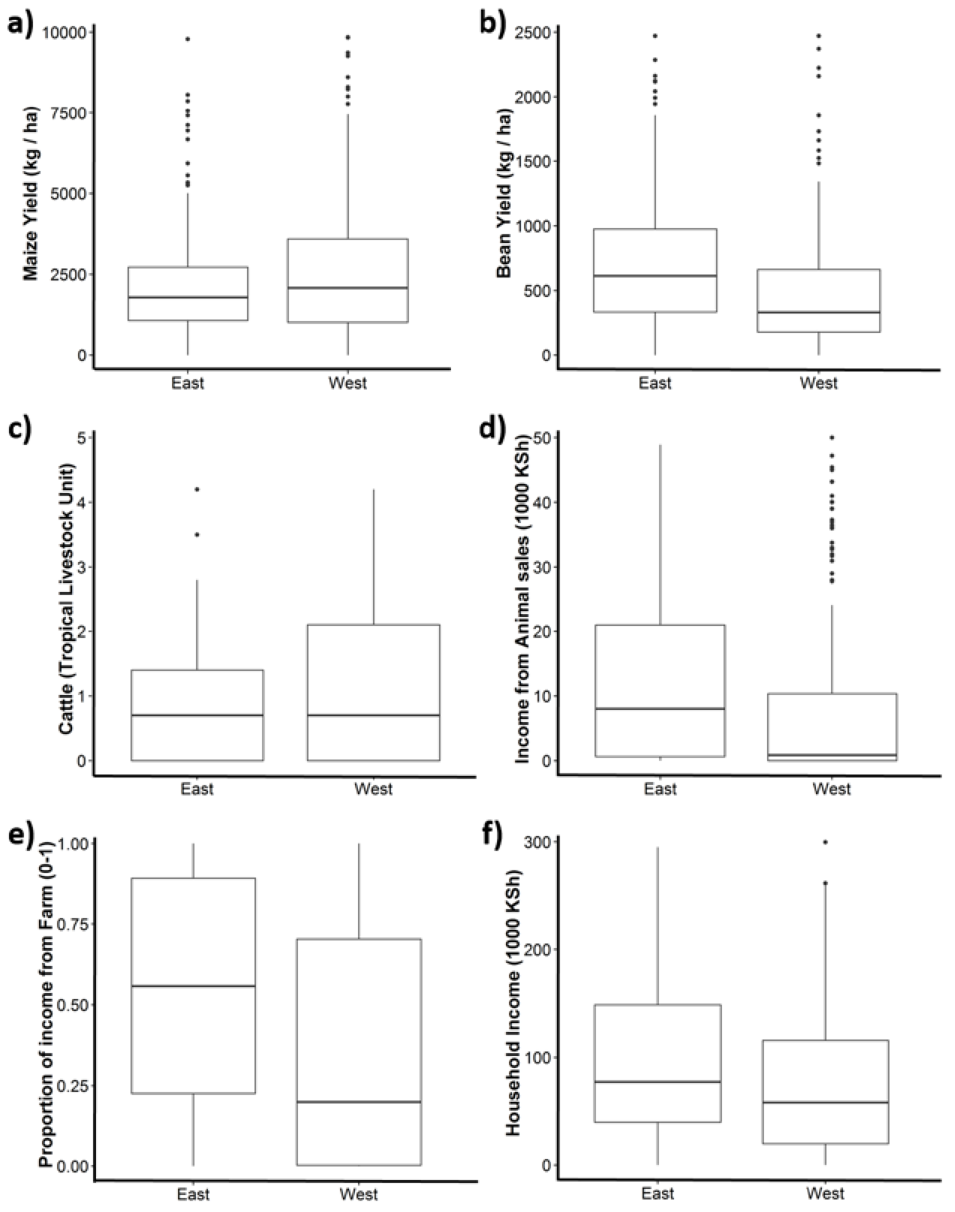


**FIGURE 5.2** Descriptive statistics for sampled farms and fields in eastern (East) and western Kenya (West). Box plots represent the 10th to 90th percentile for: (a) maize yield per hectare; (b) bean yield per hectare; (c) cattle owned; (d) income from animal product sales, e.g. meat, dairy, draught power; (e) proportion of total income derived from household production; and (f) total household income.

**TABLE 5.1** Cluster medians (and standard deviations) for the cluster variables (shaded) and independent household characteristics in Kenya

| Cluster variables | Frequencies (%) or cluster medians (standard deviations) | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | *P*-value[a] |
| **Western Kenya** | | | | |
| Farm size (ha) | 3.0 (3.9) | 1.5 (1.1) | 1.3 (1.3) | >0.000*** |
| Family size (ME) | 4.5 (2.0) | 2.4 (0.7) | 2.5 (1.4) | >0.000*** |
| Education (years) | 8 (3.9) | 8 (2.9) | 2 (2.1) | >0.000*** |
| Sheep or goats (head) | 4 (3.7) | 1 (1.3) | 2 (2.3) | >0.000*** |
| Household assets (1,000 KSh) | 44 (115) | 19 (35) | 11 (17) | >0.000*** |
| Sampled population (%) | 40 | 40 | 20 | – |
| Female-headed (%) | 18 | 16 | 30 | 0.118[b] |
| Reliant on cropping (%) [c] | 23 | 24 | 23 | 0.950 |
| Reliant on off-farm work (%) [c] | 71 | 78 | 82 | 0.083. |
| Reliant on non-cropping farming (%)[$] | 31 | 24 | 23 | 0.222 |
| Age (years) | 53 (14) | 42 (14) | 58 (15) | 0.653 |
| Household income (1,000 KSh) | 143 (913) | 60 (325) | 37 (203) | 0.000*** |
| **Eastern Kenya** | | | | |
| Farm size (ha) | 1.5 (1.4) | 2.1 (1.3) | 5.4 (3.7) | >0.000*** |
| Family size (ME) | 2 (0.7) | 3.6 (1.4) | 3.5 (1.5) | >0.000*** |
| Maize area (ha) | 0.2 (0.2) | 0.1 (0.2) | 0.6 (1.1) | >0.000*** |
| Sheep or goats (head) | 3 (1.7) | 3 (2.0) | 8 (3.6) | >0.000*** |
| Cattle (TLU) | 0.5 (0.5) | 1.4 (0.7) | 1.4 (1.0) | >0.000*** |
| Sampled population (%) | 60 | 29 | 11 | – |
| Female-headed (%) | 23 | 17 | 9 | 0.036*[b] |
| Reliant on cropping (%) [c] | 51 | 51 | 59 | 0.759 |
| Reliant on off-farm work (%) [c] | 66 | 66 | 44 | 0.047* |
| Reliant on non-cropping farming (%) [c] | 26 | 26 | 35 | 0.434 |
| Age (years) | 45 (15) | 52 (12) | 54 (14) | >0.000*** |
| Education (years) | 7 (4) | 8 (4) | 7 (4) | 0.865 |
| Household income (1,000 KSh) | 67 (211) | 134 (1789) | 225 (440) | 0.027* |

[a] ANOVA test (*, **, *** for *P*- value <0.05, 0.01 and <0.001 respectively)

## 5.4 LIVELIHOODS ACROSS KENYA

Four livelihood strategies were represented in Kenya with three groups having high food availability and three having low food availability (61% of households). These included:

- households with high food availability:
  – socially immobile, commercial farming households with high income (E3, W1 and E2)
- households with low food availability:
  – socially mobile households with low income (E1)
  – socially mobile households doing off-farm work with low income (W2)
  – socially immobile households subsistence farming with low income (W3).

All three household groups with high food availability were socially mobile, farming commercially and had higher incomes (i.e. in the top half of the observed income range). However, they were engaged in different commercial farming activities and therefore had differing sources of income. E3 households had high incomes mostly sourced from crop sales, while W1 earned most income from off-farm activities and E2 from non-crop farm sales (Figure 5.3). E3 households had a notable social constraint being located further from markets, though they were most likely to be male-headed (Figure 5.3).

Household groups with low food availability (E1, W2 and W3) all had low incomes, and one (W3) was socially immobile due to relatively low education and having the greatest distance to markets (Figure 5.3). Like those with high food availability, these groups differed in their level of income from crop sales, off-farm activities and alternative sources. E1 households were diversified, based on the range of income sources that contributed relatively moderate to low levels of income (particularly cropping and off-farm work; Figure 5.3). The remaining low food availability households with low income (W2 and W3) were in western Kenya. W2 households were not true farmers, due to the overwhelming reliance on off-farm activities for income and their limited productive resources (Figure 5.3). W3 households were also not engaged in meaningful commercial farming, though their off-farm incomes were so low that they could be classified as subsistence farmers (Figure 5.3). These W3 households were the least educated and least likely to have a male head of all groups in the country (Figure 5.3).

## 5.5 HOUSEHOLDS DEVELOPMENT OPTIONS

Households in Kenya displayed a range of characteristics depending on both their region as well as their productive resource base, social mobility indicators and sources of income. Based on our analysis, there are a diverse range of livelihoods and options for households in both eastern and western Kenya.

### 5.5.1 Stepping out

At a national level, W2 households appeared to be gaining a relatively high amount of their income from off-farm work. These households were deemed to be ‘not farmers’ given their lack of commercial farming income. They may fit the description of stepping-out households (Dorward et al. 2009); however, due to their current risk of food insecurity, options for these households should be considered in relation to their immediate needs.

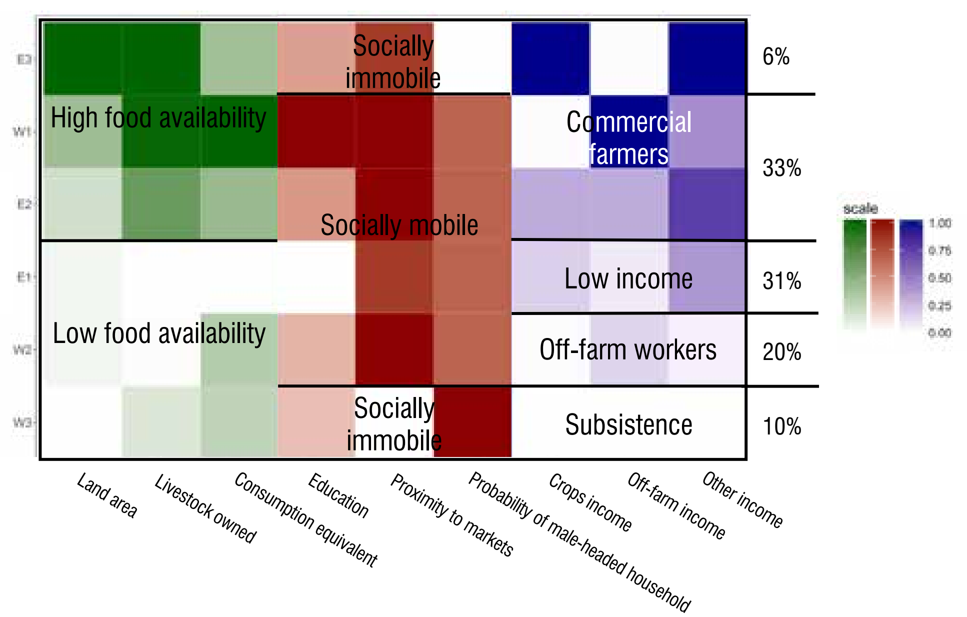


**FIGURE 5.3** Heatmap of characteristics and livelihood strategies of farmer groups in Kenya. Farm types from western (clusters W1, W2 and W3) and eastern Kenya (clusters E1, E2 and E3). The intensity of each coloured cell indicates the value of the farm system variable for a household group relative to other groups (0–1, light to dark respectively). Three types of farming system variables were used: food availability levels (green), social mobility factors (red) and sources of income generation (blue). Food availability variables were the median values for land area, total livestock units (TLU) and consumption equivalents (CE) within each group. The social mobility factors were median education level (years of formal education), proximity to markets (walking minutes) and the probability (%) of being a male-headed household within the group. Income generation components were median income levels from crop sales, off-farm activities, and other (non-crop) farm sales. The percentage of households represented within each livelihood strategy is indicated on the right-hand side of the livelihood description.

### 5.5.2 Stepping up

Three household typologies (E2, E3 and W1) appeared to be successfully exploiting their productive resources at the national level. These may therefore be characterised as stepping up (Dorward et al. 2009) as they are clearly positioned to intensify their current production activities. E2 households were the most educated in eastern Kenya and had reasonable endowment with productive assets such as cattle and land (Table 5.1). More than half of these E2 households derived at least 25% of their income from commercial cropping, indicating their suitability to productive innovations aimed at either cropping or livestock (Table 5.1). E2 households were also high-income, though their activities were diversified and therefore some stepping up and perhaps specialisation of their commercial activities could be beneficial (Figure 5.3). Given their relatively high incomes, these households may be able to benefit from more costly innovations either in their animal production or transformational technology for their cropping (e.g. improved seeds or mechanisation).

E3 households had the greatest productive assets at the local level, with smaller families than E2 households but more than twice as much land, sheep and goats and a spread of income sources. They were successfully engaged in commercial cropping activities despite living furthest from markets of all farm types (Figure 5.3). Hence, these households may benefit from institutional innovations aimed at improving their level of market access. It was also notable that this farm type had the lowest representation of female-headed households (9%), indicating the likely presence of gender inequities in eastern Kenya.

W1 households had local advantages over other households in western Kenya in their larger farms, livestock numbers and larger families (Table 5.1). W1 households were the only farm type with high income in western Kenya. Unlike stepping-up households in eastern Kenya, almost a third of these W1 households did not rely on cropping for their livelihoods (Figure 5.3). They were more focused on non-cropping farm activities (e.g. livestock), and more than two-thirds were reliant on off-farm activities. At the local level, W1 households had less productive assets (e.g. land and livestock), were younger and had smaller families than other farm types (Table 5.1). However, the higher income of W1 households suggested that they were better able to make use of the similar land and labour resources to produce an income when compared with W2 households. Their non-cropping farm income was most likely from dairy production. This would make them suitable for livestock intensification, and given their high off-farm incomes (even nationally) they may have the means to increase investment where appropriate.

### 5.5.3 Hanging in

Our analysis only identified household groups that were either successful enough to be stepping up, or were at risk of food insecurity. We therefore would not describe any groups as hanging in (Dorward et al. 2009) given either their relative affluence or immediate lack of food security.

### 5.5.4 Risk of food insecurity

We identified three household groups (E1, W2 and W3) as ‘at risk’ of food insecurity based on their food availability indicators (see Chapter 3 for method details). In total, these three groups accounted for 61% of all households surveyed in Kenya. Two ‘at-risk’ typologies (E1 and W3) had low income based on nationwide comparisons and were likely constrained by their low productive resource base at the local level. Despite being from different regions, these two typologies shared a number of characteristics at the local level. Both groups had the smallest farms, lowest access to labour, least livestock and lowest incomes in their respective region. They were also both proportionately more female-headed than most farm types. Key differences between the groups were that in eastern Kenya these households comprised 60% of all those in the region, while for western Kenya they represented only 20% (Table 5.1). In eastern Kenya they were rather reliant on both cropping and off-farm work for their incomes, while in western Kenya they were deemed to be subsistence farmers based on their relative lack of income (Figure 5.3). While both these groups may benefit from productive innovations that intensify productivity of existing resources (see Section 2.4 Field management and productivity innovations), they are likely to struggle in taking advantage of opportunities for intensification due to their low resource levels. These two household groups could benefit from programs specifically targeting female-headed households and those that aim to address low-literacy farmers. They may also benefit from direct aid given their extremely low cash income (Table 5.1).

Finally, W2 households appear to be better suited to off-farm work given their low market orientation. They may therefore be better served by efforts to transition further into off-farm activities for their livelihoods, rather than attempting to implement productive innovations with such a limited resource base. At the local level, however, they had comparable levels of productive resources as W3 households and therefore could benefit from similar productive innovations as those households.

## 5.6 CONCLUSION

In each region we identified a household typology that was deemed to have high food security and high income. In western Kenya these were more reliant on livestock production and in eastern Kenya they tended to be diversified between cropping, livestock and off-farm activities. Suitable interventions for households to improve their livelihoods were found to be highly varied, depending on particular circumstances. However, the particular livelihood sources relied upon and the level of connectivity to markets influenced what interventions were regarded as potentially beneficial. In both regions of Kenya, gender inequities were apparent as evidenced by the highest income group (eastern Kenya) being mostly male-headed households, and the lowest income group (western Kenya) being mostly female-headed households.

Given the prevalence of livestock in both regions, research and development efforts would be well targeted with a focus on crop–livestock integration as subsets of households in both study regions were more reliant on crop production for their incomes. It would appear from our analysis that many households (i.e. E1, W2 and W3) could be characterised as resource-constrained and that overcoming this will likely prove challenging for any development efforts.

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# TANZANIA

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# KEY POINTS

- The 699 households included in this case study spanned the northern and eastern zones of Tanzania.
- Compared with eastern zones, northern households had smaller farms, more livestock, larger families, more consumption demands and greater labour availability (lower land:labour ratio).
- Both the northern and eastern zones showed major disparities in household experience growing legumes, education levels and the contribution of on-farm income to total household income.
- Household groups reflected four livelihood strategies based on food availability, social mobility and market-orientation components:
  - groups with high food availability:
    - socially mobile, commercial farmers (16%)
    - socially mobile, off-farm workers (15%)
  - groups with low food availability:
    - socially immobile, off-farm workers (28%)
    - socially immobile, low-income households (41%).
- Households that were best positioned for intensification of on-farm production:
  - were more likely to have a male head of household, had high levels of access to labour and had extensive social networks to intensify field management activities and establish broad market networks
  - would likely benefit from input and output market information.
- The most at-risk, food-insecure groups would likely benefit from market access and information, especially related to markets for young and old households.

## 6.1 COUNTRY OVERVIEW

The United Republic of Tanzania is situated in the African Great Lakes region with the India Ocean to the east, Rwanda, Burundi and the Democratic Republic of the Congo to the west, Kenya and Uganda to the north, and Zambia, Malawi and Mozambique to the south. In 2016, Tanzania was home to approximately 47.7 million people (Schwab 2017). The most recent national evaluation of household poverty levels (including consumption or income from own production) found that approximately 28% of the population was living below the national poverty line in 2011 (World Bank 2011). Health in Tanzania has been among the worst in the world. Tanzania ranked 124 out of 138 countries evaluated by the World Economic Forum based on 2015 health statistics (Schwab 2017). The most recent Tanzania Demographic and Health Survey found a particularly high incidence of chronic and acute levels of undernourishment among children (Tanzania National Bureau of Statistics and ICF Macro 2011). Recent estimates based on 2010 census data found that 74% of the population represented household producers in rural areas (Tanzania National Bureau of Statistics 2010). Agroecological constraints and a vague understanding of the socioeconomic challenges faced by these households have hindered efforts to address poverty and food security in these populations.

Eastern and northern Tanzania are the maize production zones of the country. The eastern zone includes Dar es Salaam, Pwani and Morogoro. The households that represented the eastern zone in this case study were in Mvomero and Kilosa districts in the Morogoro region. At approximately 500 masl with an average annual rainfall of 935 mm, the Morogoro region was considered part of the wet, lower mid-altitude mega-environment (an area growing more than one million hectares of maize, within which interactions of variety with environment are relatively minor) of the CIMMYT maize 2004 assessment (Muthoni et al. 2017). In 2016, approximately 342,911 and 347,038 people lived in Mvomero and Kilosa districts respectively (Tanzania National Bureau of Statistics 2011). In 2010, agriculture represented the primary occupation of 69% of the population of Morogoro region (Tanzania National Bureau of Statistics and ICF Macro 2011). Although maize production levels were sufficient for a country surplus in 2015–16 and recent years (FAOSTAT 2017), yields in the Morogoro region over the last decade tended to be lower than the national average. Yields in 2015–16 were low in the Morogoro region due to floods (National Food Security Division 2016). In previous years, frequent droughts compromised yields (Paavola 2004). Paavola (2004) identified a wide range of household responses to drought and other production challenges that included forms of extensification (expanded cultivation areas and reduced fallows), movement into off-farm activities (wage employment or charcoal, timber and brick production) and migration to areas with greater production potential or easier access to markets and cities. Despite these efforts, household self-assessments from 2010 found that 75% of households from Mvomero experienced occasional food shortages and were considered 'transitory food-insecure households' (Kassie et al. 2014). In Kilosa, this figure was 81%. The health consequences for children have been particularly severe in Morogoro. The incidence of anaemia among children (6%) was the highest in the country (Tanzania National Bureau of Statistics and ICF Macro 2011).

The northern zone includes Kilimanjaro, Tanga, Arusha and Manyara regions. The households that represented the northern zone in this case study were in Karatu district in the Arusha region and Mbulu district in the Manyara region. At approximately 1,400 masl with an average annual rainfall of approximately 1,000 mm, Arusha and Manyara regions fell under the dry mid-altitude mega-environment characterised in the CIMMYT maize 2004 assessment (Muthoni et al. 2017). In 2016, the total populations of Karatu and Mbulu districts were estimated at 256,838 and 217,101 respectively. In 2010, agriculture represented the primary occupation of 9% of the population of Arusha and 30% of the

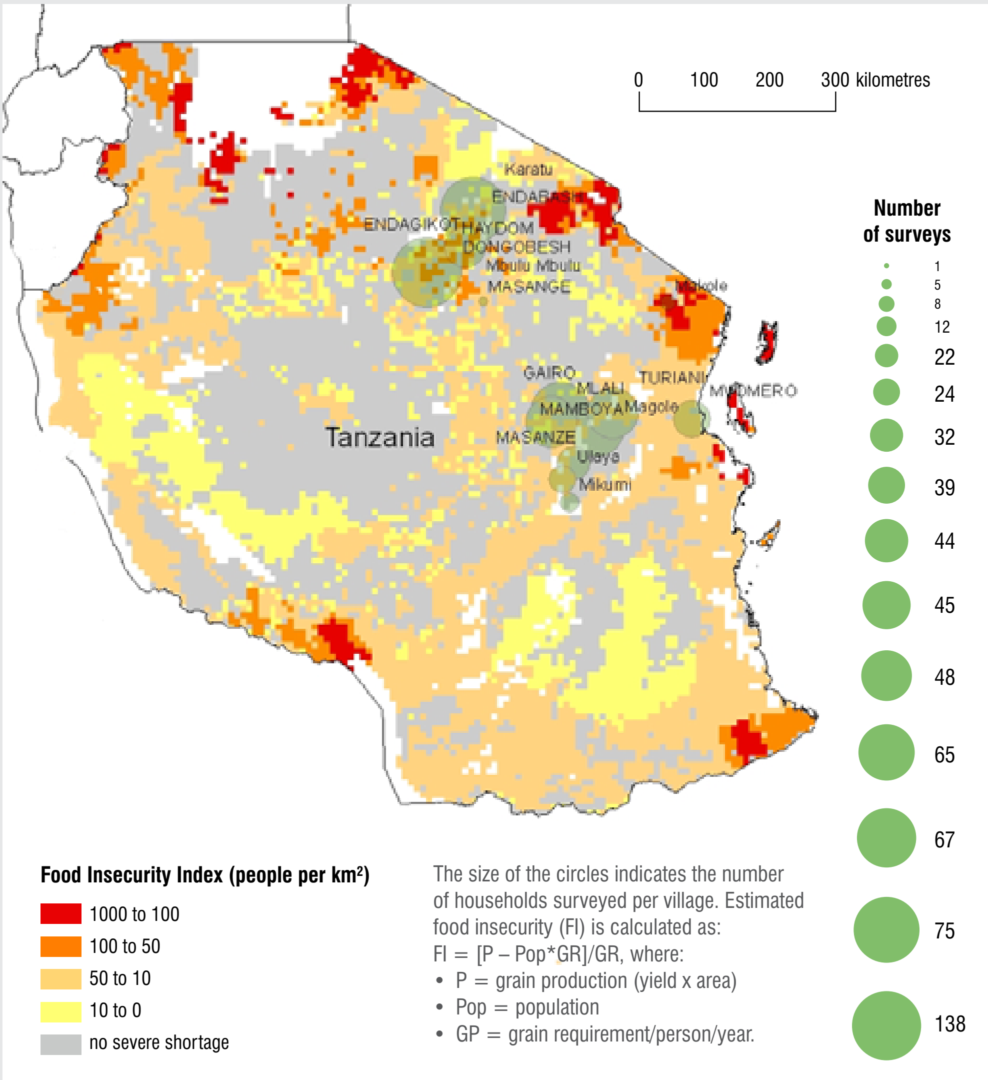


**FIGURE 6.1** The distribution of the surveyed farms in northern and eastern Tanzania (n = 699), on a map showing the frequency of food insecurity (FFI)

Potgieter et al. 2013.

population of Manyara (Tanzania National Bureau of Statistics and ICF Macro 2011). Agriculture played a more predominant role in the rural areas of Karatu and Mbulu districts, employing more than 90% of the total labour force (Douwe and Kessler 1997). Household producers have faced a wide range of challenges that limited production in recent years. Examples include the 2015 disputes over agricultural land that resulted in government restrictions, reduced casual labour migration and below-average maize yields (FEWS NET 2015). Household self-assessments from 2010 found that 67% of households in Karatu experienced occasional food shortages and were considered transitory food-insecure households (Kassie et al. 2014). In Mbulu, this figure was 85%.

## 6.2 REGIONAL DIFFERENCES

Households in the eastern zone of Tanzania cultivated larger land areas than households in the northern zone (Figure 6.2a). Most households in the north also had larger families, which was associated with access to higher levels of manual labour and a lower land:labour ratio (Figure 6.2b,c). Most households in the north also had more consumption equivalents than households in the east (Figure 6.2d). Incomes among most households in the east were comparable to those in the north (data not shown). However, households in the east depended more on off-farm sources of income than households in the north (Figure 6.2e). This suggests that agricultural activities had greater implications for household livelihood strategies in the north relative to households in the east. However, the contribution of off-farm activities to total household income varied substantially among households in the north. Most households in the north spent less on food than most households in the east (Figure 6.2f), even though most households in the north had relatively large families and high consumption requirements. This further suggests that household production played a more critical role in supporting food security among household producers in the north relative to households in the east.

## 6.3 HOUSEHOLD TYPOLOGIES

Households were classified into groups in each region based on the variables that accounted for the largest local disparities (variance). Disparities in household experience growing legumes, education and the contribution of farm activities to total household income were found in the north and east. Aside from these three variables, major sources of variability among households were region specific.

### 6.3.1 Northern zone

Major disparities that were unique to the northern zone were in the number of sheep and goats owned, consumption equivalents and connectivity to the socioeconomic corridor (number of known traders and kinship relations). Households from the northern zone fell into five groups (N1, N2, N3, N4 and N5) based on these characteristics and the disparities that were common for both zones (Table 6.1). Most N3 households had substantial production experience, older heads of household, low household consumption equivalents and few family ties relative to other northern household groups. This was the only group where heads of household had no formal education. N3 households were also more likely to have a female head than other households in Tanzania. N4 households also had many years of experience growing legumes relative to other groups, although less than the N3 households. N4 households had many connections to socioeconomic corridors compared to other household groups. For instance, they knew more traders and had many kinship relations (although not as many as N5 households, where kinship levels were especially high). In addition to their high kinship levels, N5 households had a high number of sheep and goats relative to other farmer groups.

N2 households were the only group where most households depended entirely on household production as a source of income (Table 6.1). These households were young and had relatively little experience with legume production. In contrast, N1 households had a particularly low dependence on household production as their source of income. These households also had few sheep and goats compared with other groups.

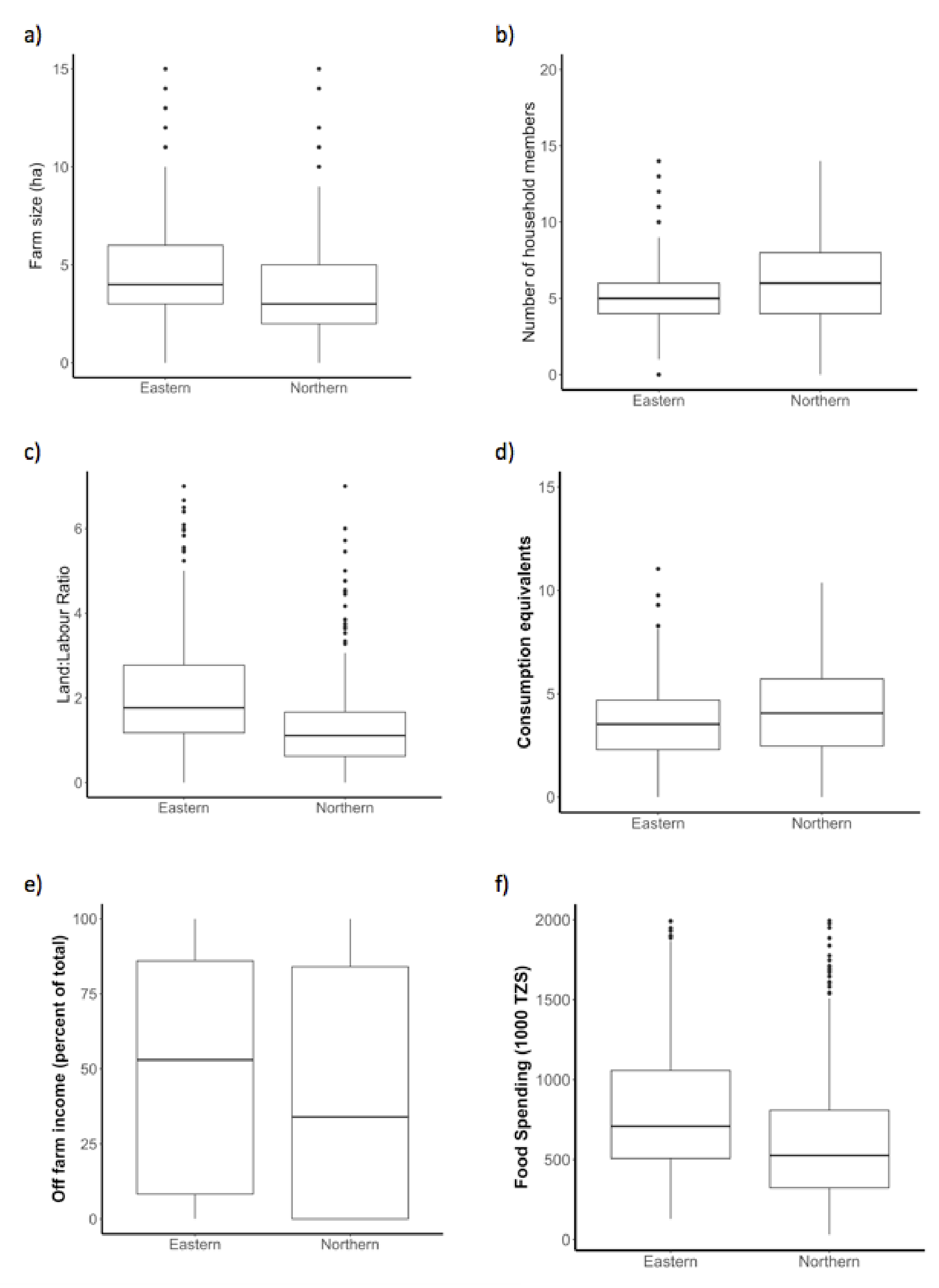


**FIGURE 6.2** Regional comparisons of farming system characteristics. (a) Median farm size, (b) number of household members, (c) land:labour ratio, (d) consumption equivalent, (e) off-farm income and (f) food spending between household producers in eastern and northern Tanzania. Box = 25th and 75th percentiles; bars = minimum and maximum values.

**TABLE 6.1** Cluster medians (and standard deviations) for the cluster variables (shaded) and independent household characteristics in the northern zone of Tanzania (n = 353)

| Cluster variables | Frequencies (%) or cluster medians (standard deviations) | | | | | |
|---|---|---|---|---|---|---|
| | N1 | N2 | N3 | N4 | N5 | |
| | 30% | 25% | 26% | 12% | 8% | *P*-value [a] |
| Experience growing legumes (years) | 19.0 (19.6) | 15.0 (13.9) | 40.0 (32.7) | 26.0 (19.6) | 15.0 (20.2) | 0.000*** |
| Education (years) | 7.0 (2.4) | 7.0 (0.9) | 0.0 (2.2) | 7.0 (3.1) | 7.0 (2.7) | 0.000*** |
| Sheep and goats owned (count) | 3.0 (7.3) | 6.0 (9.5) | 4.0 (6.7) | 10.0 (9.9) | 18.0 (22.7) | 0.000*** |
| Proportion of farm income | 0.1 (0.2) | 1.0 (0.2) | 0.7 (0.4) | 0.8 (0.3) | 0.9 (0.3) | 0.000*** |
| Consumption equivalent | 4.2 (2.3) | 3.9 (2.0) | 3.3 (2.1) | 5.0 (1.9) | 5.4 (2.2) | 0.023** |
| Kinship | 7.0 (9.6) | 8.0 (9.9) | 6.0 (6.5) | 18.0 (17.0) | 54.0 (33.4) | 0.000*** |
| Known traders | 3.0 (2.4) | 3.0 (2.2) | 3.0 (2.4) | 11.0 (6.1) | 4.0 (4.9) | 0.000*** |
| Female-headed (%) | 13 | 12 | 20 | 2 | 0 | 0.002*** |
| Age (years) | 42.0 (12.8) | 38.0 (11.3) | 60.0 (15.2) | 46.0 (14.2) | 40.0 (9.2) | 0.000*** |
| Household income (1000 TZS) | 620.0 (2,157.9) | 463.0 (1,707.6) | 403.2 (1,589.2) | 840.0 (1,699.1) | 570.0 (3,230.9) | 0.148 |
| % income from crop sales | 3.3 (12.7) | 44.6 (36.9) | 12.8 (36.4) | 8.5 (33.4) | 30.9 (0.28) | 0.000*** |
| % off-farm income | 86.0 (23.3) | 0.0 (16.6) | 21.5 (38.3) | 23.5 (31.2) | 15.5 (34.4) | 0.000*** |
| % income from 'other' | 0.7 (17.8) | 33.7 (37.1) | 4.5 (0.39) | 46.2 (35.7) | 41.1 (30.0) | 0.000*** |

[a] ANOVA test (*, **, *** for *P*- value <0.05, 0.01 and <0.001 respectively)

### 6.3.2 Eastern zone

Major disparities in the eastern zone were found in household production experience and education levels, social capital (number of institutional network connections), access to labour and number of livestock owned (Table 6.2). Households from the eastern region fell into four groups (E1, E2, E3 and E4) based on these disparate characteristics. Similar to the N3 farmer group in the north, E2 households had substantial production experience with older heads of household relative to other household groups. E2 was also the only farmer group where most heads of households had no formal education.

E4 households had many years of experience growing legumes, although still less than most E2 households. This was also the only farmer group providing evidence of a network, as indicated by their knowledge of institutional-level organisations (Table 6.2). E3 households were distinguished from their high levels of labour (i.e. adult equivalents) compared with other household groups. These households also had more livestock than others. Finally, E1 households had limited experience growing legumes and younger heads of household. Household income, the contribution of farm production to that income, female representation among heads of households and access to seed markets were all highly variable both within and across farmer groups.

**TABLE 6.2** Cluster medians (and standard deviations) for the cluster variables (shaded) and independent household characteristics in the eastern zone of Tanzania (n = 346)

| Cluster variables | Frequencies (%) or cluster medians (standard deviations) | | | | |
|---|---|---|---|---|---|
| | E1 | E2 | E3 | E4 | |
| | 39% | 30% | 13% | 18% | *P*-value [a] |
| Experience growing legumes (years) | 9.0 (12.8) | 28.0 (43.4) | 10.0 (17.6) | 15.0 (19.1) | 0.000*** |
| Access to seed market (walking minutes) | 24.0 (29.3) | 24.0 (27.5) | 20.0 (29.2) | 24.0 (28.7) | 0.732 |
| Education (years) | 7.0 (1.7) | 0.0 (2.8) | 7.0 (2.0) | 7.0 (1.7) | 0.000*** |
| Networking [c] | 0.0 (0.0) | 0.0 (0.4) | 0.0 (0.2) | 1.0 (0.5) | 0.000*** |
| Proportion of farm income | 0.4 (0.4) | 0.6 (0.4) | 0.7 (0.4) | 0.4 (0.4) | 0.102 |
| Adult equivalent (ME) | 2.0 (0.6) | 2.2 (1.0) | 3.8 (1.0) | 2.0 (0.7) | 0.000*** |
| Total livestock units (TLU) | 0.1 (0.7) | 0.1 (3.6) | 0.3 (0.5) | 0.2 (0.7) | 0.000*** |
| Female-headed (%) | 15 | 16 | 18 | 15 | 0.864 |
| Age (years) | 38.0 (13.4) | 53.0 (14.6) | 45.0 (10.7) | 42.0 (11.4) | 0.000*** |
| Household income (1000 TZS) | 840.0 (2043.3) | 450.0 (1,061.9) | 595.0 (1,120.9) | 783.2 (816.3) | 0.089 |
| % income from crops sales | 18.3 (33.3) | 42.9 (38.9) | 18.3 (38.5) | 22.1 (34.8) | 0.023** |
| % off-farm income | 61.5 (35.6) | 40.0 (39.3) | 32.0 (38.4) | 60.5 (37.3) | 0.056 |
| % income from 'other' | 0.4 (26.7) | 0.0 (25.7) | 4.0 (27.2) | 1.3 (28.2) | 0.721 |

[a] ANOVA test (*, **, *** for *P*- value <0.05, 0.01 and <0.001 respectively)

## 6.4 LIVELIHOODS ACROSS TANZANIA

Food availability levels varied across the country. Food availability (based on land area, livestock and consumption equivalents) was relatively high in four of the nine farming groups (N5, N4, E3 and N1). These groups were disproportionately represented by northern Tanzania (Figure 6.2). Overall, these groups had more land area and higher consumption equivalents than groups with low levels of food availability. All of these groups, except for the group from eastern Tanzania, had more livestock than groups with low levels of food availability. In the groups with high levels of food availability, the contribution of the components of food availability varied. For instance, most N5 had higher consumption equivalents than the other groups, while land area and livestock levels were average. N4 had the highest livestock herd sizes while most households in this group had relatively little land area under cultivation. Alternatively, E3 households cultivated large land area but had few livestock.

From a socioeconomic perspective, all of the households with high levels of food availability were socially mobile (based on education, proximity to markets and the probability of having a male head of household). Groups with high levels of food availability were either located closer to markets or were more likely to have male-headed households than the groups with low levels of food availability (Figure 6.2). All of the groups with high levels of food availability had relatively high levels of education (seven years of formal education). Access to markets and the probability of having a male head of household varied across the socially mobile groups. Two of the socially mobile groups (N5 and N4) were more likely to have a male head of household but these groups were located far from markets. In contrast, the two other socially mobile groups (E3 and N1) were located close to markets but were less likely to have a male head of household.

Three of the four groups with high food availability and social mobility were commercial farmers (based on crop, off-farm and other farm income sources and levels of income generated through these activities). Both of the groups with a high proportion of male-headed households were commercial farmers (N5 and N4), as well as E3. N1 households were off-farm workers, representing the only group with high food availability and social mobility that were not commercial farmers.

Food availability was low in the remaining five farmer groups. N2 and N3 households tended to have more livestock than the other groups with low food availability, however consumption equivalents and land area remained too low for these groups to have high levels of food availability. All of the groups with low food availability had low social mobility. They were located far away from markets and had a relatively low probability of having a male head of household. However, education levels varied across these groups. Three of the five groups had relatively high education levels, equivalent to households with high food availability and social mobility. Groups with low food availability and social mobility were either off-farm workers or their incomes were too low to indicate a market orientation. Two of the three more educated groups (E1 and E4) were off-farm workers. The remaining groups had low income levels.

## 6.5 HOUSEHOLD DEVELOPMENT OPTIONS

### 6.5.1 Stepping out

Three household groups (N1, E1 and E4) had particularly high off-farm incomes that suggested these households were best positioned to either transition or invest further in activities outside household production. These included two groups from the east (E1 and E4) with low food availability and one group from the north (N1) with high food availability. These differences in food availability suggest that food availability presents a unique challenge to stepping-out groups from the east.

E1 and E4 households showed differences at the local level that presented group-specific opportunities and challenges to pursing and benefiting from off-farm activities. Most E4 households had more ties to institutions (Table 6.2), providing a network that could help in identifying and leveraging off-farm opportunities. E4 households also had many years of experience growing legumes. These households could therefore benefit from rural off-farm activities that apply knowledge of production practices and institutional networks (e.g. agricultural extension) rather than forego this advantage in alternative off-farm activities. In contrast, most household heads in the E1 group tended to have limited experience growing legumes and were therefore better suited to off-farm activities outside of the agricultural sector than most E4 households. N1 households were located very close to markets which provided these households with a unique advantage over other groups in northern Tanzania in establishing productive off-farm activities.

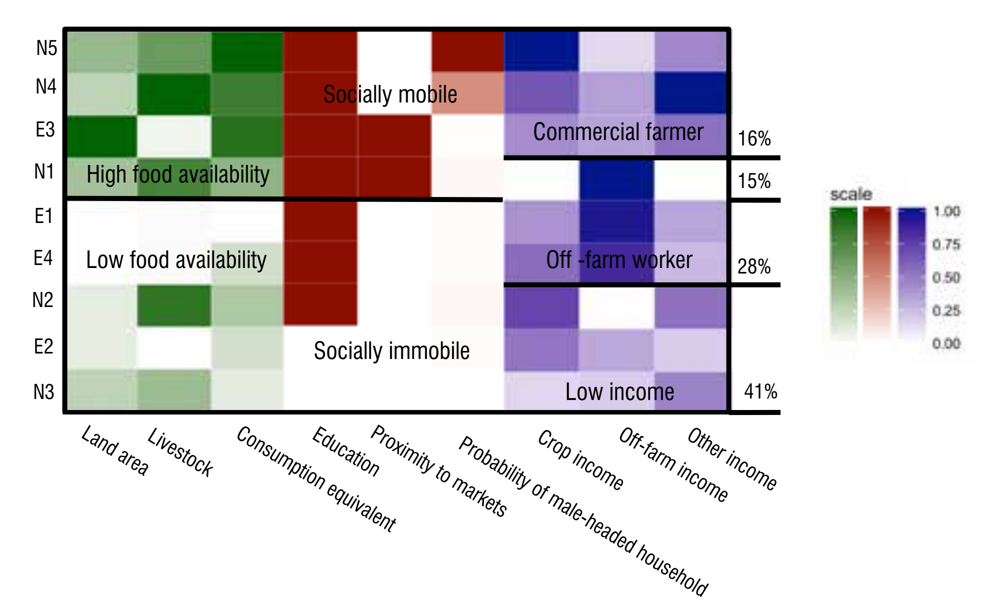


**FIGURE 6.3** Heatmap of farmer group characteristics and livelihood strategies of farmer groups from eastern (E1, E2, E3, E4) and northern (N1, N2, N3, N4, N5) Tanzania. The intensity of each coloured cell indicates the value of the farm system variable for a farmer group relative to the other farmer groups. Three types of farming system variables were used to characterise livelihood strategies: food availability levels (green), social mobility factors (red) and economic outcomes (blue). Food security variables were the median values for land area, total livestock units (TLU) and consumption equivalents (CE) within each group. The social mobility factors were median education level (years of formal edu cation), distance to main markets (walking minutes) and the proportion of female-headed households within the group. Economic outcomes were median income levels from crop sales, off-farm activities and other (non-crop) farm sales. The percentage of households represented within each livelihood strategy is indicated on the right-hand side of the livelihood description.

### 6.5.2 Stepping up

A subset of groups with high levels of food availability had high incomes from crop sales and other farm activities (N5, N4 and E3). This indicated that on-farm production activities were performing well in these household groups. The groups tended to have specific social and human capital advantages that could support intensification.

Most N4 households had more experience growing legumes than others in the northern region. This could contribute to more effective crop management and consequently give N4 households a production advantage. Both N4 and N5 groups had large familial networks that could provide certain production advantages, including additional labour and access to input and output markets. Similarly, E3 households had access to more labour than other groups in their region. Both N5 and E3 households also had more livestock than other groups in their respective regions, providing both social status and the physical or financial support to help absorb production shocks. Overall, the high levels of access to labour and extensive social networks suggest that N5, N4 and E3 households were positioned to intensify field management activities and establish broad market networks. These groups would likely benefit from input and output market information.

### 6.5.3 Risk of food insecurity

Food availability was low for the most at-risk groups. These groups were composed of low-income households with diverse income sources (E2 and N3), low-income market-oriented farmers (N2), and high-income off-farm workers (E1 and E4). Groups with low food availability generally represented an extreme age demographic, where family heads where either very young or old for the region. The groups with low food availability faced other local disadvantages in addition to the unique needs and challenges of young and old families. They tended to have less access to output markets, labour and social networks.

Both N3 and E2 households were older with many years of production experience. However, limited labour capacity among these households could have limited production for home consumption. The N3 and E2 groups were also the only two groups in Tanzania where household heads had no formal education (Figure 6.2). This might explain the low consumption equivalent of these households, as it could have further contributed to their limited knowledge of, and access to, alternative off-farm food sources. Most N3 households also had relatively small familial support networks, presenting a reduced informal safety net and an additional challenge to ensuring knowledge of and access to alternative off-farm food sources.

The younger N2 households faced challenges to ensuring their food security. Most N2 households depended entirely on crop sales as a source of income (Table 6.1). However, total incomes were particularly low, resulting in little financial resources available for food purchases. Crop incomes might have gone towards school fees, as N2 households were the only food-insecure low-income group with high levels of education.

E1 and E4 households, as previously discussed, had low levels of food availability and high off-farm incomes. Although off-farm activities contributed to particularly high incomes among these households, indicators of food availability suggest that they would be unable to access food for consumption. Ensuring access to food markets, while critical to establishing and maintaining food security among off-farm workers in general, appeared to be particularly critical for E1 and E4 households to step out of agricultural activities. Overall, groups with low food availability would likely benefit from market access and information especially related to markets for young and old households.

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# MOZAMBIQUE

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# KEY POINTS

- The 513 households included in this case study spanned three subhumid provinces and four districts of Mozambique.
- Most households in Manica and Angonia districts were relatively wealthy although sources of wealth varied.
- Households in Manica depended more on off-farm income while those in Angonia mainly relied on household agricultural production for income.
- Households in Sussundenga depended more on off-farm sources of income and owned more cattle than most households from the other regions.
- Within each district, three to four distinct household types were identified on the basis of major disparities in household resource levels, income, market connectivity and farming experience.
- Based on food availability, social mobility and market-orientation components, the farmer groups represented seven livelihood groups.
- Households with high food availability indicators (41% total) included high-income commercial farmers (15%), high-income off-farm workers (6%) and low-income diversified producers (20%).
- Groups most at risk of food insecurity (59% total) were mostly constrained by lack of productive resources.
- 40% of surveyed households could benefit from productive innovations based on existing livelihoods focused on household production.
- The most promising interventions in terms of impact revolved around field-level improvements for poorer households that were dependent on farming for their incomes, transformational technology and institutional innovation for more commercially successful farming households, and assistance transitioning out of farming for those households more dependent on off-farm work.
- The level of diversity observed even within the household groups demonstrated the importance of community-engaged identification and assessment of interventions prior to implementation in research and/or development projects.

## 7.1 COUNTRY OVERVIEW

Mozambique is a southern African country on the east coast of the continent, lying north-east of South Africa, east of Zimbabwe, south-east of Malawi and south of Tanzania. The most recent estimates show that the population reached 28 million in 2015 with 66% living in rural areas (FAOSTAT 2017). It is one of the poorest countries in the world with an estimated GDP of US$14.8 billion (113th globally) as of April 2017 (World Bank 2017). Throughout its post-colonial history, Mozambique's economy has been highly dependent on agriculture. Estimates from 2003 indicated that more than 69% of male employment and 89% of female employment was in the agricultural sector (World Bank 2017). Agricultural contribution to GDP in the early 21st century peaked in 2011 at 30.9% (FAO 2013) but has since fallen to 25.2% (World Bank 2017). However, production levels have been low relative to other African countries. National average maize yield between 2005 and 2014 was 0.88 t/ha, while the southern African average (calculated using data from Botswana, Malawi, Mozambique, Namibia, Swaziland, Tanzania, Zambia and Zimbabwe but excluding South Africa) was 1.3 t/ha (FAOSTAT 2017). Not surprisingly, agriculture is mostly subsistence oriented (99% being small-scale farmers), with low use of improved technologies, machinery and credit (IAI 2015). Of 138 countries assessed by the World Economic Forum in 2016–17, Mozambique ranked low in almost all key indicators of economic development and specific indicators that could present major challenges to addressing poverty and food security. Some of the worst performing indicators for the country were quality of infrastructure (ranked 124), primary education and health (ranked 134) and markets (ranked 118) (Schwab 2016). Data from 2008 found that 87.5% of the Mozambican population live in extreme poverty (i.e. US$3.10 per day) and that 56.9% of the rural population lives below the national poverty line (World Bank 2017). More recent data from 2014 indicate that 50.1% of the rural population lives below the national poverty line (IOF 2016). While great gains were made between the 1990s and 2010s, more than 25% of the population was estimated to be undernourished in 2015 (World Bank 2017). The humid and subhumid regions (see Section 2.2 Climate) of central and northern Mozambique are considered the high-potential areas for production, with the south mostly dependent on imported food from South Africa (FAO 2013). Nevertheless, poverty incidence in the south is lower than in the centre and north of Mozambique (32.8%, 46.2% and 55.1%, respectively) (IOF 2016).

Households in this case study were from the Manica, Sofala and Tete provinces of central Mozambique which are mostly within the subhumid zone. Manica Province is situated along the Beira corridor (linking the Mozambique port of Beira with the Zimbabwean capital Harare). Estimates from the National Institute of Statistics (INE) in 2013 were that over 1.8 million people lived in the province (INE 2014). The capital city, Chimoio, was the fifth-largest city in Mozambique and an important centre for agricultural markets. Yet, in 2014, 41% of the population lived below the national poverty line (IOF 2016). A 2014 survey found that agriculture had been a main activity in the last decade for 59.8% of people in Manica, and 30.9% of rural farm household heads were illiterate (IAI 2015). Within the province, the Manica District (same name as the province) lies at the western border with Zimbabwe. This district includes sections of the Chimanimani Mountains along the Zimbabwean border. For the last two decades, gold mining has played a significant role in supporting rural livelihoods (Dondeyne et al. 2009; Shandro et al. 2009). According to INE data, the district represented 15% of the provincial population in 2013, with most of the population under the age of 30 (INE 2013c). Household production dominated the landscape at this time with over 38,000 small-to-medium-sized farms in the district cultivating close to 49,000 ha (INE 2013c). Statistics from 2013 indicated that various forms of physical, social and human capital were low in the distinct. Only 28% of households owned a bicycle and 44% of households depended on a well without a pump as their primary water source (INE 2013c). Forty per cent of households did not have a toilet and less than 10% were connected to electricity. More than 70% of households relied on petrol, paraffin or kerosene as their only energy source.

Further south of Manica District lies the district of Sussundenga, also located in Manica Province. Like Manica District, Sussundenga is also situated along the Zimbabwean border and incorporates the Chimanimani Mountains. The district has been a focal point for agricultural research and development with a major government research station located in the district since at least the 1960s (Curtin and Smith 1968; Nyagumbo et al. 2015; Thierfelder et al. 2012). In 2013, Sussundenga had a population of over 157,000 and comprised over 25,000 small and medium-sized farms cultivating 53,000 ha of land (INE 2013d).

Sofala Province, to the east of Manica Province, is also located in the Beira corridor. The Gorongosa District within the province is located around Mount Gorongosa and Mozambique's largest national park, the Gorongosa National Park (INE 2013b). In 2013 the district had a population of more than 143,000 people and almost 20,000 small farms cultivating close to 49,000 ha (INE 2013b). The district had a much higher illiteracy rate than Manica and Sussundenga, especially among younger people, at this time.

Tete Province, north of Manica, is characteristically drier and more marginal for agricultural production. However, the northern part of the province in the district of Angonia increases in elevation, leading to a cooling of temperature and more moisture availability. Angonia lies south-west of Malawi and has a population of 359,000 (22% of the province) and over 64,000 farms (INE 2013a). Illiteracy in this region was comparable to Gorongosa District and higher than in Manica Province.

## 7.2 REGIONAL DIFFERENCES

Regional differences in productive resources, income and expenditure were apparent between the four districts. Land:labour ratios ranged from 0.2 to 2 ha/ME and were highest in Angonia and lowest in Manica (Figure 7.1a). Households in Sussundenga District had more cattle than households in the other districts and no households in Gorongosa District had cattle (Figure 7.1b). Most households in Gorongosa had lower incomes than households in the other regions, especially Manica and Angonia where most household incomes were particularly high (Figure 7.1c).

Reliance on farm activities as a household income source varied across districts, though most households earned at least 50% of their income from non-farming activities (Figure 7.1d). Households in Angonia and Gorongosa relied more on farming income than those in Manica and Sussundenga (Figure 7.1d). Most households in Manica and Sussundenga had higher total expenditures than those in other regions, although most households in Angonia and Manica spent more on food. Gorongosa was the poorest district with no cattle, low land:labour ratios, low household income and expenditure levels, and a high reliance on farming activities that generated little returns. By contrast, Manica was the wealthiest region relying on off-farm activities for much of that income (Figure 7.1c and d). Angonia was also relatively wealthy and in this district farming activities generated relatively high returns. Households in Sussundenga also relied on off-farm activities for their income, however their actual income was not nearly as high as most households from Angonia or Manica.

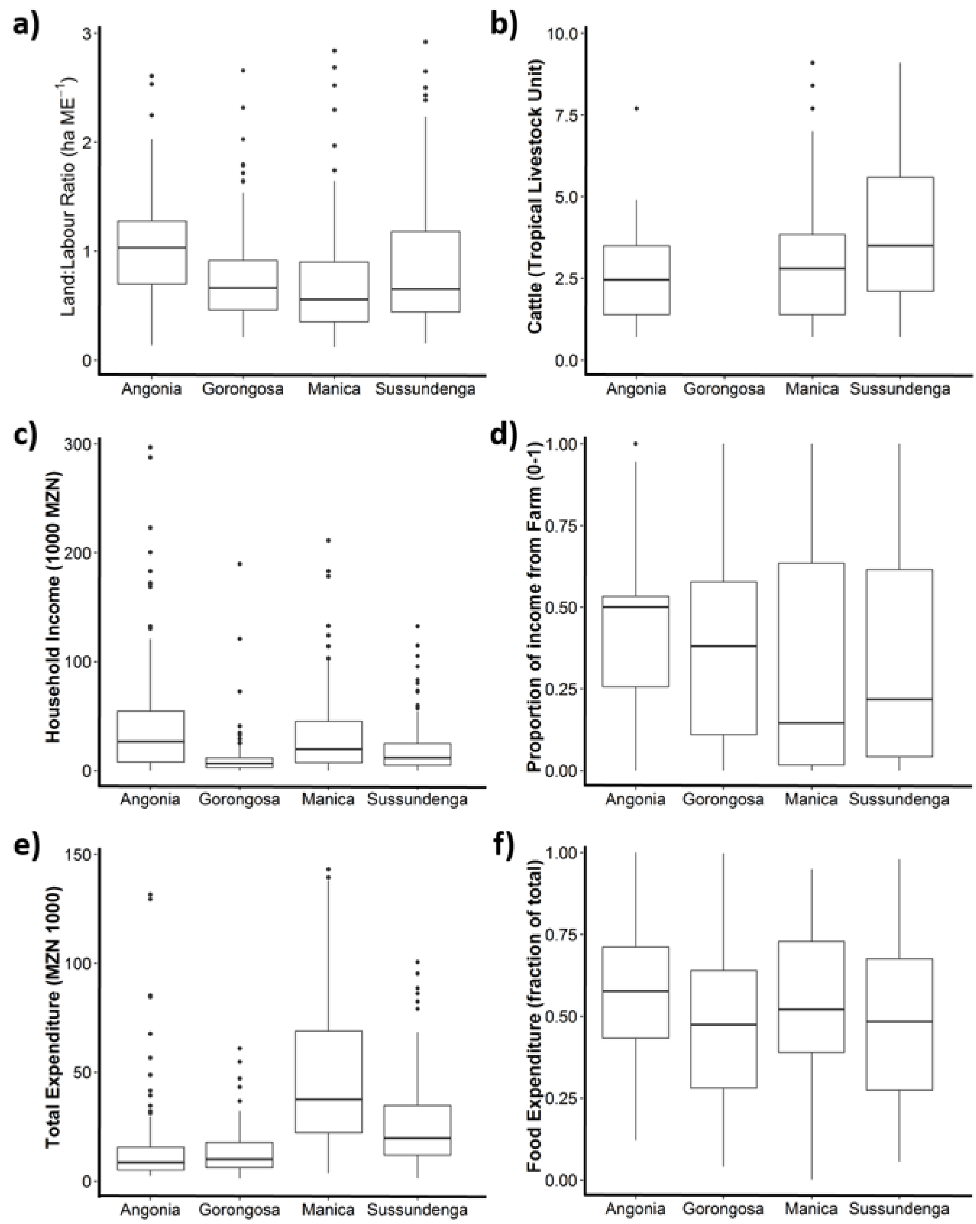


**FIGURE 7.1** Box plots showing regional differences in medians, interquartile ranges, and 10th and 90th percentile of key household indicators for Mozambique case study households: (a) land:labour ratio; (b) cattle, expressed as total livestock units; (c) household income (Mozambican metical); (d) proportion of household income derived from farming activities; (e) total household expenditure; and (f) fraction of household spending on food.

## 7.3 HOUSEHOLD TYPOLOGIES

Households were classified into groups based on the variables identified in the PCA that reflected major disparities in each district. Market connectivity (distance to markets or known traders), farm and family size and experience growing maize were major sources of disparities in all four districts. Other sources of variability among households varied by district.

### 7.3.1 Angonia

Households in Angonia showed major disparities in experience with growing maize and the number of input traders known (both significantly different between clusters), and to a lesser extent distance to fertiliser markets, family size and livestock owned in the district. Households in Angonia fell into three cluster groups (A1, A2 and A3) based these qualities. A1 households had the most experience growing maize (30 years) and knew more traders (four) than most households from the other groups. However, they were located furthest away from fertiliser markets. A1 household heads were older and less educated than the other groups. The majority of households fell into the A2 group. These households cultivated the most land (4 ha), had the largest families (5.5 ME), owned the most livestock (0.5 TLU) and had the highest incomes. They were also younger and more educated than A1 households. A3 households were the youngest (29), had the least experience growing maize (8 years) and knew fewer input traders (two) than the other groups (Table 7.1).

### 7.3.2 Gorongosa

Households in Gorongosa District of Sofala Province showed major disparities in family size, area farmed, the reported frequency of droughts, connectivity to markets (traders known, distance to markets), experience growing maize and proportion of fertile soils. Based on these characteristics, households fell into three cluster groups. G1 households had larger family sizes (6.9 ME) and farm areas (3.5 ha) than the other groups in the district (Table 7.2). G1 households were located relatively close to markets and were the most likely to have a male head of household (96% male-headed). Like G1 households, G2 households were also relatively close to markets, but G2 households also knew the highest number of input traders. They were more dependent on non-cropping farming and had higher total household incomes than the other household groups (Table 7.2).

The majority of Gorongosa households (54%) fell into the G3 group. G3 households had the smallest families, less experience growing maize and were more vulnerable to drought than the other groups. This suggests that the G3 group was faced with unique production disadvantages. G3 households also had lower total incomes than the other groups (5,000 MZN per year) and were the most likely to have a female head of household (22% female-headed).

**TABLE 7.1** Cluster medians (and standard deviations) for the cluster variables (shaded) and independent household characteristics in Angonia

| Cluster variables | Frequencies (%) or cluster medians (standard deviations) | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | *P*-value [a] |
| Distance to fertiliser markets (walking minutes) | 155 (117) | 120 (263) | 120 (75) | 0.847 |
| Experience growing maize (years) | 30 (11.2) | 17 (7.6) | 8 (3.4) | >0.000*** |
| Number of input traders known | 4 (8.6) | 3 (2.8) | 2 (2.3) | >0.000*** |
| Family size (ME) | 3.2 (1.5) | 5.5 (1.0) | 3.0 (0.8) | 0.387 |
| Livestock owned (TLU) | 0.1 (1.6) | 0.5 (2.2) | 0.1 (0.6) | 0.507 |
| Cultivated area in long rains (ha) | 3 (2.2) | 4 (6.5) | 3 (1.1) | 0.978 |
| Proportion of income from farm (%) | 43 (26) | 50 (20) | 50 (27) | 0.191 |
| Sampled population (%) | 28 | 44 | 28 | – |
| Female-headed (%) | 25 | 13 | 11 | 0.112 |
| Reliant on cropping (%) | 56 | 73 | 71 | 0.148 |
| Reliant on off-farm work (%) | 89 | 95 | 86 | 0.657 |
| Reliant on non-cropping farming (%) | 14 | 9 | 14 | 0.965 |
| Age (years) | 58 (17.4) | 43 (10.8) | 29 (8.4) | >0.000*** |
| Education (years) | 0 (3.0) | 3 (2.5) | 3 (3.4) | 0.061* |
| Household income (1000 MZN) | 17 (60) | 36 (40) | 20 (53) | 0.991 |

[a] ANOVA test (*, **, *** for *P*- value <0.05, 0.01 and <0.001 respectively)

**TABLE 7.2** Cluster medians (and standard deviations) for the cluster variables (shaded) and independent household characteristics in Gorongosa

| Cluster variables | Frequencies (%) or cluster medians (standard deviations) | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | *P*-value [a] |
| Distance to markets (walking minutes) | 180 (118) | 180 (182) | 210 (250) | 0.137 |
| Number of input traders known | 1 (3) | 25 (7) | 1 (2) | 0.445 |
| Family size (ME) | 6.9 (3.0) | 5.1 (3.6) | 3.9 (2.5) | >0.000*** |
| Experience growing maize (years) | 19 (10) | 30 (14) | 15 (14) | 0.615 |
| Cultivated area in long rains (ha) | 3.5 (1.6) | 2.0 (0.9) | 2.0 (1.1) | >0.000*** |
| Proportion of fertile soils | 0.8 (0.5) | 0.0 (0.5) | 1.0 (0.5) | 0.702 |
| Drought frequency | 2 (4) | 3 (19) | 10 (12) | >0.000*** |
| Sampled population (%) | 36 | 10 | 54 | – |
| Female-headed (%) | 4 | 8 | 22 | 0.004** |
| Reliant on cropping (%) | 24 | 15 | 31 | 0.383 |
| Reliant on off-farm work (%) | 73 | 92 | 87 | 0.085. |
| Reliant on non-cropping farming (%) | 62 | 23 | 24 | >0.000*** |
| Age (years) | 45 (11) | 45 (14) | 38 (16) | 0.103 |
| Education (years) | 3 (2) | 3 (3) | 3 (3) | 0.438 |
| Household income (1000 MZN) | 7 (3) | 8 (8) | 5 (7) | 0.009** |

[a] ANOVA test (*, **, *** for *P*- value <0.05, 0.01 and <0.001 respectively)

### 7.3.3 Manica

The major disparities in Manica were in household farm size, market connectivity, consumption equivalent and experience growing maize. Households in the Manica District of Manica Province were separated into four cluster groups based on these characteristics (Table 7.3).

M1 households were notable for being highly connected to markets. They knew many more traders than households from other groups and also had relatively high consumption equivalents. The most distinct groups were M2 and M3. Most M2 households were the youngest in Manica, had the least experience growing maize, and were less reliant on crop sales (and more reliant on off-farm work) than the other groups (Table 7.3). In contrast, M3 households were the oldest, had the most experience growing maize and were more reliant on crop sales (and less reliant on off-farm work) than the other groups.
M3 households also had a lower consumption equivalent than other groups. M4 households had the largest farms (6.3 ha) and the highest consumption equivalent (8.3 t/ME/year).

**TABLE 7.3** Cluster medians (and standard deviations) for the cluster variables (shaded) and independent household characteristics in Manica

| Cluster variables | Frequencies (%) or cluster medians (standard deviations) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | *P*-value [a] |
| Distance to seed markets (walking minutes) | 180 (68) | 120 (82) | 240 (141) | 150 (66) | 0.390 |
| Farm size (ha) | 2.5 (1.0) | 2.5 (1.8) | 5 (3.7) | 6.3 (6.7) | >0.000*** |
| Number of input traders known | 20 (10) | 3 (3) | 2 (5) | 2 (3) | >0.000*** |
| Experience growing maize (years) | 15 (12) | 13 (8) | 41 (16) | 17 (11) | 0.019* |
| Consumption equivalent (t/ME/year) | 5.4 (2.1) | 3.3 (1.4) | 3.0 (1.8) | 8.3 (1.9) | >0.000*** |
| Sampled population (%) | 18 | 42 | 16 | 24 | – |
| Female-headed (%) | 4 | 22 | 30 | 13 | 0.555 |
| Reliant on cropping (%) | 13 | 11 | 45 | 40 | >0.000*** |
| Reliant on off-farm work (%) | 78 | 91 | 50 | 70 | 0.043** |
| Reliant on non-cropping farming (%) | 26 | 22 | 35 | 20 | 0.856 |
| Age (years) | 51 (13) | 38 (13) | 65 (16) | 50 (10) | 0.027* |
| Education (years) | 4 (3) | 6 (4) | 2 (4) | 4 (3) | 0.590 |
| Household income (1000 MZN) | 34 (26) | 16 (40) | 9 (46) | 25 (262) | 0.852 |

[a] ANOVA test (*, **, *** for *P*-value <0.05, 0.01 and <0.001 respectively)

### 7.3.4 Sussundenga

The major disparities in Sussundenga were in family size, education, soil fertility and distance to extension services, and to a lesser extent experience with maize and asset values. Households were separated into four typology groups based on these characteristics.

S1 households had the largest families and were the second oldest household group (Table 7.4). S2 households had fertile soil while most households from the other groups reported that none of their land contained fertile soil. Most S3 households were older and less educated than the other groups, and were proportionately far more female-headed. In contrast, most S4 households were younger and more educated, and none were female-headed (Table 7.4).

**TABLE 7.4** Cluster medians (and standard deviations) for the cluster variables (shaded) and independent household characteristics in Sussundenga

| Cluster variables | Frequencies (%) or cluster medians (standard deviations) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | *P*-value [a] |
| Total assets value (1000 MZN) | 84 (12) | 58 (27) | 32 (220) | 97 (30) | 0.553 |
| Family size (ME) | 4.9 (1.1) | 2.8 (1.1) | 3.4 (1.1) | 2.2 (0.8) | >0.000*** |
| Education (years) | 3 (3) | 6 (3) | 2 (3) | 7 (2) | 0.025* |
| Experience growing maize (years) | 20 (11) | 15 (11) | 30 (15) | 10 (5) | 0.451 |
| Number of output traders known | 2 (2) | 5 (12) | 1 (3) | 5 (5) | 0.912 |
| Proportion of fertile soils | 0 (0.5) | 1 (0.4) | 0 (0.4) | 0 (0.0) | >0.000*** |
| Distance to extension (walking minutes) | 60 (84) | 25 (58) | 90 (214) | 68 (1.5) | 0.099. |
| Sampled population (%) | 27 | 30 | 24 | 19 | - |
| Female headed (%) | 14 | 5 | 45 | 0 | 0.718 |
| Reliant on cropping (%) | 40 | 28 | 23 | 40 | 0.759 |
| Reliant on off-farm work (%) | 77 | 93 | 90 | 72 | 0.718 |
| Reliant on non-cropping farming (%) | 20 | 23 | 26 | 20 | 0.872 |
| Age (years) | 53 (16) | 43 (14) | 54 (14) | 35 (9) | 0.018* |
| Household income (1000 MZN) | 12 (18) | 15 (33) | 7 (244) | 19 (20) | 0.589 |

[a] ANOVA test (*, **, *** for *P*- value <0.05, 0.01 and <0.001 respectively)

## 7.4 LIVELIHOODS ACROSS MOZAMBIQUE

Across the different regions, clusters were grouped into one of seven categories on the basis of food availability indicators, socioeconomic conditions and economic outcomes. These were:

- households with high food availability:
  - socially mobile, commercial farming households with high incomes (M1, A2)
  - socially mobile households, working off-farm with high incomes (M4)
  - socially mobile, generalist households with low incomes (S1, G1)
  - socially immobile, generalist households with low incomes (M3)
- households with low food availability:
  - socially immobile households with low incomes (S3, G2, G3, A1)
  - socially mobile households with low incomes (A3, S4)
  - socially mobile households working off-farm with low incomes (M2, S2).

Five out of the six household groups with high food availability indicators were socially mobile, largely due to their higher education and high probability of being male-headed. These household groups displayed a range of livelihood strategies. Among these, we identified three typologies with high incomes and three with low incomes. The high-income households were commercial farmers producing cash crops (A2), livestock products (M1), or they were off-farm workers (M4). Commercial farming households also had substantial off-farm income sources (Figure 7.2). For the two high-income groups in Manica District (M1 and M4), this off-farm income may be related to the substantial artisanal gold mining activities (Dondeyne et al. 2009). Land ownership among M1 households was especially low, but they were nonetheless earning significant incomes from non-cropping production activities (most likely livestock sales) and therefore could not be considered non-farming households. The third high-income household group was from Angonia (A2). The relatively high-income households in Angonia earned more from cropping and off-farm activities, were socially mobile with high proximity to markets, and had less livestock than those in Manica (Figure 7.2).

The three remaining household groups with high food availability had low incomes. They were located in Sussundenga (S1), Gorongosa (G1) and Manica (M3). These groups were engaged in a mixture of income-generating activities, though they did not earn enough to be considered commercial farmers. M3 households were distinct from the other groups with high food availability from Manica District based on their relatively low incomes and consumption equivalents and high reliance on cropping income (rather than livestock or off-farm activities). S1 households were diverse in their income sources but appeared to make most money from non-cropping activities such as animal production (Figure 7.2). G1 households had high non-cropping farm income, though they owned no cattle (Figure 7.2) suggesting they may be earning more from chickens or goats.

Groups with low food availability included socially immobile low-income households (S3, G2, G3 and A1), socially mobile low-income households (A3 and S4), and socially mobile households working off-farm (M2 and S2). Relative to all other groups, the socially immobile households faced particular challenges. G2 households, in particular, lacked land and livestock, presenting a major challenge to agricultural production activities. S3 households had better productive resource endowment than G2 and G3 households, but were notable for having the highest proportion of female-headed families (Figure 7.2). G3 households were located furthest from markets among all groups identified in Mozambique, had little livestock and had the lowest income nationally (Figure 7.2). A1 households had relatively more (cropping and off-farm) income than S3, G2 and G3 households but had relatively low land availability and much less education. This suggests that they may be resource- (land) and knowledge-constrained, providing further challenges for sustainable intensification.

The socially mobile, low-income households were from Angonia (A3) and Sussundenga (S4). As with other households from Angonia, A3 households had a relatively higher income from cropping and off-farm work (Figure 7.2). They were also located relatively close to markets. S4 households were relatively more educated than other low-income households and had a high probability of being male-headed. However, these household were inexperienced with maize, had smaller family sizes (Table 7.4) and had low incomes from all sources.

The final household groups with low food availability (M2 and S2) had high social mobility but were not true farmers. They were found to be primarily off-farm workers based on their relatively low farming income and their high off-farm incomes (Figure 7.2). They both had relatively high education levels and were either located close to markets (M2 households) or had a high probability of being male-headed (S2 households).

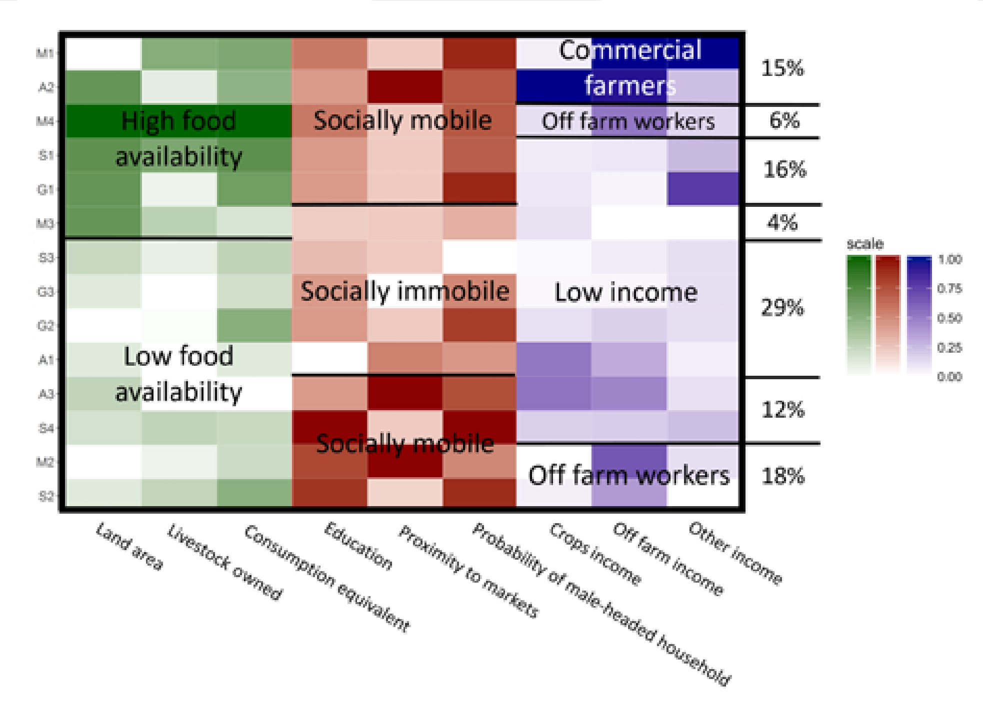


**FIGURE 7.2** Heatmap of farmer group characteristics and livelihood strategies of farmer groups in Mozambique. Farm types included from Angonia (clusters A1, A2 and A3), Gorongosa (clusters G1, G2 and G3), Manica (M1, M2, M3 and M4) and Sussundenga (S1, S2, S3 and S4). The intensity of each coloured cell indicates the value of the farm system variable for a household group relative to other groups (0–1, light to dark respectively). Three types of farming system variables were used: food availability levels (green), social mobility factors (red) and sources of income generation (blue). Food availability variables were the median values for land area, total livestock units (TLU) and consumption equivalents (CE) within each group. The social mobility factors were median education level (years of formal education), proximity to markets (walking minutes) and the probability (%) of being a male-headed household within the group. Income generation components were median income levels from crop sales, off-farm activities, and other (non-crop) farm sales. The percentage of households represented within each livelihood strategy is indicated on the right-hand side of the livelihood description.

## 7.5 HOUSEHOLD DEVELOPMENT OPTIONS

Households of the four districts covered in this study displayed a diversity of food availability indicators, social mobility and economic livelihoods. Resource endowment and connectivity to markets varied widely. This diversity, in turn, affected the suitability of various interventions.

### 7.5.1 Stepping out

A number of household types (M4, M2 and S2) showed characteristics of stepping out of low-income livelihoods into either high-value agriculture or non-household production. Of these, the M4 households were the only ones that had high food availability and high incomes that suggested they could be successfully stepping out. While across all sites M4 households appear able to transition out of agricultural production, their high level of productive assets and reliance on farm income at the district level cast some doubt on this assessment. M4 households (24% of those sampled in Manica) had the most land and highest consumption equivalents of households in their district. Forty per cent of M4 households gained at least 25% of their income from crop production. Therefore, it may be that only some of the M4 households would be able to transition from household production to other non-farm work.

### 7.5.2 Stepping up

Two household groups displayed clear characteristics of improving their wellbeing through improving existing activities. This is what Dorward et al. (2009) termed stepping up. These were M1 and A2 households, both of which were successful high-income groups. Another three household groups (A1, A3 and S4) may be viewed as stepping up when considering their development options, but their low income and low food availability indicators meant they failed to properly fit into this category.

M1 and A2 households were both successful commercial farming households. They had clear but somewhat distinct local advantages, and would be likely to benefit from productive innovations. Both A2 and M1 groups were deemed socially mobile, with A2 being particularly close to markets and M1 households having a high probability of being male-headed. They are likely to be able to take advantage of improvements to local crop or livestock management given their existing success in commercial cropping. M1 households were notable for the extremely high number of input traders known (Table 7.3), while A2 households had several advantages such as relatively good market connectivity, and more labour and livestock (Table 7.1). As highly successful farmers, farm-related options for improving their livelihoods could act as suitable opportunities for this group. Specific interventions may be transformative technology such as herbicides, improved seeds or mechanisation—possibly requiring access to credit. They may also benefit from improved institutional and market settings given their existing commercial orientation and proximity to markets (see Section 2.5 Institutional setting and innovations).

### 7.5.3 Hanging in

The remaining households with high food availability indicators (S1, M3 and G1) were all low income and diversified in their livelihoods. None of these households indicated strong commercial farming relative to the total sample (Figure 7.2). Those in Manica and Sussundenga were similar in being older, less educated and proportionately more female-headed (M3 in particular) compared to other household groups in their respective districts (Tables 7.3 and 7.4). This would suggest that some degree of knowledge deficit or lack of access to information may be constraining these household groups.

M3 households were earning more income from their cropping, meaning they may be responsive to field-level production innovations (see Section 2.4 Field management and productivity innovations). S1 households had a relatively high proportion of female-headed households and therefore programs looking to address gender inequities may look to improvements in livestock (particularly cattle) management as a means to benefit women farmers. G1 households had more cultivated areas than other households in Gorongosa (Table 7.2) and had relatively high non-cropping production incomes at the national level (Figure 7.2). This high non-cropping income may be derived from chicken sales meaning assistance with poultry management could allow for more secure livelihoods of these households.

### 7.5.4 Risk of food insecurity

Fifty-nine per cent of all surveyed households were deemed to be at risk of food insecurity. These groups all displayed relatively low levels of indicators of food availability (Frelat et al. 2015) at the national level (Figure 7.2). Among these household groups were those with diversified income sources (G2, S3, G3 and S4), or more market-oriented farming incomes (A3 and A1), and those considered not farmers (M2 and S2). In general, there was a trend towards less education in at-risk households, though aside from this they varied in most key social mobility indicators and economic outcomes (Figure 7.2). At the local level, all of these households had relatively less land (in Angonia, Manica and Gorongosa) or labour (in Sussundenga) suggesting they suffered key resource constraints to household food production (Tables 7.1, 7.2, 7.3 and 7.4). The low-income households in Angonia (A1 and A3) had much higher incomes than most at-risk households. This suggests that due to their income they may not currently be food-insecure but rather could be vulnerable to economic shocks that affect their commercial activities. Thus, the risk of food insecurity in Mozambique appears to be primarily a function of productive resource constraint.

***Market-oriented at-risk households***

The low-income but market-oriented households (A1 and A3) had higher incomes than other at-risk households but were vulnerable to external shocks given their lack of household production (Figure 7.2). These households demonstrate that market participation is necessary (but not solely sufficient) for high incomes. Other factors such as prices received and the degree of participation (i.e. amount sold) are critical. These households may benefit from productive innovations, but despite differences all face some resource constraint to intensification. A1 and A3 households differed in age and experience with maize production, though their family sizes and livestock were similar and smaller than the more affluent A2 households (Table 7.1).

A1 households were the least educated of all household types and had lower probability of being male-headed households. They might benefit from efforts to reduce knowledge gaps in field-level management that target female farmers. A1 households were also located further from markets and would likely be assisted by institutional innovations to allow greater (and cheaper) market access. They may also benefit from specialising more towards intensive crop production given their limited land availability. This may require access to different crop seeds and assistance in non-maize cropping.

A3 households had easier access to markets but had less experience in maize production (Table 7.1) and low consumption equivalents (Figure 7.2). These households could benefit from interventions aimed at an increase in cropping activities. This could encompass credit schemes for inputs (particularly seed) and increasing labour efficiency.

### *Diversified at-risk households*

Low-income and diversified at-risk households (G2, G3, S3 and S4) were all constrained by relatively less productive resources (Figure 7.2), and except for S4 were socially immobile. The lower productive resources of these four household groups was likely related to regional disparities (G2 and G3), gender inequities (S3) or their youth (S4).

S3 households had a lower probability of being male-headed than any other group (Figure 7.2), suggesting some possible connectivity or resource constraints due to gender inequities. Locally, S3 households had the lowest estimated asset values and were the least educated group (Table 7.4). S4 households had relatively smaller families at the district level and had the least proportion of fertile soil in their region (Table 7.4). Due to their less experience with maize, younger age of household head, relatively high distance from extension and reliance on cropping for income (Table 7.4), S4 households seem likely to benefit from increased knowledge of best crop management.

The remaining diversified at-risk households were in the Gorongosa District (Table 7.2). These household groups may have suffered district-level characteristics that disadvantaged them. All were relatively worse off due to their low land:labour ratio (Figure 7.1a), lack of cattle (Figure 7.1b) and lesser market access (Figure 7.2). Despite poor outcomes in production, special effort may be needed in this district to allow transformation of the market and/or institutional environment to provide better opportunities for these households. They may be able to increase their incomes if market access were improved in their communities. Recent efforts to develop the district in conjunction with the Gorongosa Restoration Project as a vehicle for social and environmentally conscious market development are encouraging (Diallo 2015), though these efforts are hampered by ongoing conflict in the area (Schuetze 2015).

### *Non-farming at-risk households*

The low-income households engaged in significant off-farm work included a group from Manica (M2) and one from Sussundenga (S2). Despite their low income, both of these groups had local advantages for off-farm work that related to their social mobility. They were both well connected to markets or institutions and well educated (Tables 7.3 and 7.4). Due to their lower productive resources (e.g. farm size), stepping out of household production may be a development option for them. Both of these household groups were younger, as well as already reliant on off-farm work for their livelihoods. Given these households are primarily off-farm workers, their at-risk status is largely a reflection of their low-income status rather than their food availability indicators.

## 7.6 CONCLUSIONS

Our results demonstrate how even within a single community or typology group, pathways to sustainable intensification and livelihood improvement will vary greatly. Depending on households' present performance, assets and livelihood strategies, efforts to improve incomes and livelihoods will be focused on one or more areas:

- assistance transitioning out of farming work and into employment in other sectors
- improvement in field-level crop management (either maize or cash crops depending on the particular needs) to increase food security or farm income
- improved livestock management and production to increase farm incomes

- training, provision of credit and assistance in adopting transformative technology (e.g. improved germplasm, mechanisation, herbicides)
- improved market access to increase commercial opportunities.

Which of the broad strategies listed above are suitable depends on the particular resource, performance and income profile of each household group. In this chapter, we have explored how these strategies may match particular groups. However, rigorous assessment of household status and possible interventions, with genuine community participation, is an essential step in any targeted and successful research and/or development project. What we have demonstrated is the breadth of diversity in smallholder communities of Mozambique, along with a template for quantifying and accounting for this diversity.

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# MALAWI

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# KEY POINTS

- The 891 households included in this case study spanned high and low productive potential areas, representing six districts of central (five) and southern (one) Malawi.
- The households from high-potential districts depended more on farm production as their income source than households from low-potential regions.
- Local disparities in market access, experience in growing crops, household assets (land, labour, animals) and household consumption equivalent were found in both the high-potential and low-potential regions.
- Households fell into three groups in the high-potential area and three groups in the low-potential area based on differences in characteristics that reflected local disparities.
- Four livelihood strategies were represented among farmer groups in Malawi:
  - socially mobile, commercial farming households with high food availability and high income (42%)
  - socially mobile off-farm workers with high food availability and low income (14%)
  - socially mobile diversified farming households with high food availability and low income (18%)
  - socially mobile off-farm workers with low food availability and low income (26%).
- Only 26% of households were at risk of food insecurity, and these were socially constrained by either low education or being female-headed households.
- The highest income households were commercial farmers and earned their income from sales of crop and livestock products.
- Two low-income farming household groups that were well positioned for intensification would likely benefit from transformative production innovations or institutional innovations, particularly access to markets.
- The most at-risk, food-insecure groups could benefit from either direct aid (safety nets/social security), more off-farm work opportunities or assistance in intensifying their production.

## 8.1 COUNTRY OVERVIEW

Malawi is a southern African country located north-east of Tanzania, north-west of Mozambique and west of Lake Malawi. It is a poor and mostly rural country with low levels of human development. In 2015, the national population was 17.2 million and 83.7% of the people lived in rural areas (World Bank 2017). GDP in 2015 was only US$6.4 billion (World Bank 2017). The Human Development Index from 2016 national data positioned Malawi at 125 out of 138 countries. This ranking reflects the poor quality of infrastructure, including roads, railroads, electricity and mobile phone subscription levels (Schwab 2016). Malawi was ranked particularly low in factors that could limit household income potential and food security, including the macroeconomic environment, health, primary education and market efficiency (Schwab 2016). Based on 2012 figures, the country relies on agriculture for 35% of its GDP and 80% of its employment (Ngwira et al. 2012). Based on 2010 figures, 56.6% of the rural population lived below the national poverty line (World Bank 2017). According to 2008 national census data, over 80% of the population lives in the central and southern regions (NSO 2010). Between 2014 and 2016, over 20% of the population was undernourished, and 71% of energy supply came from cereals, roots and tubers (FAOSTAT 2017). Based on this, the wellbeing of Malawi's population and the economy are closely tied to the agricultural sector and particularly household crop production.

Smallholders in Malawi face a unique set of production circumstances. The country's subhumid environment is broadly favourable, with average rainfall ranging from 600 to 1,300 mm in the southern and central regions (Thierfelder et al. 2013). Maize has been the major crop for household producers, with around 70% of land historically dedicated to maize production (Alwang and Siegel 1999). Maize yields have been high when compared with regional standards. Between 2005 and 2014, maize yields averaged 1.9 t/ha across the country, compared with 1.3 t/ha for southern Africa (excluding South Africa) over the same period (FAOSTAT 2017). Field management practices, especially conservation agriculture, have been promoted to help reduce land degradation from increasing production pressure, as well as to address labour shortages (Ngwira et al. 2012; Thierfelder et al. 2013). Malawi stands out from the other case study countries for its Farm Input Subsidy Programme (FISP) (Dorward and Chirwa 2011), and also the longstanding conservation agriculture practice by household producers of using tied ridges (Andersson and D'Souza 2014). Fertiliser use on maize crops has been recorded as high as 88% in central Malawi, and hybrid maize seeds are commonly used (Mungai et al. 2016). However, contrasting these advantages, land holdings are particularly small and have been declining. For instance, 40% of smallholders owned less than 0.5 ha of land in the 1990s (World Bank 1996), and more recent research indicated holdings of only 0.2–0.3 ha (World Bank 2007). The country's population growth has been cited as the main reason for this decrease (Alwang and Siegel 1999; Mungai et al. 2016), although production area has been increasing (FAOSTAT 2017). Legume production is given less importance than maize (e.g. no fertiliser or manure, residue removal from fields) due in part to a lack of promotion through extension programs (Mungai et al. 2016), with negative implications for nutrient and soil management of small landholdings. Another important challenge is the widely reported labour scarcity among smallholder producers during times of peak demand (Mungai et al. 2016).

Key development indicators such as literacy levels, childhood malnutrition and schooling are similar across many central and southern districts (NSO 2017). However, the country's variable agroecological conditions and household management practices are major factors shaping local crop yields, household incomes and food security (Mukherjee and Benson 2003). Multiple subregions of Malawi have been characterised to reflect varying levels of productivity potential, based on evapotranspiration and rainfall variability (Mungai et al. 2016). The households included in this case study were from three high-potential districts (Lilongwe, Kasungu and Mchinji) and two low-potential districts (Salima and Ntcheu) in the central region (Benson et al. 2016). A third, low-potential district in the southern region(Balaka) was also included in the study (Benson et al. 2016). All these districts fall within the moist and semi-arid agroecological zones, though a small northern segment of Kasungu District falls in the subhumid agroecological zone. Based on 2008 census data, the high-potential districts in this study include 17.7% of the national population, while only 8.6% live in the low productive districts (NSO 2010). Social indicators in these regions are similar. The proportion of the population without any formal education was 21.6% and 24% for high-potential and low-potential districts respectively (NSO 2010).

## 8.2 REGIONAL DIFFERENCES

Households in higher potential districts (Lilongwe, Kasungu and Mchinji) had greater land:labour ratios (Figure 8.1a), higher incomes (Figure 8.1c), more education (Figure 8.1e), higher crop income (Figure 8f) and were more reliant on income from farming (Figure 8.1d). Total livestock owned was comparable between regions though median total livestock units (TLU) were slightly higher in low-potential districts (Figure 8.1b). No discernible differences were observed in either total spending or food spending (data not shown), indicating that households in higher potential areas had greater cash surpluses.

## 8.3 HOUSEHOLD TYPOLOGIES

Households within the high (Lilongwe, Kasungu, Mchinji) and low (Balaka, Ntcheu and Salima) productivity potential regions were classified into groups based on characteristics that accounted for the largest disparities (i.e. variance) in those regions. Disparities in household access to markets, experience in growing crops, asset acquisition (land, labour, animals), and the household consumption equivalent were identified in both regions.

### 8.3.1 High productivity potential regions

Major disparities in the high-potential areas were in household access to the components of the socioeconomic corridor (access to fertiliser markets, extension services and knowledge of institutions), farm size, number of chickens owned, level of experience growing maize and consumption equivalents. Households in high-potential areas fell into three groups (H1, H2 and H3) based on these characteristics. H1 households (40% of high-potential households) were younger and less experienced at growing maize than the other groups in the high-potential region. Their food production (i.e. consumption equivalent) was also the lowest in the high-potential region (Table 8.1). H2 households (30%) were the oldest, most experienced in crop production, and had more chickens and consumption equivalents of all the groups in the high-potential region. However, H2 households had the lowest incomes and asset values in the region (Table 8.1). These characteristics suggest that H2 households were more subsistence than commercial in their production orientation. H3 households (30%) had the highest land area and asset values, and despite being furthest from input (seed) markets, also had the highest incomes.

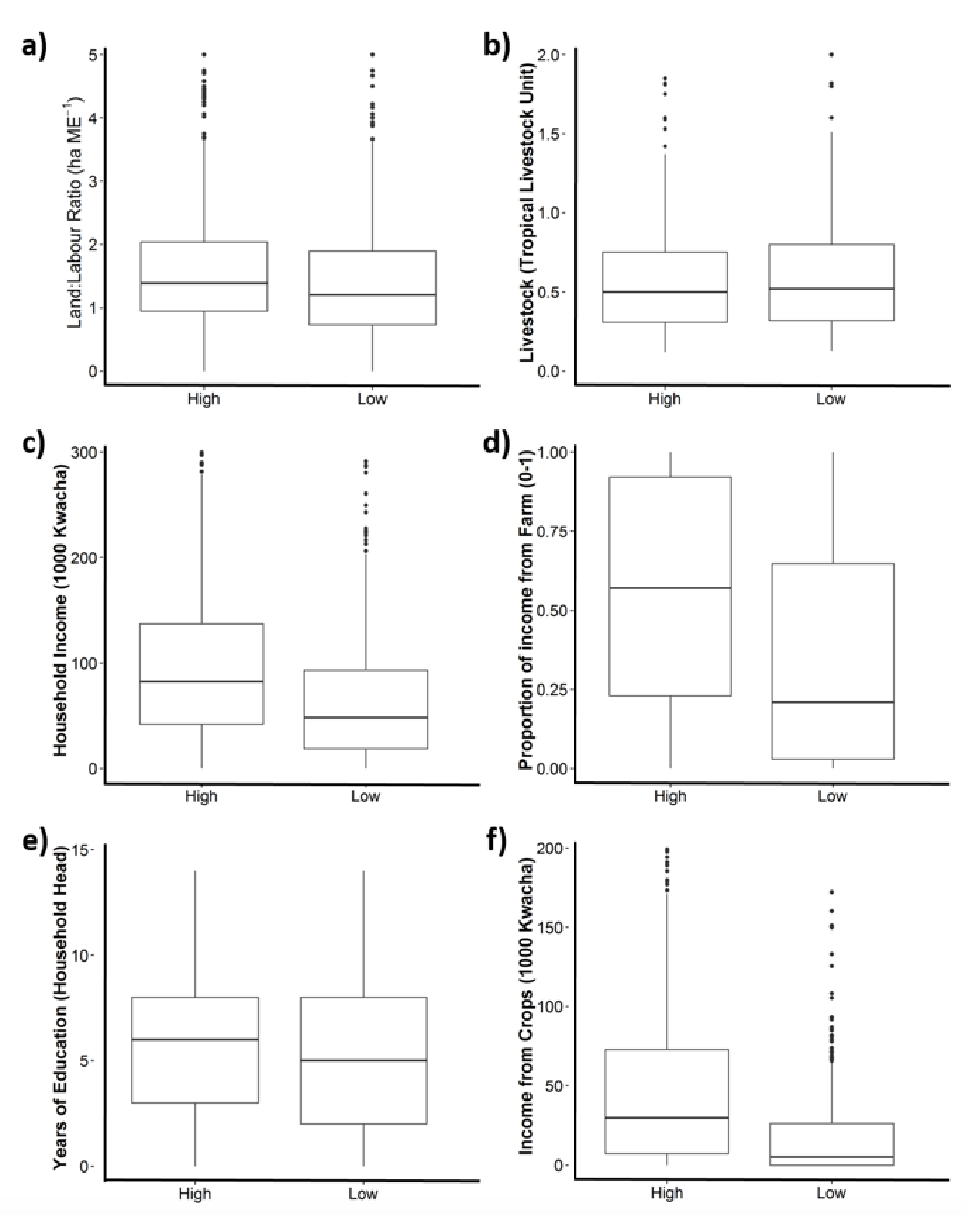


**FIGURE 8.1** Box plots showing differences between high (Lilongwe, Kasungu and Mchinji) and low (Balaka, Ntcheu and Salima) production potential districts in median, interquartile ranges, and 10th and 90th percentile of key household indicators: (a) land:labour ratio; (b) livestock (TLU); (c) household income (Malawian Kwacha); (d) proportion of household income derived from farming activities; (e) education of household head; and (f) income from crop sales.

**TABLE 8.1** Cluster medians (and standard deviations) for the cluster variables (shaded) and independent household characteristics in high production potential districts of Malawi (Kasungu, Lilongwe and Mchinji) (n = 532)

| Cluster variables | Frequencies (%) or cluster medians (standard deviations) | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | *P*-value [a] |
| | 40% | 30% | 30% | |
| Distance to fertiliser (walking minutes) | 60 (47) | 60 (39) | 120 (81) | 0.103 |
| Experience growing maize (years) | 9 (6) | 29 (12) | 13 (10) | >0.000*** |
| Consumption equivalent (t/ME/year) | 3.3 (1.3) | 5.2 (1.9) | 4.5 (2.1) | >0.000*** |
| Farm size (ha) | 2.6 (1.5) | 3.3 (1.8) | 4.5 (4.4) | 0.023** |
| Distance to extension (walking minutes) | 5 (23) | 9 (17) | 30 (68) | 0.382 |
| Total asset value (1,000 Kwacha) | 20 (43) | 19 (35) | 29 (138) | 0.659 |
| Institutions known | 0 (0.89) | 0 (0.48) | 0 (0.68) | >0.000*** |
| Chickens owned | 7 (5) | 15 (14) | 7 (4) | 0.501 |
| Female-headed (%) | 13 | 6 | 11 | 0.825 |
| Reliant on cropping (%) | 62 | 70 | 65 | 0.597 |
| Reliant on off-farm work (%) | 70 | 46 | 66 | 0.776 |
| Reliant on non-cropping farming (%) | 8 | 12 | 4 | 0.078. |
| Age (years) | 32 (9) | 52 (13) | 39 (13) | >0.000*** |
| Education (years) | 6 (4) | 5 (3) | 6 (3) | >0.000*** |
| Household income (1,000 Kwacha) | 114 (117) | 79 (154) | 129 (208) | 0.338 |

[a] ANOVA test (*, **, *** for *P*- value <0.05, 0.01 and <0.001 respectively)

### 8.3.2 Low productivity potential regions

Major disparities in the low potential area were in household access to the components of the socioeconomic corridor (access to seed markets and knowledge of institutions), manure application levels, number of sheep and goats owned, level of experience growing maize and consumption equivalents. Households in these districts fell into three clusters (L1, L2 and L3). L1 households (34%) were more experienced growing maize, had higher consumption equivalents, smaller farms (2.3 ha), were less educated, and had lower incomes and estimated asset values than the other low-potential groups (Table 8.2). L2 households (39%) were the wealthiest group in the low-potential area. They had the largest farms (3.5 ha), the highest consumption equivalents, most sheep and goats, knew more institutions, and had the highest incomes and asset values (Table 8.2). L3 households (27%) were the poorest of all household clusters in both regions. They were also young, had little experience growing maize, low consumption equivalents, small farms, and low income and asset values relative to the other groups in the low-potential region (Table 8.2).

**TABLE 8.2** Cluster medians (and standard deviations) for the cluster variables (shaded) and independent household characteristics in low production potential districts of Malawi (Balaka, Ntcheu and Salima) (n = 359)

| Cluster variables | Frequencies (%) or cluster medians (standard deviations) | | | |
|---|---|---|---|---|
| | L1<br>34% | L2<br>39% | L3<br>27% | *P*-value [a] |
| Distance to seed markets (walking minutes) | 60 (57) | 60 (83) | 60 (61) | 0.401 |
| Experience growing maize (years) | 25 (15) | 18 (11) | 5 (5) | >0.000*** |
| Consumption equivalent (t/ME/year) | 4.3 (1.5) | 4.5 (1.8) | 2.8 (0.8) | >0.000*** |
| Farm size (ha) | 2.3 (1.0) | 3.5 (2.8) | 2.1 (1.2) | >0.000*** |
| Sheep and goats owned | 3 (3) | 5 (11) | 3 (2) | 0.025* |
| Amount of manure applied to maize (kg/ha) | 0 (78) | 0 (268) | 0 (86) | >0.000*** |
| Institutions known | 0 (0.33) | 1 (0.7) | 0 (0.26) | >0.000*** |
| Female-headed (%) | 6 | 11 | 25 | 0.491 |
| Reliant on cropping (%) | 43 | 34 | 40 | 0.505 |
| Reliant on off-farm work (%) | 72 | 81 | 83 | 0.026* |
| Reliant on non-cropping farming (%) | 9 | 8 | 3 | 0.084. |
| Age (years) | 52 (15) | 43 (14) | 29 (10) | >0.000*** |
| Education (years) | 3 (3) | 6 (4) | 6 (4) | 0.830 |
| Household income (1000 Kwacha) | 46 (142) | 69 (198) | 40 (102) | >0.000*** |
| Total asset value (1000 Kwacha) | 20 (74) | 33 (133) | 12 (46) | >0.000*** |

[a] ANOVA test (*, **, *** for *P*-value <0.05, 0.01, and <0.001, respectively)

## 8.4 LIVELIHOODS ACROSS MALAWI

Four livelihood strategies were represented among farmer groups in Malawi. The majority of households had relatively high food availability. Typology groups represented a range of social mobility factors but were all considered socially mobile. The relative dependence on crop and off-farm sources of income, as well as overall income levels, were the principal sources of distinction between groups. The groups were:

- high food availability:
  - socially mobile commercial farming households with high income (H3 and H1)
  - socially mobile non-farming households with low income (L2)
  - socially mobile diversified farming households with low income (H2)
- low food availability:
  - socially mobile non-farming households with low income (L1 and L3).

H3 and H1 groups had high food availability, were engaged in commercial farming and had high incomes. These groups were more educated than three of the four low-income households, i.e. L2, H2 and L1 (Figure 8.2). The high-income households were located in the higher potential districts of Lilongwe, Kasungu and Mchinji. H3 households were highly successful farmers, relying only on crops and livestock for their income (Figure 8.2). Their location far from markets might have limited crop sales among these households. In contrast to the H3 group, H1 households relied on a combination of off-farm income, cropping and non-crop activities (Figure 8.2).

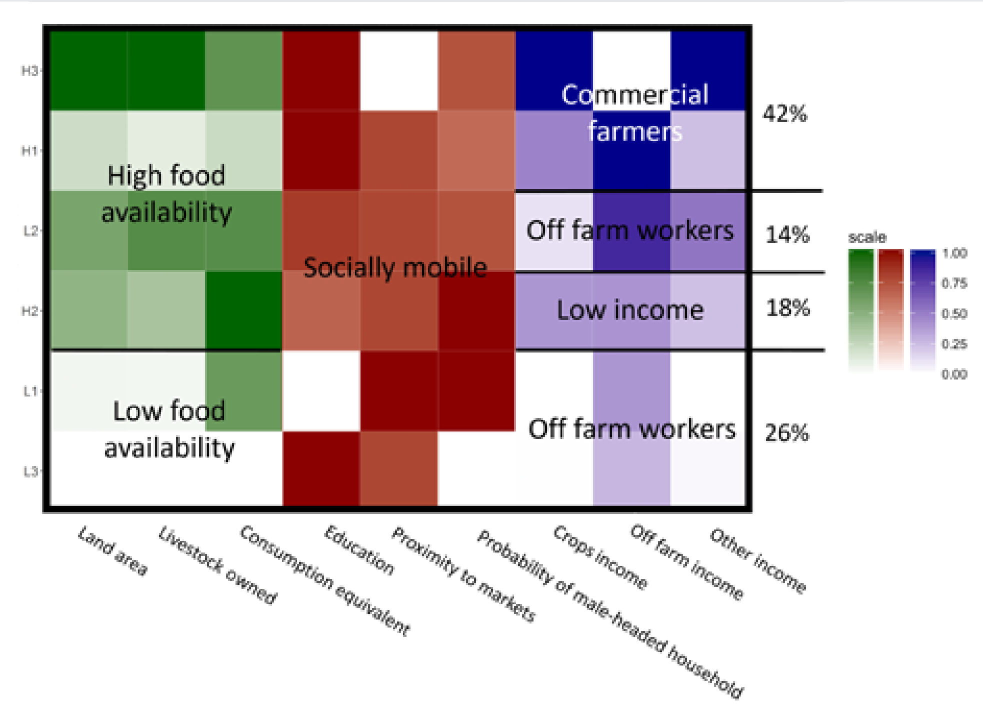


**FIGURE 8.2** Heatmap of farmer group characteristics and livelihood strategies of farmer groups in Malawi. Farm types included from high production potential districts (clusters H1, H2 and H3) and low production potential districts (clusters L1, L2 and L3). The intensity of each coloured cell indicates the value of the farm system variable for a household group relative to other groups (0–1, light to dark respectively). Three types of farming system variables were used: food availability levels (green), social mobility factors (red) and sources of income generation (blue). Food availability variables were the median values for land area, total livestock units (TLU) and consumption equivalents (CE) within each group. The social mobility factors were median education level (years of formal education), proximity to markets (walking minutes) and the probability (%) of being a male-headed household within the group. Income generation components were median income levels from crop sales, off-farm activities, and other (non-crop) farm sales. The percentage of households represented within each livelihood strategy is indicated on the right-hand side of the livelihood description.

The L2 typology group also had high food availability and commercial farming income, but was considered to be primarily ‘off-farm workers’ due to their relatively high income from this activity (Figure 8.2). L2 households gained most of their income from a mix of livestock and off-farm activities. These low-income households were located in the low productive potential districts and were relatively less educated than H3 and H1 households (Figure 8.2).

The only diversified livelihood group with high food availability (H2 households) comprised 18% of the total sample and was located in the high-potential districts. These were relatively less educated that other households from high-potential districts (Figure 8.2). They were overwhelmingly male-headed and, though they pursued a diversified livelihood strategy, had greater earnings from crop production than non-crop farming (Figure 8.2).

The remaining two household groups with low food availability (L1 and L3) were both specialised in off-farm work for their incomes (Figure 8.2). L1 households tended to be proportionately more male. They were also the least educated of all typologies, suggesting their off-farm work was unskilled and therefore likely to be lower paid (Figure 8.2). The L3 group, representing 10% of households, also lived in the low productive region and, like L1 households, depended mainly on off-farm sources of income and were not true farmers. These households were more educated and proportionately more female-headed than L1 households and appeared to be resource-constrained (Figure 8.2).

## 8.5 HOUSEHOLD DEVELOPMENT OPTIONS

### 8.5.1 Stepping out

H1 households were high-income and highly successful off-farm workers and are suitably positioned to make the transition out of agricultural livelihoods. While they were able to earn income from crop production (in particular) and non-crop farming (to a lesser extent), they had low productive resources at the national level (Figure 8.2). These households had local advantages in being younger, more educated, having high estimated household asset value and were located much closer to markets (Table 8.1). However, they had fewer productive resources than H3 households (particularly land and livestock). Their food crop yields were among the lowest of all farm types (1 t/ha maize yield and 419 kg/ha bean yield). These low yields underpinned their low consumption equivalent (their higher incomes made them food-secure). Therefore, they may have potential for improved field management (see Section 2.4 Field management and productivity innovations). However, because they appeared to be better off due to their high non-farming income (possibly due to market proximity), these households may be best suited to specialising in off-farm activities. Therefore, institutional innovations (see Section 2.5 Institutional setting and innovations) that facilitate this transition may be of most benefit to H1 households.

### 8.5.2 Stepping up

The next group of households (L2, H2 and H3) identified in Malawi offer the most suitable target group for traditional field-level productivity innovations.

The highest performing of these households (H3) appeared suitable for transformative productivity innovations (such as mechanisation) or institutional innovations (e.g. improved market accessibility). They had local advantages in their land and education levels, but were located further from markets than other household types in high productive regions (Table 8.1). Despite their disadvantaged market access, they had the highest income of all farm types in Malawi, demonstrating effective exploitation of their high resource endowment and education. Thus, these households may benefit from greater market access and further commercial opportunities (e.g. new crops). They may also be suited to transformational interventions such as new genetic resources, mechanisation or credit for land investment. These types of interventions would require teams with different skills (e.g. agribusiness experts, economists, value chain specialists) rather than more traditional agricultural research for development projects. There may also need to be a greater effort to understand cultural factors in local agribusiness and government policy in order for such projects to succeed.

The other stepping-up households (L2 and H2) are likely to benefit more from productive innovations. They have shared advantages in their experience with maize, medium farm sizes and livestock owned. They also have specific advantages in their proximity to markets (H2) or total asset value (L2). Both farm types had moderate land resources, mid-level education, and relatively close proximity to markets (Tables 8.1 and 8.2). While their incomes were not in the top half of the range observed, these households show good potential as sound farm managers. L2 households were apparently earning most of their income from off-farm work, perhaps suggesting they do not view agriculture as a means of increasing their income. Households in these two groups may require assistance in transitioning to other commercial cropping activities, including credit provision for inputs and seed. They may also need extension assistance with livestock management to improve their herd fertility and milk or meat production. They could benefit from assistance in agronomy, crop variety selection (where appropriate), improving animal nutrition and judicious residue and soil management. Such efforts would allow them to intensify their production and increase incomes.

### 8.5.3 Risk of food insecurity

Two household groups (L1 and L3) were found to be at risk of food insecurity based on their low food availability. L1 households appeared to be resource-constrained in comparison to higher income groups. These households are unlikely to be able to improve their farm productivity or income without some increase in those resources. In particular, they owned relatively small areas of land and had less livestock (Table 8.2). This, along with their location in lower potential areas, means they are less able to derive income from their farming. This raises challenges for sustainable intensification efforts in the country as these farmers may, in fact, be better suited to transition out of farming. L1 households may be restricted in achieving this by their poor education. Further study of these households may find that there are opportunities to improve their household food security through simple, non-cost interventions at the field level, though labour and land availability may prove constraining in this context.

The other at-risk group (L3) were proportionately more female-headed, suggesting particular gendered circumstances of disadvantage could exist in the lower productivity regions. While they had a reasonably high education level, their estimated asset value was extremely low (Table 8.2). At the local level, these households were more constrained by their relative youth and lack of experience with maize production and they may actually benefit from more off-farm income (Table 8.2). They may also require some direct aid assistance and, despite their low land and livestock (Figure 8.2), would certainty benefit from some level of field-management assistance to improve crop productivity and enhance food security.

## 8.6 CONCLUSIONS

The households surveyed in Malawi presented three pathways with respect to sustainable intensification of the various farm types. First, there was a category of very poor and resource-constrained households, not truly engaged in farming activities for income and with low potential for improvement (L1 and L3). Second, there were the high performing households with demonstrable skill in farm management (H3) or an indication of having successfully focused earning from rewarding off-farm work (H1). Finally, there were households in both areas that presented engagement with farming, some degree of success in their exploitation of productive resources, but had room to improve (i.e. intensify) their production with their existing resource base (L2 and H2). By separating households by their major differences and summarising key attributes, we can better understand how to strategically approach sustainable intensification of cropping systems, aid and development efforts.

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# SECTION 3

# THE FUTURE OF INTENSIFICATION IN EASTERN AND SOUTHERN AFRICA

# DYNAMIC MODELLING OF HOUSEHOLD DATA

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# KEY POINTS

- Modelling tools can be valuable for quantifying benefits and trade-offs in both short-term management practices and tactics that increase productivity and reduce risks in variable climates; and the medium- and longer-term impacts from changes in strategies, farming system designs and resource allocations.
- Advances in connectivity, access to internet, developments in big data, networks of sensors and computing speed mean that, more than ever before, research and practice for change in dryland agricultural systems will rely on simulation and prediction.
- Over the last 20 years, we have moved from modelling plants, crops, cropping systems and farming systems (including livestock) to modelling farms and farmers. Though a number of challenges still exist, progress is expected in the near future from modelling multiple farms and farmers in a shared landscape, their interactions and connectivity with markets and rural communities.
- The use of complicated whole-farm models remains in the realm of research. Developing critical mass in the use of dynamic modelling tools to support farming system research activities should remain a key effort in research for development programs.

## 9.1 UNDERSTANDING THE CONSEQUENCES OF INTENSIFICATION

As the previous chapters demonstrate, households can be highly diverse. They display wide variation in numerous farm components and different types of intensification opportunities and constraints. Household typologies provide a useful means of understanding this diversity and have often formed the basis of development recommendations (Maltsoglou and Taniguchi 2004; Yuerlita et al. 2013; Sakane et al. 2014). However, typologies developed from survey data only represent a point in time, and completely miss the trajectories or dynamics that are likely to be available to different household types, both temporally and spatially (van Wijk 2014). A remaining challenge in establishing development recommendations is to move beyond inferences based on typologies to ask: 'What are the likely responses of different households to alternative interventions?' This chapter aims to answer that question.

Here we highlight the importance of systems thinking in:

1. identifying problems
2. analysing boundaries of the system under improvement
3. designing interventions
4. combining big data and dynamic modelling tools to predict likely impacts from alternative interventions
5. monitoring and evaluating successes and failures.

However, a note of caution is needed. The use of dynamic modelling tools best fits the realm of complicated though *predictable* biophysical systems, i.e. systems composed of a number of measurable and interacting components driven by nature's first principles or functional relationships. Households are not only complicated, they are also complex systems (Rodriguez and Sadras 2011). Human factors (e.g. decision-maker preferences, emotions, values), social dynamics and their interactions with biophysical aspects of production contribute substantially to the challenge of predicting farming-system outcomes. A common language for engaging in dialogue with stakeholders has been essential for overcoming this challenge in development and application of dynamic whole-farm models. Therefore, the value of combining dynamic whole-farm models to help describe, explore and explain survey household data (see Box 3.1) remains in the domain of producing relevant and actionable information to inform discussions with decision-makers. An example of relevant information that can be derived from dynamic whole-farm models includes the quantification of benefits and trade-offs from alternative innovations or development scenarios. With dialogue in a common language, modellers, societies and farmers themselves can be better informed of the likely consequences and risks associated with alternative decisions.

### 9.1.1 Households as the boundary of the system under study

High productivity is the result of optimum combinations of crops, cultivars and management variables that best fit a particular environment, characterised in part by limited resources (e.g. labour, land, finances), allocated across enterprises and fields at the whole-farm level (Calviño and Monzon 2009; Rodriguez and Sadras 2011; Power et al. 2011). As a result, focusing on individual crop yields is necessary but insufficient to produce whole-farm level insights (e.g. total food production, farm profits and down side risks), particularly when multiple resources co-limit the system. Large improvements in production or income often occur from interventions at scales beyond the crop, the selection of the cultivar or the management of a particular field. Crop yields often emerge out of management to satisfy competing objectives (e.g. livelihoods, returns, lifestyle and environmental or societal outputs) rather than to singularly increase crop yields. Therefore, only when the analysis is performed at the whole-farm level can the implications from changes in one enterprise at any point in time be observed on the farm (e.g. due to cash, land, labour or machinery constraints) and across seasons (e.g. due to follow-on implications for soil water and nutrient availability or the need for pest or disease breaks between successive crops) (Sadras et al. 2009; Rodriguez and Sadras 2011; Power et al. 2011). This chapter discusses the value of stepping up the analysis from the field to the whole farm, and how dynamic whole-farm modelling tools can be used to capture these effects across the diversity of smallholder farmers. The primary aim of the analysis is to provide quantitative measures of benefits and trade-offs from alternative interventions and intensification options at the level that farmers think and make decisions: the whole farm and the household.

In whole-farm system analyses, the boundaries of the system become the farm rather than the field, and key resources become the availability of land (of different use, type and fertility), labour, cash, management resources and skills. It is at this level of analysis that agricultural system modelling tools are most useful. Such models can quantify synergies and interactions, benefits and trade-offs from alternative practices, tactics within alternative strategies and competing objectives. All this can be achieved against the background of the need for increasing food production or income among poorly resourced farmers facing high levels of climate variability and uncertainties.

## 9.2 THE APSFARM-LIVSIM MODEL

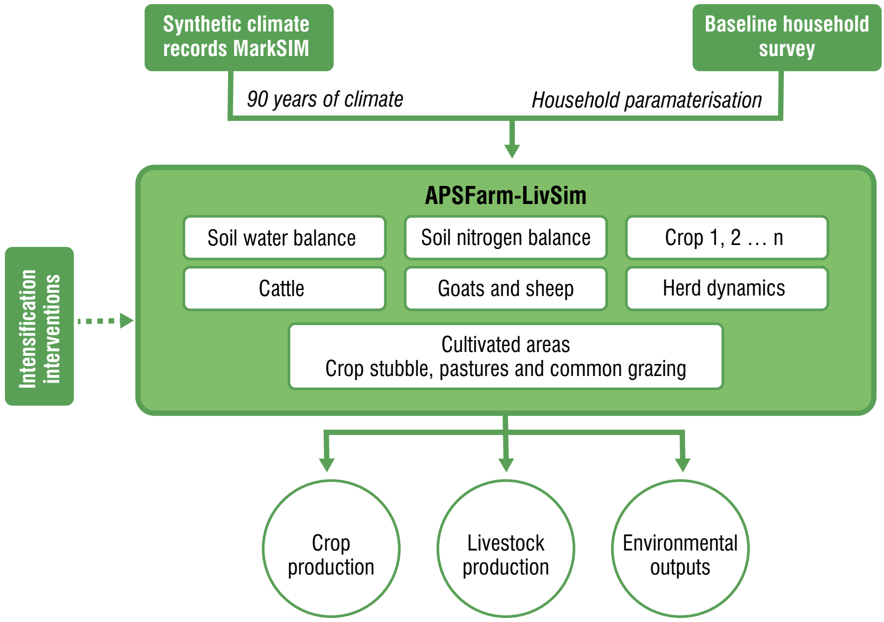
The whole-farm model APSFarm (Rodriguez and Sadras 2011), developed over the last 10 years, is an extended configuration of the APSIM model (**www.apsim.info**). APSFarm allows users—primarily researchers—to simulate the impacts (i.e. economic, financial, environmental) of alternative allocations of limited production resources (e.g. land, labour, time, irrigation water, livestock, machinery and finance) across alternative farm enterprises at the whole-farm level. Model outputs can then be used to inform discussions with stakeholders of interest (e.g. farmers, innovation platforms, policy, businesses). APSFarm was first released with APSIM 7.2, and includes templates for the simulation of large-scale commercial rain-fed cropping (Rodriguez and Sadras 2011), irrigated cropping (Power et al. 2011) and mixed grain and grazing farm businesses (Rodriguez et al*.* 2014, 2017).

The main limitations in the use of whole-farm models in research for development has been model parameterisation. Empirical data from household surveys, like those presented in the case studies of the preceding chapters, can be used to parameterise complicated whole-farm models (Box 9.1).

### 9.2.1 Applications of the APSFarm-LivSim model

Previous chapters review history and recent evidence that smallholder farmers of ESA manage limited resources, and can face a high risk of livelihood and food insecurity. Under high-risk dynamics, changes in the allocation of land, cash or labour may result in benefits but also trade-offs, where other household characteristics fall below crucial threshold levels. Tools that help quantify these trade-offs can also help to identify opportunities to manage them by generating information that better matches innovations to local circumstances.

## BOX 9.1 The APSFarm-LivSim model




A schematic diagram illustrating the integration of the APSFarm and LivSim models using climate and household data to model crop, livestock and environmental outputs from intensification interventions.

APSFarm-LivSim was developed by combining the APSFarm model developed by Rodriguez and Sadras (2011) and a livestock model developed by Rufino (2008). APSFarm is the extended whole-farm configuration of APSIM. It allows users to simulate the impacts (i.e. economic, financial, environmental) of alternative allocations of limited production resources (e.g. land, labour, time, irrigation water, livestock, machinery and finance) across a number of farm enterprises at the whole-farm level. It can also simulate impacts of new technologies or crops, or new farming system designs. LivSim is a standalone R script application, implemented using modular naming conventions that are coordinated by a 'top level' loop that runs the simulation. The script runs a dynamic model of individual animals in a herd and simulates their performance based on genetics and the availability and quality of available feedstock. The model was designed to simulate the impact of alternative farmer allocation of resources on animal productivity.

Merging various simulation modules from standalone LivSim into an APSIM component required that the state variables and events shared by both modules were correctly linked. Merging APSFarm and LivSim involved linking both mechanical and conceptual components of two distinct modelling frameworks (Rodriguez et al. 2017). The simulation framework, APSIM (Holzworth et al. 2014), acts as the underlying engine of the APSFarm model by passing encoded messages between components that represent events in the system such as the transfer of resources between modules and the operation of farm-level management (e.g. planting a crop). Data from household surveys and observed or generated climate records (e.g. from MarkSim) can be used to parameterise the model for each household in the survey. The APSFarm-LivSim model can then be used to research 'What if?' questions and scenarios, and quantify benefits and trade-offs of alternative interventions. This can improve our understanding of the system performance in terms of production, economic and environmental responses.

Across ESA, maize is often grown in mixed crop–livestock smallholder farms, with strong interactions between cropping and livestock activities. Maize stubble is usually used as livestock feed in these systems (de Groote 2013). The use of crop residues as mulches is constrained in situations where there is livestock and other sources of biomass or feedstock are limiting, because poorly resourced farmers often feed crop residues to livestock. For instance, even though it is well established that the use of mulches can effectively reduce soil loss and increase rainfall infiltration (Rusinamhodzi et al. 2011), smallholder farmers in eastern and western Kenya tend to allocate crop residues preferentially as feed for livestock (Romney et al. 2003; Giller et al. 2015; Rodriguez et al. 2017). The use of whole-farm models to study trade-offs in the allocation of limited resources has been common (Rodriguez et al. 2014; Tittonell et al. 2007, 2009), highlighting the need for more holistic analysis of the impact of changes in the availability of not one but multiple inputs and the interactions between system components (Box 9.2).

## 9.3 RISK AND DOWNSIDE RISK IN SMALLHOLDER FARMING

Managing uncertainty and identifying opportunity has been especially relevant to smallholder agriculture, where highly vulnerable farmers are likely to experience unexpected events with major consequences. Uncertainty is one of the key constraints that farmers, NGOs and development agencies struggle with when promoting the adoption of technological innovations among highly risk-averse and poorly resourced smallholder farmers. To a point, in highly uncertain and vulnerable environments, risk aversion makes sense, as we cannot manage what we do not measure or know. While embedded in the puzzlement of the unknown-unknowns, lack of investment remains a justification for the present low-input/low-output production systems. Under these circumstances, climate risk acts as a disincentive for farmers to invest in needed technologies and markets, reducing our chances of increasing yields through higher adoption rates. Various heuristic devises and methodologies have been developed to assist in determining farmers' risk levels and management options (Figure 9.1).

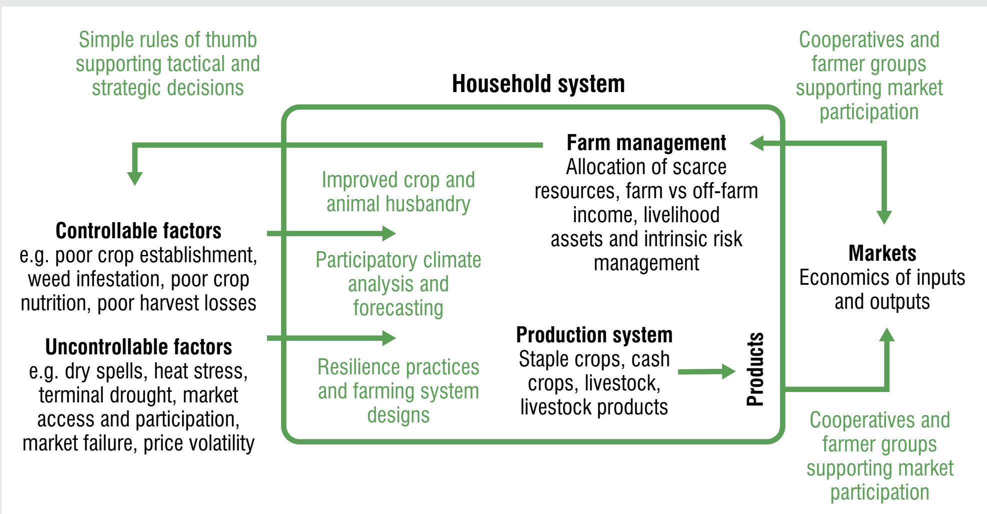
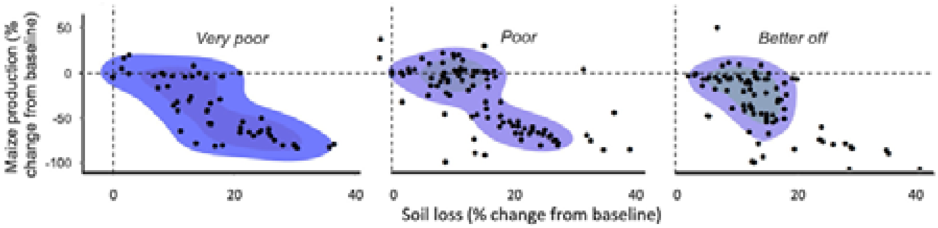



**FIGURE 9.1** Household system characteristics determining smallholder farmers' exposure to variability and risk, and possible intervention options that mitigate the impact of controllable and uncontrollable factors.

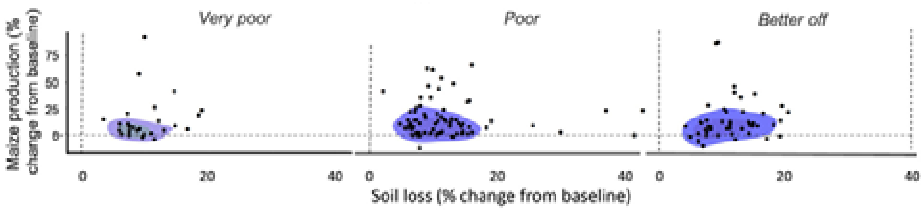
## BOX 9.2 To mulch or to munch: a case study on crop residue allocation in Kenya

**Western Kenya**

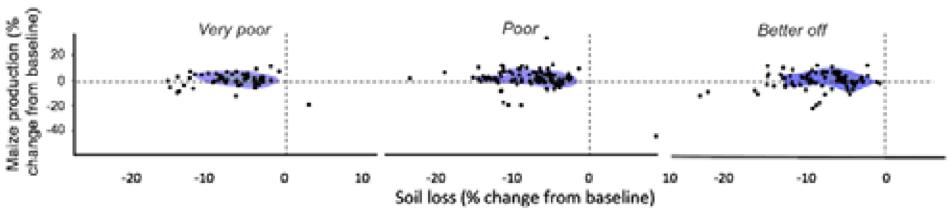
Give crop residues to livestock and low N fertiliser use




Give crop residues to livestock and higher N fertiliser use




Give half of the crop residues to livestock and higher N fertiliser use




Density plots showing changes in household maize production as a function of changes in soil loss from alternative intensification options in western Kenya, for different household types. Changes are relative to the current practice, and two intensification options using crop residues as livestock feedstock, and using higher levels of N fertiliser. Each dot in the density plot represents a household. Adapted from Rodriguez et al. (2017).

Rodriguez et al. (2017) compared the benefits and trade-offs on maize yield, livestock production, soil erosion and farm profits that were associated with using crop residues as mulch or as feedstock across multiple households from eastern and western Kenya. The study applied the whole-farm model APSFarm in conjunction with LivSim as described in Box 9.1. In the analysis, each individual household in the same household survey outlined in this book (n = 613) was parameterised in the model and run for 100 years of synthetic climate records. Simulated scenarios included the following changes from the baseline:

1. the use of crop residues as mulch
2. the use of crop residues as feedstock
3. the use of an additional 50 kg N/ha as fertiliser on the maize crop.

The simulation results demonstrated that benefits and trade-offs associated with allocating crop residue towards feedstock or mulch differed across types of households. They found that very poor and poor households were likely to be more adversely affected by reallocating crop residue from mulch to livestock feed than wealthy farmers. This group also had the most limited capacity to alleviate the negative consequences of reallocating residue from feedstock to mulch.

As expected, the results from the APSFarm-LivSim simulation indicated that maize production would likely increase and soil erosion decrease when households applied crop residues as mulch rather than feedstock. However, the benefits of applying crop residues as mulch for soil erosion were associated with a decrease in feedstock availability, the number of animals sold in the market, and a reduced household income. This trade-off was greatest among the poorest households, who experienced the largest decrease in household income when crop residues were used as mulch. They found that increasing application levels of nitrogen fertiliser could increase the productivity of the maize crop and alleviate the trade-offs.

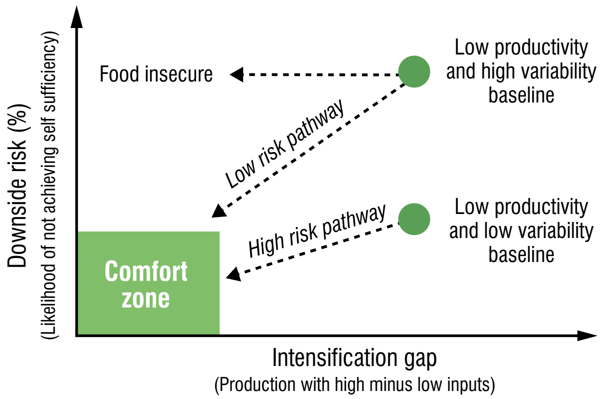
In addition to having the smallest herd sizes and the lowest maize–legume production levels, the poorest households applied the smallest amount of fertiliser and manure of the three typologies. In contrast, the intermediate level households (i.e. 'poor' typology) in eastern Kenya applied the highest levels of fertilisers and manure to their maize–legume plots. Since fertilisers were limited among the poorest households, this group had less capacity to adjust crop management. However, the most interesting result in the analysis was the capacity of the model to dynamically simulate the likely trajectory and diversity in household responses to the imposed scenarios.

According to Rao et al. (2011) what matters is not climate variability or climate risk, but how poorly resourced and highly vulnerable smallholder farmers act upon their perception of high climate variability and risk. Across Africa, highly vulnerable risk-averse farmers will tend to favour precautionary strategies that buffer against climatic extremes over activities that might be more profitable on average (Hansen et al. 2009, 2011; Rao et al. 2011). Farmers' perceptions of risk and its consequences are paramount here. The key questions are: how do farmers' perceptions relate to the actual variability in yields driven by climate variability; and to what extent do existing yield gaps driven by poor agronomic practice or lack of use of agricultural inputs engrain farmers' risk-averse attitudes and generate poverty traps? It appears that investments that could increase productivity (e.g. fertilisers) are avoided as they are seen as highly variable and therefore too risky. This is particularly the case if farmers have to pay for these expensive agricultural inputs in advance. Investigations of perceptions on climate variability and risk among farmers from Kenya show that farmers give greater weight to negative experiences (Rao et al. 2011), which is no different from findings in the Western world (Arvai and Kahneman 2013). The consequence is that highly vulnerable and poorly resourced smallholder farmers consistently miss good opportunities and the cycle of low-input/low-output becomes difficult to break. As demonstrated by Rao et al. (2011), one of the most common applications of systems modelling is in quantifying and informing the relationship between on-farm investment, profits and risks. However there have been very few examples where risks or downside risks were calculated at the whole-farm level, and none until now where downside risk has been expressed in terms of risk of food insecurity for hundreds of households having contrasting levels of endowment (Box 9.3).

## 9.4 LIMITATIONS OF MODELLING APPROACHES

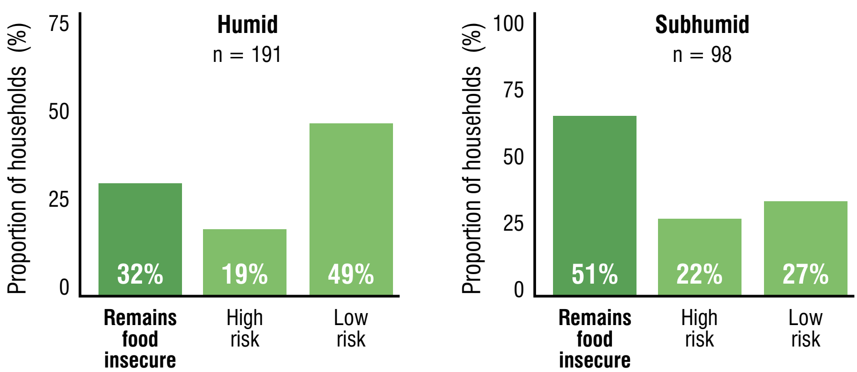
In addition to data availability, an important limitation in the use of dynamic biophysical models is that they do not capture the emerging relationships between individuals and/or households in their communities, nor do they capture those emerging relationships between households and local institutions. These social relationships can also be dynamic, based on the changing state of the individuals or communities that a household producer interacts with, rather than a fixed rule for interacting. Agent-based models may provide a method for capturing such variability in household relationships with other stakeholders and value chains as shown by Li et al. (2015).

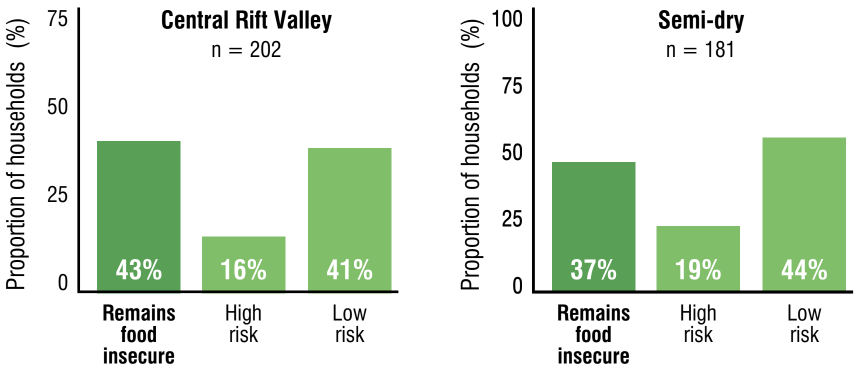
## BOX 9.3 Household downside risks for food insecurity in Ethiopia




Pathways to intensification and their associated impact on risk of food insecurity.

Quantifying the level of risk exposure to food insecurity in smallholder farming can be used to inform interventions that better suit farmers' circumstances, and increase adoption of more productive and resilient technologies. Using the APSFarm model described earlier, Rodriguez et al. (2017) quantified the downside risk (defined as the likelihood of a household being food-insecure), of crop and livestock intensification and relationship (trade-off) between production and risk. Using APSFarm, the intensification pathway for each household in the baseline survey was simulated by gradually increasing availability of fertilisers and feedstock to the household (n = 672) (see Chapter 4). Based on the risk intensification pathway towards a 'comfort zone', households were classified into three groups: those having a low-risk intensification pathway, those having high-risk intensification pathway, and those likely to remain food-insecure even after closing productivity gaps. Given the diversity in resource availability, households showed different risk intensification pathways.






Percentage of households in each surveyed region of Ethiopia that fall into the intensification pathways shown in the figure above.

Results showed that cropping cereals was the main source of household energy across all regions. Simulation results also showed that the proportion of households in the low-risk, high-risk and food-insecure groups was different across agroecologies (i.e. humid, subhumid, Central Rift Valley and semi-arid regions). With present levels of production assets and family sizes, in some regions up to 51% of the households would remain food (energy) insecure after intensifying food production. These households would therefore require significant sources of off-farm income. In other regions, most farmers would be able to produce enough food from the intensification of agriculture.

## 9.5 CONCLUSIONS

Smallholder households across ESA are highly diverse, and such a diversity limits the benefits of broadly applied options and pathways in our effort to sustainably intensify agriculture and achieve food security and poverty mitigation goals. In previous chapters we showed how data sets from household surveys can be used to identify patterns of resource availability and use, as well as types of household socioeconomic make-ups. However, we also recognised that the static nature of household survey data and the large effects that climate variability play in determining the performance of rain-fed systems impose constraints in their use to inform opportunities for research for development intervention. In this chapter we proposed that linking socioeconomic data and whole-farm modelling tools can help overcome this constraint. The examples we provided showed that household survey data can be used to parameterise whole-farm models, and that these models can help quantify benefits and trade-offs from alternative intervention options or farming systems designs. Examples were provided on their application to:

1. assessing the alternative allocations of crop residues between achieving soil health or livestock feed objectives
2. assessing the likely pathways of different household towards achieving food security through the sustainable intensification of agriculture.

Lessons from both examples indicate the value of the technology to generate new insights on the behaviour of complex systems. The insight that different household types were likely to benefit differently from different allocations of crop residues as mulches calls for caution at the time of promoting practices without a clear understanding of consequences at the whole-farm or system levels. Evidence that large fractions of the population were unlikely to achieve food security without significant transformations in their livelihood systems highlights the need for both incremental change and transformation. Under these conditions, research for development investments balance promotion of technologies that generate incremental change with those that support transformational gains in food production, farmers' income or peoples' sources of livelihoods.

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# CONCLUSIONS

ERIN LYNN WILKUS AND CASPAR WILL ROXBURGH

## 10.1 DIVERSE HOUSEHOLDS NEED DIVERSE SOLUTIONS

A wide range of development strategies have the potential to alleviate the acute and chronic levels of poverty and food insecurity in ESA. Among these is the sustainable intensification of household production systems through the adoption of productivity-enhancing innovations (e.g. fertilisers and improved seed). Due to the diversity of household production systems, this strategy has potential to benefit some but not all households. Typology characteristics help identify those households best positioned to intensify production and those that are better positioned to pursue alternative strategies (e.g. abandoning agriculture or stepping out). Simulations of household responses to intensification have provided additional insight into the potential benefits (e.g. risk reduction) and trade-offs associated with intensification for different households. Taken together, household typologies and predicted outcomes can identify strategies that are both feasible in the short term and have long-term potential gains.

Opportunities and potential benefits of intensification varied across the case study households presented in this monograph. A subset of households within Ethiopia, Kenya, Tanzania, Mozambique and Malawi were in a position to intensify production. While the case studies identify great potential for intensification, they also highlight the need for alternative development pathways as many households were less likely (or able) to benefit from intensification.

## 10.2 POLICY RECOMMENDATIONS TO SUPPORT EQUITABLE BENEFITS

Policy instruments can serve two important functions in supporting agricultural intensification in ESA:

- support household investment in intensification innovations
- support non-farm rural economies for households to pursue alternative development trajectories.

Policy instruments that create an enabling environment for household investment in intensification innovations can play a substantial role in increasing the agricultural productivity and economic growth of ESA. However, a potential consequence of existing inequities in resource levels is the uneven distribution of benefits from intensification. Opportunities and potential benefits of intensification were greater for households that already tended to have high food availability and household assets. On the other hand, the households that were most at risk of food insecurity faced more constraints to intensification. Consequently, intensification by some households would likely widen the gap in household wealth and food security. Policy must, therefore, address existing inequalities as sustainable intensification practices are adopted in ESA.

### 10.2.1 Support for investment in intensification innovations

The households that were well positioned for intensification were characteristically better off in terms of food availability (based on their productive resources), social mobility and economic activity. Their high income from on-farm activities distinguished these commercial farmers from off-farm workers and low-income households. These households tended to have higher levels of access to labour and more extensive social networks than others within their region. In addition to this competitive advantage, they also tended to be located relatively close to input and output markets. With more resources to invest in intensification and relativity high-income generation from on-farm activities, these households are suited to apply stepping-up strategies, i.e. investments in assets to expand the scale or productivity of existing assets and activities (Dorward et al. 2009).

Policies can help these households manage increased production levels and predict demand by fostering an enabling environment for household investment in intensification innovations. By increasing production and producing for the market, households take on supply- and demand-side risks. For instance, increased production levels might require increased transportation and storage capacity, presenting new challenges to realising the benefits of intensification. To manage this challenge, households might benefit from government support for cooperative management schemes, as farmer cooperatives can increase human capacity and storage, bulking and transportation resources. In addition, many of these households had few decision support tools for navigating input and output markets. Efforts to support intensification might therefore involve ICT support services or other mechanisms that can increase household access to market information. Such tools might also provide seasonal climate forecasting and measures of risk.

### 10.2.2 Support for non-farm rural economies

The households that were most at risk of food insecurity were the least likely to intensify. With the acute risk of food insecurity, these at-risk households would likely prioritise short-term coping strategies over investments in intensification (Hansen et al. 2009, 2011). As a result, these households might forego long-term benefits of intensification even when they have potential to increase production and decrease the risk of food insecurity. They were therefore positioned to benefit more immediately from alternative development strategies such as rural non-farm work. In order to avoid growing inequality as intensification proceeds, policy responses must consider how they can support these at-risk households as well as those suited to intensification. For instance, investment in infrastructure like roads and transportation services could help increase household access to markets, thereby increasing the possibility of income-generating activities off-farm.

Many households at risk of food insecurity had characteristics that gave them a local advantage in establishing off-farm work and/or abandoning agriculture (i.e. stepping out). They were often younger and more educated than the other groups in their countries, making them competitive candidates for skilled work positions in the region. Many of the younger and educated groups also had had less experience growing maize—meaning they had invested less of their lives in production activities and therefore had less to lose from abandoning farming activities. However, job prospects outside of agriculture and the risks and potential benefits of off-farm work remain unclear. With less farming experience and resources, these households might have fewer employment options in the rural economy.

Policy responses must actively strive to ensure genuine alternatives are available for households stuck in low-resource poverty traps. One possible policy response might be to enable favourable taxation and regulatory environments for new small-scale rural businesses. Evidence that other groups in the region are better positioned to intensify production suggests that demand for fertiliser and other inputs will increase over time. Therefore, young and educated households with few productive resources of their own might be well positioned to benefit indirectly from intensification. With adequate support and access to credit, they could prove to be promising agribusiness entrepreneurs, able to establish fertiliser markets that could support intensification by other groups in the region.

Finally, despite their lower capacity for intensification, some low-income households have potential for gains in production. Given this, overcoming group-specific challenges might be worthwhile. Intensification by older households might require access to and co-adoption of labour-saving technologies. Long-term investment in intensification by young and educated households might be desirable if rural non-farm work opportunities are particularly hard to obtain (e.g. jobs do not exist, job market information is unavailable or household members require additional skills). Since these households also tended to be located far from markets, it might also require investment in infrastructure or new markets that provide access to inputs for intensification.

## 10.3 NEXT STEPS

Understanding how intensification by some households impacts diverse communities requires an understanding of relationships between individuals and households within communities, as well as with key institutions. Agent-based models have offered a valuable tool for incorporating rules of exchange among 'agents' (i.e. households) to predict community-level dynamics. Ongoing efforts aim to combine household typology information, whole-farm dynamics (e.g. economic, financial and environmental impacts), crop and livestock production dynamics (LivSIM) and community-level decision-making processes (agent-based models).

While these efforts are underway, an additional challenge in communicating the outcomes of these studies must be addressed. Data collection and analysis results need to reach households and other stakeholders to ensure these research efforts contribute to positive change. There is much to be gained from improving the capacity of these analyses to generate immediate feedback with data collection. To further this aim, this report presents a methodology and supporting R script (Appendix 1) that can be applied broadly as tools to rapidly process household data into recommendations for development. Combining such approaches with emerging platforms for digital household data collection and cloud storage can allow for almost instant feedback to households participating in future studies. Finally, trends towards open access of research data should allow future researchers to synthesise data at a global scale to discern wider trends in diversity of livelihoods and pathways out of poverty. These efforts should be pursued with the explicit goal of informing development policy priorities and approaches, so that research can truly enhance development.

## 10.4 REFERENCES

Dorward, A., S. Anderson, Y.N. Bernal, E.S. Vera, J. Rushton, J. Pattison et al. 2009. Hanging in, stepping up and stepping out: livelihood aspirations and strategies of the poor. Development in Practice 19: 240–247. doi:10.1080/09614520802689535.

Hansen J.W., Mishra A., Rao K.P.C., Indeje M. and Ngugi R.K. 2009. Potential value of GCM-based seasonal rainfall forecasts for maize management in semi-arid Kenya. Agricultural Systems 101, 80–90. Available at: <**http://www.sciencedirect.com/science/article/pii/S0308521X09000468**>

Hansen J.M., Mason S.J., Sun L. and Tall A. 2011. Review of seasonal climate forecasting for agriculture in sub-Saharan Africa. Experimental Agriculture 47, 205–240. Available at: <**https://www.cambridge.org/core/journals/experimental-agriculture/article/review-of-seasonal-climate-forecasting-for-agriculture-in-sub-saharan-africa/99F866C3A1A52BDCA6618D8D050BCFDC**>

# APPENDIX

## R SCRIPT CODE USED TO RUN HOUSEHOLD SURVEY ANALYSIS, ADAPTED FOR WIDE APPLICABILITY

## NOTES ON USING R SCRIPT CODE

**This appendix provides relevant code for conducting the household data analysis outlined in Chapters 3 to 8 of this book. All of our analysis was completed using the R statistical programming environment (R Core Team 2013). R is freely available software that can be downloaded without payment from numerous servers around the world (see http://www.R-project.org). The program is extremely powerful and versatile, and is rapidly becoming the preferred statistical software for statisticians and scientists. Because it is open source, all the analysis we have performed can be repeated by anyone in the world with a computer and internet access, regardless of financial resources.**

R is sometimes difficult for new users. We recommend using accompanying software RStudio (**https://www.rstudio.com/**) as the user interface. RStudio greatly improves the user experience and is much easier for new users to navigate. A valuable resource for learning how to use R is the Quick R website (**http://www.statmethods.net/**), which also includes further training resources.

Finally, the Australian Centre for International Agricultural Research (ACIAR) in conjunction with the SIMLESA project has developed a free online statistical training course called *BEST for Africa: Bespoke eStyle Statistical Training for Africa and South Asia*. The course is specifically tailored to agricultural research in Africa and South Asia and provides training and instruction for R. It can be accessed at **http://yieldingresults.org.** It is our hope that this report and the accompanying R code will allow others to easily conduct similar studies of household diversity.

## OBTAINING R CODE FOR HOUSEHOLD DATA ANALYSIS

The R code used for household data analysis described in this publication may be obtained from:

1. GitHub repository at **https://github.com/aciar/SIMLESA**
2. text file published with the online version of this publication, at **www.aciar.gov.au/publication/household-diversity**
3. the following pages of this document if you are reading the online version of this publication.

Coding is provided for:

1. Principal component analysis
2. Cluster analysis
3. Analysing cluster data
4. Generating heatmaps

## REFERENCES

R Core Team 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: **http://www.R-project.org**.

# 1. R CODE FOR PRINCIPAL COMPONENT ANALYSIS

The following code (below this sentence) can be copied and pasted into the R console.

```
# Factor Analysis of HH survey data
# Instructions.
#
# 1. Run R, change 'directory' to your work area (i.e. computer folder where the data is)
# 2. "Source R code" -> P4-2.R (this file)
# 3. Edit your household data file to save as a comma delimited csv file
# 4. Then edit below the name of your .csv file (the spreadsheet with your data) and the list of variables to include into the 'keep1' list
# make sure you type the upper and lower cases for your variables the same as in the csv file
# 5. Interpret the Factor.txt file (see Chapter 2) and select the names of the variables you
# will use for the cluster analysis
# 6. You will need to download the 'psych' and 'nFactors' R packages to use this script
# (see Quick R for information on downloading packages)

rm(list=ls()) # removes any lists and dataframes already loaded in to R

# Change the file name
HH_survey_data<- "YOUR DATA FILE NAME HERE.csv"

# Change the name of the directory the name of a new folder where your data is located
# You will need to create a new folder on your computer with the same name (letters are case sensitive)
# This is where the outputs of your analysis will be saved
# Example provided for outputs from Western Kenya
out.dir<-"Kenya_West"

# List of variables you want to include for your principal component analysis
# Remember for each variable you should include at least 10 observations
# (i.e. 10 variables requires at least 100 households)
# Principal Component Analysis can only properly run with around 20 variables at most
keep1<-c("variable 1","variable 2","variable 3","variable 4","variable 5","variable 6","variable 7",
  "variable 8","variable 9")

# read data
df<-read.csv(HH_survey_data)

# Calculate any extra variables needed
# (example given for new plot size calculated from plot length and plot width variables)
#df$PLOTSIZE<-df$PLOTLENGTH * df$PLOTWIDTH
#keep1 <- c(keep1, "PLOTSIZE")
# Any extra variables ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^
```

```
# only keep variables we're interested in
df<-df[ , names(df) %in% keep1]

## ensure all data is numeric - convert factor variables
for (x in names(df)) {if (is.factor(df[[x]])) {cat(x," is a factor - now transformed\n"); df[[x]]<-xtfrm(df[[x]])}c}

# replace any missing values
df<-as.data.frame(apply(df,2,function(x) {x[is.na(x)] <- mean(x,na.rm=T) ; x} ))

for (x in names(df)) {if (sd(df[[x]]) == 0 || is.na(sd(df[[x]]))) {cat(x," has no variance\n"); df <-
df[,!(x==names(df))] }}

# Principal Components Analysis creating 15 principal components (i.e. artificial variables)
cat("Doing PCA\n")
library(psych)
# change the number "15" in the code below this line if you want to adjust the number of principal
components to be created from your data
pc <- principal(df, nfactors=min(ncol(df),15), rotate="varimax") #rotated
sink(paste(out.dir,"/factors.txt",sep=""))
print(summary(pc)) # print the variance accounted for by each principal component
print(loadings(pc)) # pc loadings for each observed variable
sink()

# create scree plot (to help decide how many PCs to keep)
png(paste(out.dir,"/scree plot 1.png",sep=""))
plot(pc$values,type="l",main="", xlab="# factors", ylab="Eigenvalue") # scree plot
dev.off()

# Create second scree plot of eigenvalues (look for the elbow in the line)
library(nFactors)
ev <- eigen(cor(df))
ap <- parallel(subject=nrow(df),var=ncol(df), rep=100, cent=.05)
nS <- nScree(ev$values, ap$eigen$qevpea)
png(paste(out.dir,"/ scree plot 2 - elbow.png",sep=""))
plotnScree(nS)
dev.off()

cat("PC loadings\n")
print(loadings(pc))
sink(paste(out.dir,"/ScreeValues.txt",sep=""))
print (pc$values)
sink()
flush(stdout())
```

## 2. R CODE FOR CLUSTER ANALYSIS

The following code (below this sentence) can be copied and pasted directly into the R console.

```
# Household Cluster Analysis (to be run after PCA)
# Instructions.
# 1. Your household survey data file needs to have a variable for the ID of each household
# and this variable needs to be called "hhldid"
# 2. Run R, change 'directory' to your work area (i.e. computer folder where the data is)
# 3. Edit your household data file to save as a comma delimited csv file
# 4. Then edit the name of your .csv file (the spreadsheet with your data) in the code below
# 5. Edit the list of variables to include into the 'keep1' list
# make sure you type the upper and lower cases for your variables the same as in the csv file
# 6. Interpret the Cluster dendrogram plot (see Chapter 2) to identify how many clusters you
# want to keep (then run the cluster analysis again with that number)
# 7. You will need to download the 'ape' and 'sparcl' R packages to use this script
# (see Quick R for information on downloading packages)

# Set Working Directory (location of your datafile) – change example filepath in "" below
setwd("C:/My Computer/SIMLESA Typologies/ country chapters/Kenya/Analysis")

# load packages needed from library
library(ape)
library(sparcl)

# remove previously loaded lists and data from workspace
rm(list=ls())

# Load household data file (change name below to your file name - letters are case sensitive)
HH_survey_data<- "YOUR HOUSEHOLD DATA FILE.csv"

# Select the number of clusters to keep (currently set to 3). This should be adjusted after examining
dendrograms and all subsequent code run again.
nclust<-3

# list variables (from PCA + any additions) that you want to use in Cluster Analysis
keep1<-c("variable 1","variable 2","variable 3","variable 4","variable 5")

# read data
 dfAll<-read.csv(HH_survey_data)
 df<-dfAll[ , names(dfAll) %in% keep1]

 ## ensure all data is numeric - convert factor data
 for (x in names(df)) {if (is.factor(df[[x]])) {cat(x," is transformed\n"); df[[x]]<-xtfrm(df[[x]])}}
```

```
 # replace any missing values with averages
 df<-as.data.frame(apply(df,2,function(x) {x[is.na(x)] <- mean(x,na.rm=T) ; x} ))

#create distance matrix using Euclidean distance
 d<-dist(scale(df), method = “euclidean”)

 # Ward’s Hierarchical Clustering of distance matrix
 fit <- hclust(d, method=”ward”)
 # apply number of clusters to keep
 c <- cutree(fit, k = nclust)

 # Create dendrogram plots
 plot(fit, xlab=”Households”)
# draw red rectangles around clusters – specify number by changing “3” in code below
rect.hclust(fit, k=3, border=”red”)
# Save dendrogram, (adjust plot dimensions – i.e. width and length - by changing the ‘500, 500’ below)
png(“FILENAME FOR SAVING DENDROGRAM HERE.png”, 500, 500)
y = cutree(fit, 3)
# create dendrogram with each household coloured per cluster. Don’t forget to change the plot title.
ColorDendrogram(fit, y = y, labels = names(y), main = “ENTER PLOT TITLE HERE”,
       branchlength = 80)
dev.off()
# Finish export to excel
 dist.cluster <- function(i, distmat, clusters) {
   ind <- (clusters == i)
   return(rowSums( distmat[ind, ind]))
 }
 d1<-as.matrix(d)
 out<-data.frame(hhldid=dfAll$hhldid,cluster=c,dist=NA,cluster.rank=NA)
 for (i in unique(c)) {
              print (i)
  m<-dist.cluster(i,d1,c)
  out$dist[as.numeric(names(m))] <- m
  out$cluster.rank[as.numeric(names(m))] <- order(m)
 }

 write.csv(out, “FILENAME FOR SAVING DATA WITH HOUSEHOLD ID AND ALLOCATED CLUSTER.csv”,row.
names=F)
dev.off(filename=”FILENAME FOR FINAL COLOUR DENDROGRAM PLOT.png”)

####################################################
##########################
```

```
### Calculating file for medians of each observed variable given for each cluster groups
# Read data
dfAll<-read.csv(HH_survey_data)
for (x in names(dfAll)) {if (is.factor(dfAll[[x]])) {cat(x," is transformed\n"); dfAll[[x]]<-xtfrm(dfAll[[x]])}}
dfAll<-as.data.frame(apply(dfAll,2,function(x) {x[is.na(x)] <- mean(x,na.rm=T) ; x} ))

statclus <- aggregate(dfAll[,-c(1,2)],list(c),median)
medianstats<-data.frame(Cluster=statclus[,1],Freq=as.vector(table(c)),statclus[,-1])
write.csv(medianstats, file="FILENAME FOR NEW FILE WITH MEDIANS OF OBSERVED VARIABLES FOR EACH CLUSTER.csv")
```

## 3. R CODE FOR ANALYSING CLUSTER DATA

The following code (below this sentence) can be copied and pasted directly into the R console.

```
# Instructions
# 1. Before you can run this code, you need to add in a variable (i.e. column) into your
# survey data called ‘cluster’. This needs to have the cluster number input for every
# household. These cluster numbers can be taken from the output file created from the
# cluster analysis script
# 2. Run R, change ‘directory’ to your work area (i.e. computer folder where the data is)
# 3. Edit your household data file to save as a comma delimited csv file
# 4. Then edit the name of your .csv file (the spreadsheet with your data) in the code below
# 5. You will need to download the ‘psych’ R package to use this script
# (see Quick R for information on downloading packages)

### Cluster analysis - creating boxplots and descriptive statistics
#Analysing Clusters for describe by stats

# Set Working Directory (location of your datafile) – change example filepath in “” below
setwd(“C:/My Computer/SIMLESA Typologies/ country chapters/Kenya/Analysis/Cluster results”)

# Remove previously loaded data from workspace
rm(list=ls())
# load packages needed
library(psych)

# Name of your csv file, remember this needs to have cluster numbers in a column for
# each household (taken from earlier cluster analysis)
HH_survey_data<- “NAME OF YOUR DATAFILE HERE.csv”

# Change the name of the directory where you want the output files to be
# make sure there is a folder with the exact same name in the same location
# where your household data is
out.dir<-” OUTPUTS DATA FOLDER NAME HERE”

######################################################
######################
### Run analysis for boxplots and descriptive statistics

# make boxplots
cnt.n <- function(x,n) sum(x>=n,na.rm=T)
draw.boxplot <- function(v1) {
 boxplot(as.formula(paste(v1, “~ cluster”)),data=df,main=v1,ylab=v1,xlab=”cluster”)
 m1 <- tapply(df[[v1]],df$cluster,mean,na.rm=T)
 cls.no<-length(unique(df$cluster))
```

```
 y <- matrix(m1,nrow=cls.no,ncol=2)
 x <- outer(1:cls.no,c(-0.4,0.4),"+")
 for (i in 1:cls.no) lines(x[i,],y[i,],lty=2)
}

# read raw data again
df<-read.csv(HH_survey_data)

printSummaryOld<-function(v) {
 cat("Dataset,\"", HH_survey_data, "\"\n")
 cat("Variable,", v, "\n")
 all<-as.data.frame(describeBy(df[[v]], group=rep("all",nrow(df)))[1])
 for (clust in describeBy(df[[v]], df$cluster)) { all<- rbind(all, unlist(clust))}

 names(all)<-c("var","n","mean","sd","median","trimmed","mad","min","max","range","skew","kurtosis")
 row.names(all)<-c("all", levels(df$cluster))
 cat(write.csv(all))
}

printSummary<-function(v) {
 cat("Dataset,\"", HH_survey_data, "\"\n")
 cat("Variable,", v, "\n")
 all<-as.data.frame(describeBy(df[[v]] ))
 all$sum<-sum(df[[v]])
 c<-NULL
 for (clust in describeBy(df[[v]], df$cluster)) {
  c<- rbind(c, unlist(clust))
 }
 c<-cbind(c,sum=as.vector(by(df[[v]], df$cluster,sum)))
 out<-rbind(all, c)
 row.names(out)<-c("all", as.character(unique(df$cluster)))
 cat(write.csv(out))
}

for (v1 in names(df)) {
 if (is.numeric(df[[v1]])) {
  png(paste(out.dir,"/",v1,".png",sep=""))
  try(draw.boxplot(v1), silent=T)
  dev.off()
  sink(paste(out.dir,"/",v1,".csv",sep=""))
  try(printSummary(v1), silent=T)
  sink()
 }
}
```

## 4. R CODE FOR GENERATING HEATMAPS

The R following code (below this sentence) can be copied and pasted directly into the R console.

```
# Instructions
# 1. Before you can run this code, you need to create a datafile with the variables
# you want included in your heatmap (saved as comma delimited file '.csv')
# In this example we use the variables from the heatmaps in this book
# 2. Run R, change 'directory' to your work area (i.e. computer folder where the data is)
# 3. Edit the name of your heatmap .csv file (the spreadsheet with your data) in the code
# 5. You will need to download the 'ggplot2', 'plyr', 'scales' and 'reshape2' R packages to use this code
# (see Quick R for information on downloading packages)

# Generating coloured heatmaps for household clusters
# Load packages needed
library(ggplot2)
library(plyr)
library(scales)
library(reshape2)

# Set Working Directory (location of your datafile) – change example filepath in "" below
setwd("C:/My Computer/SIMLESA Typologies/ country chapters/Kenya/Analysis/Cluster results")

# remove previously loaded data from your R workspace
rm(list=ls())

# The name of your .csv heatmap data file should be inserted below:
# Load data
df0 <- read.csv("YOUR HEATMAP FILE NAME HERE.csv",as.is=T)

# calculate order of typologies by total income (TotalInc) for heatmap
# highest to lowest income
attach(df0)
heatmaporder<-df0[order(-TotalInc),]

detach(df0)

# read order for graph
heatmaporder$Farm.type

####### Rescale data for heatmap figures #######
df1 <- melt(df0)
df2 <- ddply(df1, .(variable), transform,scale = rescale(value))
```

```
# Subset only variables for heatmap
# (if you have more variables in your heatmap file than you want in your figure)
dfs<-subset(df2, variable==”Farm.type”|variable==”Land”|variable==”TLU_all”
|variable==”CE”|variable==”Education”|variable==”wlkminse”|variable==”h.female.
perc”|variable==”cropsales”|variable==”off.farm.inc”|variable==”other.income”|variable==”TotalInc”)
# need to make the variables name above are correctly written as they appear in your datafile

# Reorder clusters for final figure. This can be according to the order in “heatmaporder” values of
# “Farm.type” - SEE ABOVE) or simply however you want your clusters ordered.
# Change cluster names in the quotation marks below
dfs$Farm.type <- factor(dfs$Farm.type,ordered=T,levels= rev(c(“CLUSTER 1”,”CLUSTER 2”,”CLUSTER
3”,”CLUSTER 4”,”CLUSTER 5”,”CLUSTER 6”)))

# Create the graph (red colour)
p <- ggplot(dfs, aes(variable,Farm.type)) + geom_tile(aes(fill = scale),
                    colour = “white”)+labs(y=”Household Cluster”, x=””) + scale_fill_gradient(low =
“white”,
                                        high = “darkred”)+theme_bw()+theme(axis.text.x = element_
text(angle = -45, hjust = 0), axis.text=element_text(size=16), panel.grid.major = element_blank(), panel.
grid.minor = element_blank(), panel.background = element_blank(), axis.line = element_line(colour =
“black”), axis.title=element_text(size=18,face=”bold”), legend.title=element_text(size=16,face=”bold”),
legend.text=element_text(size=16), strip.text=element_text(size=20, face=”bold”), plot.title=element_
text(size=18, face=”bold”))+labs(colour=”Relative value of Variable (0-1)”)

# Create the graph (green colour)
p2 <- ggplot(dfs, aes(variable,Farm.type)) + geom_tile(aes(fill = scale),
                    colour = “white”)+labs(y=”Household Cluster”, x=””) + scale_fill_gradient(low =
“white”,
                                        high = “darkgreen”)+theme_bw()+theme(axis.text.x = element_
text(angle = -45, hjust = 0), axis.text=element_text(size=16), panel.grid.major = element_blank(), panel.
grid.minor = element_blank(), panel.background = element_blank(), axis.line = element_line(colour =
“black”), axis.title=element_text(size=18,face=”bold”), legend.title=element_text(size=16,face=”bold”),
legend.text=element_text(size=16), strip.text=element_text(size=20, face=”bold”), plot.title=element_
text(size=18, face=”bold”))+labs(colour=”Relative value of Variable (0-1)”)

# Create the graph (blue colour)
p3 <- ggplot(dfs, aes(variable,Farm.type)) + geom_tile(aes(fill = scale),
                    colour = “white”)+labs(y=”Household Cluster”, x=””) + scale_fill_gradient(low =
“white”,
                                        high = “darkblue”)+theme_bw()+theme(axis.text.x = element_
text(angle = -45, hjust = 0), axis.text=element_text(size=16), panel.grid.major = element_blank(), panel.
grid.minor = element_blank(), panel.background = element_blank(), axis.line = element_line(colour =
“black”), axis.title=element_text(size=18,face=”bold”), legend.title=element_text(size=16,face=”bold”),
legend.text=element_text(size=16), strip.text=element_text(size=20, face=”bold”), plot.title=element_
text(size=18, face=”bold”))+labs(colour=”Relative value of Variable (0-1)”)
```

```
# Save the graphs to file (may need to adjust height or width dimensions depending on your data)
ggsave(p, filename="Kenya Heatmap - red.png", width=350, height=250, units="mm", dpi=350)
ggsave(p2, filename="Kenya Heatmap - green.png", width=350, height=250, units="mm", dpi=350)
ggsave(p3, filename="Kenya Heatmap - blue.png", width=350, height=250, units="mm", dpi=350)
# Identify whether clusters are either low income or high Income,
# (based on being in the top half of the observed income range)
# (in other words, by scaled income above 0.5) – remember to rename "TotalInc"
# to your income variable
inor<-subset(dfs, variable=="TotalInc")
inor$incrank<-ifelse(inor$scale > 0.5,c("High Income"), c("Low Income"))
View(inor)
#######################################################
```

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