A FARMING SYSTEM APPROACH TO SUPPORT POLICIES FOR FOOD SECURITY UNDER CLIMATE CHANGE IN DEVELOPING COUNTRIES: THE CASE OF MOZAMBIQUE

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Doutor José Manuel Osório de Lima e Santos

TESE ELABORADA PARA OBTENÇÃO DO GRAU DE DOUTOR EM ESTUDOS DE DESENVOLVIMENTO

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RESUMO ALARGADO

A insegurança alimentar é um aspeto complexo, que tem afetado essencialmente a população rural em países em desenvolvimento. Devido às alterações climáticas, espera-se que a prevalência da insegurança alimentar aumente consideravelmente, que irá afetar desproporcionalmente à população rural, em particular os pequenos agricultores, nos países em desenvolvimento. Os países em desenvolvimento são extremamente vulneráveis às alterações climáticas, com impactos significativos na segurança alimentar, especialmente entre os pequenos agricultores. Os pequenos agricultores são considerados os mais vulneráveis e expostos à pobreza, insegurança alimentar e alterações climáticas, devido a elevada dependência dos seus meios de subsistência em recursos naturais como a água, terra, florestas, entre outros, que são essências para o desenvolvimento da atividade agrícola – seu maior meio de subsistência.

A segurança alimentar tem estado no topo da agenda política da maior parte dos governos, em particular dos países em desenvolvimento. Ao longo dos últimos anos, várias estratégias e políticas têm sido implementadas pelos governos, para fazer face à insegurança alimentar e reduzir os efeitos negativos das alterações climáticas nos mais vulneráveis. No entanto, os governos foram muitas vezes criticados pelas políticas adotadas, que se mostraram muitas vezes inadequadas, não satisfazendo as necessidades da população rural e, portanto, não produziram os efeitos positivos esperados para a melhoria das condições de vida e da segurança alimentar da população rural, em particular os pequenos agricultores. De modo geral, estes governos têm adotado políticas únicas, ou seja, *"one-size-fits-all policies"*, sem considerar a heterogeneidade dos agricultores e a complexidade dos sistemas de produção. Agricultores, com caraterísticas diferentes, respondem de forma diference à uma determinada medida ou política. O desenho e formulação eficiente de políticas deve ter em conta o contexto social, cultural, biofísico e económico na qual o agricultor está inserido.

Desta forma, esta pesquisa pretende desenvolver e propor uma abordagem de sistemas de produção para apoiar políticas para a segurança alimentar em países em desenvolvimento, num contexto de alterações climáticas. A abordagem proposta foi aplicada ao caso de Moçambique. Para tal, faz-se uma classificação de sistemas de produção à nível do país, baseada apenas nas decisões produtivas dos agricultores. Ou seja, os sistemas de produção refletem as decisões tomadas pelo agricultor – no que se refere ao tipo de culturas e animais, uso de insumos (como por exemplo, fertilizantes, pesticidas, tratores, tração animal), entre outros – num leque de escolhas possíveis, tendo em conta o contexto socioeconómico e biofísico em que este está inserido. Foram identificados 16 sistemas de produção na área de estudo, tendo sido associado o grau de exposição à segurança alimentar em cada um dos sistemas, através da percentagem de agricultores que reportaram escassez de alimentos em cada um dos sistemas. A classificação dos sistemas de produção bem como os níveis de segurança alimentar por sistema de produção, é feita exclusivamente com base nos dados do censo agropecuário. Os resultados mostraram que os sistemas de produção que estão mais integrados no mercado e com maior uso de insumos (e.g., os sistemas de culturas de rendimento, de produção de hortícolas e o sistema misto com culturas alimentares e animais) são os que apresentam maiores níveis de segurança alimentar.

A abordagem para a classificação dos sistemas de produção adotada, permitiu analisar os fatores biofísicos e socioeconómicos que determinam ou influenciam a escolha dos sistemas de produção por parte dos agricultores, tendo se realçado o papel das variáveis climáticas. Considerando o papel importante das variáveis climáticas na escolha dos sistemas de produção, e o fato destas variáveis (climáticas) estarem sujeitas à mudança ao longo do tempo, adotou-se uma estratégia de modelação "*space for time*" para medir o impacto das alterações climáticas na escolha dos sistemas de produção e, consequentemente na segurança alimentar entre os agricultores. Os resultados revelaram grandes mudanças na escolha dos sistemas de produção e a sua distribuição espacial devido às alterações climáticas, com efeitos consideráveis sobre os meios de subsistência e a situação de segurança alimentar dos agricultores. Com base nos resultados, espera-se que os sistemas, atualmente, mais integrados no mercado e com maior uso de insumos, desapareçam até o final do século, num contexto de alterações climáticas. Por outro lado, verificou-se uma expansão dos sistemas de produção mais tradicionais e rudimentares, que produzem essencialmente culturas alimentares para o seu consumo e com a criação de pequenos animais, intensivos em trabalho, pouco integrados no mercado e com baixo ou nenhum uso de insumos.

Com base nesta abordagem de sistemas de produção, e tendo em conta as mudanças na escolha dos sistemas de produção, foi possível mapear as zonas em que os agricultores terão maior stress para a mudança, tanto em termos de conhecimento como de investimento adicional necessário pelo fato de mudarem de um sistema de produção para outro que é particularmente diferente do primeiro. As zonas húmidas, cujas predições indicam que se tornarão áridas, são as que apresentam elevado stress para a mudança. Alterações nos sistemas de produção e o aumento do stress para a mudança, vai influenciar significativamente a segurança alimentar entre os pequenos agricultores.

Num contexto em que os recursos são escassos, principalmente nos países em desenvolvimento, é necessário identificar áreas ou sectores prioritários para intervenção governamental, quer em termos de políticas ou de apoios, para minimizar os efeitos das alterações climáticas na segurança alimentar entre os pequenos agricultores. Conforme referido, a abordagem proposta nesta pesquisa foi aplicada ao caso de Moçambique, tendo uma grande vantagem de poder ser aplicada a qualquer outro país em desenvolvimento, pelo fato de ter sido baseada apenas em dados secundários, como por exemplo dados do censo agrícola (uma fonte de informação disponível e económica), dados climáticos mundiais disponíveis publicamente, e outros dados biofísicos e socioeconómicos publicamente acessíveis. Esta abordagem oferece um contributo significativo para a formulação de políticas para a segurança alimentar num contexto de alterações climáticas, permitindo que os governos realizem avaliações de políticas com poucos recursos, reconhecendo a diversidade de sistemas de produção existentes e incluindo os principais atores que se beneficiarão com a implementação da política.

Palavras-chave: sistemas de produção, segurança alimentar, mudanças climáticas, política de adaptação, países em desenvolvimento.

ABSTRACT

Food insecurity is a concerning issue affecting most developing countries, and it is projected to be exacerbated by climate change, especially among farmers. Small farmers are among the most exposed and vulnerable to food insecurity, and climate change, due to the high dependence of their livelihoods on natural resources, essential for agricultural activity. Governments in developing countries, have adopted several strategies and policies to help reduce the negative effects of climate change on food security. However, they have been criticized due to the failure of their policies in addressing the needs of the rural population, therefore not producing the desired positive outcomes on farmers' livelihoods. Overall, most governments have adopted one-size-fits-all policies, not considering the heterogeneity of farmers and the complexity of farming systems. Therefore, this research develops and proposes a farming system approach to support policy for food security under climate change in developing countries. First, a farming system typology is built, having been identified 16 farming systems; then the biophysical and socioeconomic drivers of farming system choice are modelled, where climatic variables were evidenced. The final step consisted in predicting the impact of climate change on farming systems choice and on food security among rural farmers using a space for time modelling approach, and priority areas for policy intervention were identified. The framework developed, based on a farming system approach is evaluated, and tested for the case of Mozambique. Nevertheless, the proposed approach can be applied in other developing countries, as this framework is essentially based on secondary data readily available. This framework is a cost-effective way for governments in developing countries, to carry out policy evaluations, while acknowledging the existing diversity of farming systems and including the key actors that will benefit with the policy implementation.

Keywords: farming systems, food security, climate change, adaptation policy, developing countries.

RESUMEN

La inseguridad alimentaria es un problema importante que afecta a la mayoría de los países en desarrollo, y se prevé que se agrave por el cambio climático, especialmente entre los agricultores. Los pequeños agricultores se encuentran entre los más expuestos y vulnerables a la inseguridad alimentaria y el cambio climático, debido a la alta dependencia de sus medios de vida de los recursos naturales, esenciales para la actividad agrícola. Los gobiernos de los países en desarrollo han adoptado varias estrategias y políticas para ayudar a reducir los efectos negativos del cambio climático en la seguridad alimentaria. Sin embargo, han sido criticados por el fracaso de sus políticas para abordar las necesidades de la población rural, por lo que no producen los resultados positivos deseados en los medios de vida de los agricultores. En general, la mayoría de los gobiernos han adoptado políticas de talla única, sin considerar la heterogeneidad de los agricultores y la complejidad de los sistemas agrícolas. Por lo tanto, esta investigación desarrolla y propone un enfoque de sistema agrícola para apoyar la política de seguridad alimentaria bajo el cambio climático en los países en desarrollo. Primero, se construye una tipología de sistema agrícola, habiéndose identificado 16 sistemas agrícolas; luego se modelan los impulsores biofísicos y socioeconómicos de la elección del sistema agrícola, donde se evidenciaron las variables climáticas. El paso final consistió en predecir el impacto del cambio climático en la elección de los sistemas agrícolas y en la seguridad alimentaria entre los agricultores rurales utilizando un modelo de *sapce for time*, y se identificaron las áreas prioritarias para la intervención de políticas. El marco desarrollado, basado en un enfoque de sistema agrícola, se evalúa y prueba para el caso de Mozambique. No obstante, el enfoque propuesto puede aplicarse en otros países en desarrollo, ya que este marco se basa esencialmente en datos secundarios fácilmente disponibles. Este marco es una forma rentable para que los gobiernos de los países en desarrollo lleven a cabo evaluaciones de políticas, reconociendo al mismo tiempo la diversidad existente de sistemas agrícolas e incluyendo a los actores clave que se beneficiarán con la implementación de las políticas.

Palabras clave: sistemas agrícolas, seguridad alimentaria, cambio climático, política de adaptación, países en desarrollo.

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CHAPTER 1

GENERAL INTRODUCTION AND CONCEPTUAL APPROACH

1. INTRODUCTION

The present thesis aims at developing a farming system approach to support policies for food security among the most vulnerable and poor population i.e., small farmers in developing countries, considering the impacts of climate change. For this purpose, the framework is developed and tested using the case of Mozambique. This is a relevant topic, especially in developing countries, as most of the food-insecure population in these countries live in rural areas, are poor and have a farming livelihood. By addressing the issue of food security focusing on this group the proposed approach could inform policies aiming at improving the livelihoods of 70% of the population.

The next sections of this chapter present a contextual background that helps framing the relevance of this topic, by addressing the status and interrelationships between agriculture, food security and climate change as well as the policy framework addressing these issues in developing countries. The conceptual approach is also introduced in this chapter, focusing on the farming system approach, its evolution, and relevance for problem-solving in different areas, having the farmer as the centre of the approach. The thesis' objectives and how they were addressed in the thesis are also explained in the next sections.

2. CONTEXTUAL BACKGROUND AND CONCEPTUAL APPROACH

2.1. Agriculture, food security and climate change in developing countries

Agriculture is a key sector worldwide and, especially, in developing countries, as it provides food as well as income for most of the rural poor population. Poverty is largely a rural phenomenon, with about 70% of the world's poor population living in rural areas, and is often associated with hunger (Borras 2009; Dobermann, Nelson, and et al 2013). For example, in Mozambique poverty incidence is higher in regions where food production is predominant, with the highest prevalence of agricultural population (Abbas 2017b). The lack of sufficient income to purchase food is one of the major causes of food insecurity, and hunger contributes to poverty by reducing labour productivity, increasing vulnerability to diseases and depressing educational achievements (Borras 2009; Dixon, Gulliver, and Gibbon 2001).

Worldwide, population is projected to increase to 9 billion people by 2050 – with most of this population living in developing countries (ca. 87%) – posing additional stress on land, water and biodiversity, which are already scarce (Dobermann, Nelson, and et al 2013; FAO 2014). On the other hand, climate change will also considerably affect most countries, with particular emphasis to developing countries, through changes in temperature and rainfall patterns, the expansion of locally new pests and diseases, as well as increases in the occurrence of climatic extreme events, such as droughts, floods, cyclones, among others. These changes will have significant effects on agricultural activity, adding more stress to an already vulnerable population. Sub-Saharan Africa is expected to be the region most affected by climate change in a business-as-usual scenario of unsustainable agricultural development, with projected high impacts on food security, malnutrition, poverty, rural infrastructure, conversion of natural land, soil and land degradation, water shortage, and biodiversity loss (Dixon, Gulliver, and Gibbon 2001; Dobermann, Nelson, and et al 2013).

Food security is a complex issue concerning most governments around the world, especially in developing countries. Although a lot of effort has been made to improve food security in many African countries, Sub-Saharan Africa is the region with the highest prevalence of hunger (19% of the population – more than twice the world average) (FAO et al. 2020). The developing regions (i.e. Asia, Africa, and Latin America and the Caribbean) concentrate about 98% of the undernourished people in the world, with 36% of these living in Africa (FAO et al. 2020). Projected trends show that by 2030 Africa will become the region with the highest number of undernourished and food insecure people – accounting for about 52% of the total undernourished and 51% of total food insecure population in the world (FAO et al. 2020). Studies have found that households involved in production and commercialization of agricultural products and livestock are usually the most vulnerable to food insecurity and climate change (SETSAN 2014 - Mozambique).

Moreover, developing countries are considered the most susceptible and vulnerable to the impacts of climate change. In these countries, climate change will mostly affect people living in rural areas, that is: the poorest and most food insecure. Their vulnerability has to do with their high dependence on natural resources (e.g. land, water and forests), essential to agricultural activity, which constitutes a large share of household incomes. Limited adaptive capacity to cope with the impacts of climate change and extreme climatic events (e.g. droughts, floods and cyclones) also contributes to their vulnerability (Ford et al. 2015).

Climate-related disasters are among the main drivers of food insecurity in developing countries, being droughts the major driver (Dixon, Gulliver, and Gibbon 2001; Garrity, Dixon, and Boffa 2012). The impacts of climate change are already being felt and future projections show that it will considerably affect the agricultural sector, with negative impacts on the most vulnerable people, and causing stress to food security. By 2030, it is expected that southern Africa could experience a decline of up to 50% in agricultural productivity due to water scarcity and insufficient irrigation (Brito and Holman 2012). Many studies confirm an expected decrease in yields across many crop types in developing regions (e.g. Brito and Holman 2012 - Mozambique; Knox et al. 2012 - Africa and South Asia; Philip K. Thornton et al. 2011 - Sub-Saharan Africa).

Decreases in agricultural productivity will negatively impact food production and farmer's income, affecting food availability and access, contributing to increase in food prices, which will affect significantly poor households who spend a higher share of their income on food (Porter et al. 2014). Moreover, land use will change both in terms of total area for crop production as well as the geographic distribution of that area, impacting cropping systems (Porter et al. 2014).

As the impacts of climate change will be clearer in developing countries, where they will disproportionally affect small-scale farmers, which are already poor and food insecure, this is the population group of interest in this study. Being the ones that contributed the least for climate change, they will be the most affected by it. Thus, this thesis is focused on small-scale food-insecure farmers.

2.2. The policy framework for food security and climate change in developing countries: the case of Mozambique

Rural population dedicated to agricultural activity are the most poor and food insecure, and also the most vulnerable to climate, therefore policies to eradicate poverty and reduce food insecurity and malnutrition should focus on this sector, especially on small-scale farmers (Dixon, Gulliver, and Gibbon 2001; Stephens, Jones, and Parsons 2018). In Sub-Saharan Africa, the growth generated by agriculture is considered more effective in reducing poverty than any other sector (Dixon, Gulliver, and Gibbon 2001; Dobermann, Nelson, and et al 2013). In Mozambique, Agriculture is the larger contributor to Gross Domestic Product – GDP (about 26% in the last decade 2009-2019 – including forestry).

The evolution of the focus on policies for food security has been substantial. After the independence of many developing countries, e.g. African countries, food self-sufficiency was at the top of the policy agenda, and in the 60s and 70s most African countries tried to produce as much as possible of their own food in order to guarantee food security (Moseley, Schnurr, and Bezner Kerr 2015), in this period food self-sufficiency dominated the narratives on food security. During the 1980s the structural adjustment programmes started to be implemented in Mozambique and in most African countries. In this period the focus of food security as food self-sufficiency in African food policy circles was abandoned, which was in line with the implementation and objectives of the structural adjustment programs[1]. Therefore, the conceptions of food security began to shift dramatically focusing on access, dominating the international African food policy circles for about 15 years, from the late 1980s through the early 2000s (Moseley, Schnurr, and Bezner Kerr 2015). This focus on access, promoted by Amartya Sen's theses (Sen 1981), although unintendedly, was increasingly involved in a free market approach to food security, where African countries were encouraged to specialize in a few exports, for which they had comparative advantage, and trade for food if needed[2] (Moseley, Schnurr, and Bezner Kerr 2015). This approach began to shift in 2000 when global food prices started to slowly rise. At this point, the global community's attention shifted back to African agriculture, and the focus on food production to solve food security was adopted again and a New Green Revolution was envisioned, which included an emphasis on linking farmers to global value chains. Some academics considered that a food security approach would target the poorest of the poor who are usually the most food insecure, by introducing low cost, sustainable enhancements to farming (Moseley, Schnurr, and Bezner Kerr 2015).

[1] In Mozambique the program aimed to tackle the economic crisis through a series of stabilization measures, which aimed to promote production to export, increase productivity and productive efficiency, and reduce debts. To achieve this purpose a set of measures were implemented in the following years such as trade and market liberalization, or privatization (PRIVATIZATION OF WHAT?) (Mosca 2005). The objectives of these privatizations were to achieve greater efficiency of the economy, to reduce subsidies to state-owned companies and to raise revenue for the public budget, to gain competitiveness through increased productivity, to modernize firms and to improve management. In addition, the privatization was a way of accessing resources and capital (Arndt 1999; Mosca 2005).

2 However, in Mozambique, the opposite took place. There was a massive increase in food aid to reduce scarcity of food, representing a major share in the supply of food and having a major impact on the domestic small farmers and industries (Mosca 2005).

In recent years African agriculture and rural development have been regaining attention, due to its importance on economic growth, food security and sustainable rural development (Hoeffler 2011). Poor agricultural policies have been identified as the reason why agriculture has fallen short of its potential (Hoeffler 2011). Public policies in the agricultural sector, especially in developing countries, e.g. Mozambique, usually fail to address the needs of the rural population and do not meet the primary goals and objectives for which they were designed, e.g., reduce the negative effects of climate change while ensuring food security. They are usually based in a conception of rural and agricultural development that is based on medium and large-scale farmers or on a capitalist transformation of the small farmer integrated in a non-competitive, non-regulated and distorted market (Mosca and Abbas 2016). This happens because the design of policies follows a top-down approach, without the integration of key actors, such as small farmers themselves (Mosca and Abbas 2016).

Moreover, in the last decades, climate change has posed challenges on food security around the globe, especially in developing countries. Climate change has increased the deficiencies of the already vulnerable policies and strategies aimed at improving food security. Social, cultural and political factors are central to any solution to African agriculture (Hoeffler 2011). To face climate change it is also important to consider location, cultural values, practices and behaviours of the targeted population (Hulme 2009).

As most developing countries, Mozambique has engaged in development policies aiming at reducing poverty through a set of actions in different sectors, including access to basic health care, improving food security and nutrition, water and sanitation, and access to clean and renewable electricity. Nevertheless, the implementation of these policies has faced challenges posed by climate change (MICOA 2010). Although some government strategies address food security and nutrition, there is no integrated, coherent and effectively implemented government strategy to address the issue of climate change (Carrilho et al. 2016; Joala et al. 2020). This is the case in many other developing countries (Joala et al. 2019).

The issue of food security and climate change is transversal, therefore policies aiming at improving food security, especially among farmers, should consider the impacts of climate change. The impacts of climate change will be differentiated among regions, with some regions and/or areas within a region expected to experience positive effects of climate change and other negative outcomes. Public policies should support and allow small-scale farmers to innovate within a system that recognizes the existing agricultural diversity and the complexity of the challenges ahead (FAO 2014).

2.3. A farming system approach for policy options

Farming systems emerged with the farm management survey research in the 1960s; and its application to agriculture arose in Latin America, Africa and Asia during the 1970s (Dixon et al. 2009). The lack of success of the Green Revolution in most Sub-Saharan Africa and other regions – due to factors such as climatic conditions, poor soils, poor markets, and low technology – enabled the evolution of the Farming System Research approach (Dixon et al. 2009; Norman et al. 1995; Simmonds 1985). The evolution of the farming system approach was to involve poor farmers, in developing countries, into the technology development process for it to be inclusive, acceptable and to fit the characteristics of each region (Norman et al. 1995).

In the mid-1980s the farming system approach to development was adopted, focusing on the farmer, which had the central role in farming systems development (Dixon et al. 2009; Norman et al. 1995). The main goal was to improve the well-being of individual farming families by improving the overall productivity and sustainability of the farming system, given the constraints and potentials imposed by the factors determining the existing farming system (Norman et al. 1995). After the 1990s the emphasis of the approach widened, focusing on the household and their livelihoods (including off-farm work), and aimed at agricultural development, natural resource management and market access policies (Dixon et al. 2009). The conceptualization and evolution of the farming system approach has been significant, and the use of the approach as an analytical framework became common contributing to a paradigm change in rural development thinking (Dixon et al. 2009; Dixon, Gulliver, and Gibbon 2001).

To maximize rural and agricultural development, the heterogeneity of farmers and farming systems should be considered in policy design, as the diversity of farmers, especially in developing countries, implies that these may respond differently to the same development support or policy intervention (Kansiime, Asten, and Sneyers 2018; Kuivanen et al. 2016; Tittonell et al. 2010). The farming system framework provides a relatively simple and practical approach to evaluate agricultural changes, which enable useful and powerful insights into strategic priorities for policy design aiming at improving farmers livelihoods (Dixon, Gulliver, and Gibbon 2001; Stephens, Jones, and Parsons 2018).

Challenges faced by many developing countries are associated to the continuing population increase, low productivity, food insecurity and malnutrition. Food security and poverty levels differ considerably across farming systems, and the strategies used by families to cope with food shortages also vary according to the farming system practiced by the household. Therefore understanding the characteristics of the main farming systems in a region/nation provides a consistent framework to address food security problems while integrating agricultural diversity and exploring fitted solutions for each case (Dixon, Gulliver, and Gibbon 2001; Massawe 2017; Mnenwa and Maliti 2010; P. Thornton et al. 2010). Farming systems adopted by farm households have a strong direct influence on their food security status, and this happens in two pathways: first, the farming system forms a focal point for targeting interventions through improved farming practices, which ultimately result in increased farm production, productivity and/or profitability (Dixon et al., 2001), which in in turn, may influence positively on availability and diversity of food to farm-households; second, increased farm productivity and sale of agricultural production may improve farmers' income contributing to better access to goods and services that would allow to achieve food security goals (Massawe 2017).

The Farming System Research (FSR) has been much discussed in the literature, and many studies have warned about the ambiguity associated to its concepts and approaches (Ker 1995; Simmonds 1985; Whitfield et al. 2015). The FSR have evolved and become broader, consequently the approaches and applications within have also diversified. As a result, the FSR is now considered as a catch-all concepts or applications, including for instance farm-scale processes, innovation/technological processes, landscape modelling, economic analysis, policy analysis, and others (Whitfield et al. 2015).

Dixon et al. (2001) defines the farming system as a population of individual farm systems – i.e., the household, its resources and the resource flows and interactions at the individual farm level – that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate. The biophysical, socioeconomic and human elements of a farm are interdependent, therefore farms can be analysed and classified as systems from various perspectives (Dixon, Gulliver, and Gibbon 2001; Fresco and Westphal 1988). The physical basis for farming systems is determined by the interaction between natural resources, climate and population (Dixon, Gulliver, and Gibbon 2001; Garrity, Dixon, and Boffa 2012; Mnenwa and Maliti 2010). Garrity et al., (2012) added markets and trade, energy, technology and science, human capital, and institutions and policies as some of the determinants that shape the development of farming systems in Sub-Saharan Africa.

Dixon et al. (2001) classified faming systems, based on: i) the available natural resource base (water, land, grazing areas, forest, climate, landscape, farm size, tenure, and organization); ii) the dominant pattern of farm activities and households' livelihoods (field crops, livestock, trees, aquaculture, hunting, gathering, processing, and off-farm activities); and iii) the intensity of production activities (technologies).

Many studies have classified farming systems based on both drivers of farming system choice – often independent from farmers' decisions (exogenous), such as biophysical and socioeconomic factors as e.g. rainfall or farm size – and descriptors of farming systems – dependent on farmers' decisions (endogenous), e.g., type of crops grown, use of yield-raising inputs (Erling Andersen et al. 2007; e.g. Dixon, Gulliver, and Gibbon 2001). Other studies propose the use of a farming system approach, in which farming systems are classified based only on farmer's management choices, or productive decisions, i.e. descriptors of farming systems (Santos et al. 2020; Silva et al. 2020). The advantage of adopting the latter approach is that by not integrating the drivers of farming system choice (i.e., biophysical, e.g. climate, and socioeconomic, e.g. access to markets factors) in the definition of farming systems enables an analysis of the dynamics of farming systems as these drivers change across time and space. In this thesis we have adopted this second approach to farming systems.

Therefore, the farming system approach adopted in this thesis emphasizes the classification of farming systems based only on farmers' productive decisions, e.g. land use and cover, livestock composition, the use of yield-raising and labour saving inputs. This approach allowed to model farming system dynamics, and thus to predict how farmers' choices might change as the drivers of farming system choice (e.g., climate), change. The output of this analysis is relevant to support policy design for food security under climate change as it enabled the identification of priority areas that will most likely need government support so that poor food insecure farmers' in developing countries can guarantee their livelihoods and meet their food security goals under climate change. Given the lack of resources in poor developing countries, efficient allocation of resources in priority areas that will translate into positive outcomes for rural small-scale vulnerable farmers is of utmost importance.

An important contribution of this thesis, besides its ultimate goal – which is to contribute to support policy for food security among rural small-scale poor farmers under climate change – is that this framework is a cost-effective way that can be applied in many other developing countries, as it relies mostly on available secondary data (e.g. agricultural census data, worldwide online climate data). This allows governments to carry out policy evaluations with low resources, while acknowledging the existing diversity of farming systems and including the key actors that will benefit with the policy implementation.

3. GENERAL AND SPECIFIC OBJECTIVES OF THE THESIS

The overall objective of this thesis is to develop and evaluate a farming system approach to predict and map, at the national scale, the impacts of climate change on food security in developing countries. This approach is aimed at contributing to better adaptation policies, namely through the identification of priority areas for food security under climate change.

For that purpose, several specific objectives have been set:

i. Identifying and mapping farming systems for the whole country based on available farm-level data;

ii. Assessing the diverse farming systems as regards food security;

iii. Modelling the choice of farming system by each small-scale farmer, based on climatic and other drivers, at the farm level and countrywide;

iv. Assessing the impact of climate change on food security based on predictions of farming system transitions under alternative climate scenarios.

The specific objectives presented were addressed in three separate papers that complement each other. Objectives (i) and (ii) were addressed in the first paper (Chapter 2 of the thesis), and objectives (iii) and (iv) in the two following papers (Chapter 3 and 4 of the thesis, respectively).

4. OUTLINE OF THE THESIS

The thesis is organized in five main chapters, the first being this general introduction (Chapter 1), where an introduction to the topic under analysis is presented along with the contextual background and conceptual approach; the overall objectives of the thesis are also presented.

The three following chapters address the abovementioned specific objectives of the thesis and represent the empirical work of the thesis.

In Chapter 2, the first paper is presented, setting the starting point of the empirical work of the thesis. This paper is the fundamental basis for the research and for the framework that is proposed. It defines the farming system approach to be used, by identifying the farming system typology and assessing food security levels by faming system type. The classification of farms by farming systems was based exclusively on agricultural census data, which provided farm-level data on the productive decisions made by farmers, for about 40 000 small and medium farms in Mozambique. This census included data regarding several indicators, including production volumes of a variety of crops and livestock in several different unit measures, which had to be converted one by one to a standard unit measure. This raw data was composed of 33 separate files and was subject to a series of analysis, computation of variables and data aggregation, culminating in a database with a usable sample of 27 805 small and medium farms with 42 computed variables, representing farmers' individual productive decisions regarding agricultural land use, livestock composition and intensity, the use of yield-raising and labour-saving inputs, referred as farming systems descriptors, which were then used to derive the farming systems.

Chapter 3 focus on identifying the main drivers of farming system choice, establishing the interconnection between climate and socioeconomic drivers and farmers' productive decisions, as well as the mechanisms through which public policies may affect farmers' choices, which in turn affect their food security status. This is an important step prior to assessing the effects of climate change on food security, which is done in Chapter 4.

Chapter 4 uses the model estimated in Chapter 3 and the farming system typology of Chapter 2 to assess the impacts of climate change on food security through transitions of farming system that are expected to occur in each farm under each climate scenario. This is done at the farm level for the whole country and mapped at a precise spatial scale. The framework proposed has enabled the identification of priority areas that will most likely need government intervention so that the livelihoods and food security goals of the farmers are met and secured under climate change.

Finally, Chapter 5 presents the general conclusions and suggest topics for future research. In this chapter the link between the three intermediate chapters (Chapter 2 to 4) is made, and general conclusions and the general objective of the thesis is addressed.

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CHAPTER 2

A CENSUS-BASED COUNTRYWIDE FARMING SYSTEM APPROACH TO EXPLORE THE PRODUCTION DECISIONS OF SMALL FOOD-INSECURE FARMERS IN DEVELOPING COUNTRIES

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A census-based countrywide farming system approach to explore the production decisions of small food-insecure farmers in developing countries

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ABSTRACT

Small farmers in developing countries are among the most exposed and vulnerable to food insecurity and poverty. A farming system approach has been largely recognized to play an important role in supporting strategies to improve food security and alleviate poverty among small farmers. This paper aims at developing a census-based countrywide approach to identify farming systems in developing countries by classifying farms based on farmers' production decisions. Multivariate analysis – Principal Component and Hierarchical Cluster Analysis – was used. A second aim is illustrating the applicability and potential of this approach in contributing to better policy design, by exploring biophysical and socioeconomic covariates of farming systems that may contribute to identify the policy problem and policy options for food security and poverty alleviation. Results indicate that farming systems with better access to markets, using yield-raising and labour-saving inputs are more likely to be food secure, which leads us to discuss relevant policy options.

Keywords: Farming systems, agricultural census, farmers' production decisions, policy design, developing countries.

1. INTRODUCTION

Most of the population in developing countries lives in rural areas, where poverty and hunger are concentrated. Governments have implemented various development programmes and strategies to improve food security and alleviate poverty. However, these policies have been criticized for their failure, as they fail to understand the concerns behind farmers' land use decisions and to address the needs of the rural population (Kansiime, Asten, and Sneyers 2018; Mascarenhas et al. 1986; Mosca and Abbas 2016).

To maximize rural and agricultural development, the heterogeneity of farming systems should be considered in policy design (Mascarenhas et al. 1986; Stylianou, Sdrali, and Apostolopoulos 2020). One way of dealing with this heterogeneity is by aggregating farms into groups with similar production patterns i.e., similar decisions regarding farm-level production, which is precisely what is done within the farming system approach. "A farming system approach makes it possible to understand the rationality behind farmers' decision making in the field of agricultural production. This provides a basis for understanding how government policies affect the farmer's management and decision making. Government policies can be evaluated with the reference to the probability of farmers responding in a way which realize government objectives" (Mascarenhas et al. 1986, 291)

Farming systems can be identified based on either farming system descriptors alone (Silva et al. 2020), i.e. information regarding farm-level production decisions, such as type of crops and livestock, use of yield-raising or labour-saving inputs, and others; or also include biophysical and socioeconomic variables, namely access to resources such as land (farm size), soil quality, rainfall, roads, storage and conservation facilities and others, which are usually exogenous to farm-level production decisions. The latter may be seen as drivers of farming system choice, because they help explaining why each particular farmer has chosen one farming system over another (Silva et al. 2020). The use of both, descriptors and drivers of farming systems when classifying farms by farming system, as in Dixon et al. (2001), prevents an explicit analysis of the dynamics of farming systems based on the ways the choice of farming system by farmers respond to changes in these drivers across time and space (Claus Köbrich 1997; Silva et al. 2020).

This paper develops a new approach for the classification of farms by farming system in developing countries, based exclusively on data from agricultural censuses, and reflecting only farmers' productive decisions, i.e. farming system descriptors. Thus, the proposed classification describes the actual choices made by farmers in the study area, which are taken as the broader set of possible options for farmers in that geographic area. Farming systems describe the multitude of decisions made by the farmer on different dimensions, i.e. agricultural land use, livestock composition and intensity, use of yield-raising and labour-saving inputs. This simplified description of so many decisions as a discrete choice among N possible farming systems is made possible because all these decisions are linked to one another, which allows classifying farms by farming system and interpreting the resulting classes, or farming systems, as the possibility set for farmers in that region. The farming system approach presented in this paper differs thus from the ones presented in other studies (e.g. Erling Andersen 2017; Dixon, Gulliver, and Gibbon 2001).

Another significant contribution of the proposed approach is its use of statistical agricultural data, i.e. agricultural census data (a cost-effective available source of information), to classify farms by farming system, based on detailed information describing, for a whole country, the many productive decisions made by farmers on multiple dimensions. Provided that agricultural census data exist, this method may be a key solution to develop a farming system typology in developing regions, which have little research information or lack other exhaustive, consistent, and continued data regarding production decisions in the agricultural sector. The high costs involved in household surveys limits the scale of its application. Therefore, farming system typologies based on primary household survey data, in developing countries, have focused in specific areas or regions in a country (e.g. Claus Köbrich 1997 - Central Chile; Kuivanen et al. 2016 - Northern Ghana; Massawe 2017 - two districts in Tanzania; Steeg et al. 2010 - Kenya Highlands).

The potential application of the proposed approach is very wide, as it can be used e.g. for policy analysis (Claus Köbrich 1997; Ribeiro et al. 2018), to explore issues such as food security (Boere et al. 2018; Massawe 2017), poverty (Boere et al. 2018; Dixon, Gulliver, and Gibbon 2001; Mnenwa and Maliti 2010), climate change (P. Thornton et al. 2010; P K Thornton et al. 2009), agricultural innovation (Kuivanen et al. 2016; Stylianou, Sdrali, and Apostolopoulos 2020), household livelihoods' strategies and behaviours (Kansiime, Asten, and Sneyers 2018; Tittonell et al. 2020), biodiversity and ecosystem services (Ribeiro et al. 2016; Santos et al. 2020) and others.

This paper aims at: i) developing and illustrating with an application, a census-based, countrywide approach to identify farming systems in developing countries through the classification of farms included in agricultural census data; ii) exploring the applicability of such an approach to analyse the dependence of farming system choice on context, biophysical and socioeconomic, variables (drivers); iii) exploring how farmers' vulnerability to food shortages and corresponding coping strategies vary across farming systems; iv) exploring the positive feedbacks between income rises, investment in yield-raising and labour-saving inputs, and labour productivity; objectives iii and iv are used as examples of the usefulness of the proposed approach in providing clear identification of the policy problem and policy options for food security and poverty alleviation. The identification of farming systems was based on multivariate analysis, including Principal Component Analysis (PCA), followed by Hierarchical Cluster Analysis (HCA) (C. Köbrich, Rehman, and Khan 2003; Claus Köbrich 1997; Stylianou, Sdrali, and Apostolopoulos 2020).

The methodology presented is applied to Mozambique, one of the poorest countries in the world, with high levels of food insecurity and essentially agricultural (Abbas 2017a), for which the farming system approach although debated and recommended (Mascarenhas et al. 1986) has just begun to be explicitly explored, with few studies focusing on it (e.g. Mbanze et al. 2020).

2. MATERIALS AND METHODS

2.1. Study area

The study area is Mozambique, located in the South Eastern coast of Africa (Figure 2.1). Mozambique has 36 million hectares of arable land, of which only approximately 15% is in use (Carrilho et al. 2016). The country's agroecological potential for agriculture is heterogeneous, encompassing ten agroecological zones (MASA 2016) with different aptitudes, which are defined mainly by rainfall and soil type.

Mozambique has a tropical to sub-tropical climate, characterized by two seasons, a cool and dry season (May to September) and a hot and humid season (October and April) (Marques et al. 2009). The average mean temperature tend to be higher along the coast and lower in inland and high altitude regions (Marques et al. 2009; Warner et al. 2016). The rainfall distribution follows an east-west gradient, with more rainfall along the coast (annual average between 800-1200mm), followed by the inland high-altitude in north and central regions (1000mm); the inland central and south regions are the driest (600mm or lower) (Marques et al. 2009).

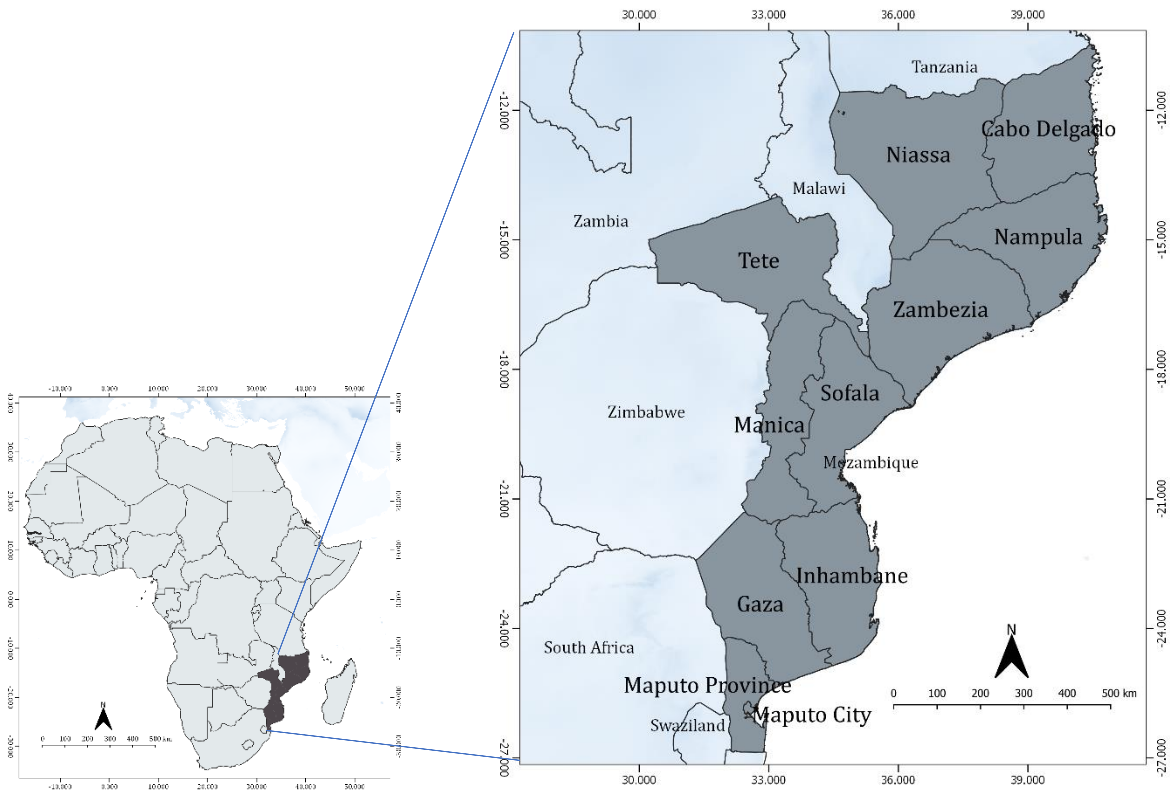


Figure 2.1 The study area: Mozambique's administrative division

In Mozambique poverty affects ca. 46% of the population, being predominant in rural areas where 2/3 of the population is located (MEF 2016), having agriculture as their major source of employment, subsistence and income (Abbas 2015). The potential of the agricultural sector in decreasing poverty and improving food security is highly recognized (MINAG 2010), therefore it is considered the basis for development and a priority sector of the economy.

The agricultural sector is dominated by smallholders – representing 99% of total farms (INE, 2011), and agriculture is practiced mostly in a rainfed system (98% of the farms), being extremely dependent on rainfall. Most of the domestic food production (ca. 95%) is produced by small farmers, being dominated by roots and tubers (especially cassava), cereals (maize, millet, sorghum, and rice), groundnuts and horticultural crops. Important cash crops are tobacco, cotton, sugar cane, sesame and soybean (Mosca and Nova 2019). Food output is extremely variable, and basic food crops are mostly for household's own consumption, with marginal surpluses being sold at local markets (World Bank 2011). This associated with the restrictions to meet food needs through imports, poses challenges to food security in the country (MINAG 2010).

2.2. Data collection and analysis

A database was built from the most recent national agricultural census in Mozambique at date, *Censo Agropecuário* – CAP 2009-2010, to identify the main farming systems in the country and explore its spatial distribution. A farm-level database was provided by the National Institute of Statistics (*Instituto Nacional de Estatística* – INE).

2.2.1. The Agricultural Census 2009-2010

Data collection for CAP 2009-2010 was carried from January to November 2010, in a survey covering the entire country. Agricultural data refers to the 2009/2010 agricultural season, which in Mozambique usually starts in October and ends in March/April, followed by the harvest; livestock data refers to 2010 (INE 2011).

According to INE (2011) the total sample was approximately 3500 large and medium farms and 35020 small farms[3]. Large and medium farms were fully surveyed (100%) in the selected enumeration areas – a well-defined geographic area (urban or rural), i.e. a village, neighbourhood, block, etc. (INE 2011) – and for small farms a fixed sample of 10 households[4] was defined for each enumeration area, in all districts (third administrative level), with a probabilistic proportion based on size, i.e. the number of households in the enumeration area.

CAP covered data for crops and livestock (arable area, i.e. the area cultivated with annual crops (hectares), production and sales – in quantity and value), labour, food security, agricultural practices and services, and others (INE 2011) – see Table 2.1 for crops and livestock considered in the analysis. Due to lack of data for all farms, some crops (annual and permanent) were excluded from the analysis: Sisal, Tea, Jatropha, Parsley, Coriander, Cress, Spinach, Mint, Turnip, Radish, Chives, Pineapple, Banana, Passion Fruit and Vine.

Due to farm characteristics, INE (2011) considered two different questionnaires; the same questionnaire was applied to small and medium-sized farms and another to large farms. Therefore, only small, and medium farms were considered in this analysis, as they represent the majority of households and are responsible for almost the entire food production in Mozambique. Data was analysed at the farm level.

[3] A farm is classified as: 1) Small – if all factors are less than limit 1; 2) Medium - if a factor is greater than or equal to limit 1 and less than limit 2; and, 3) Large - if a factor is greater than or equal to limit 2 (INE 2011).

Factors	**Limit 1**	**Limit 2**
Non-irrigated cultivated area (ha)	10	50
Irrigated cultivated area, orchards in production, plantations, horticulture, floriculture (ha)	5	10
Number of cattle	10	100
Number of goats /sheep/pigs	50	500
Number of poultry	2 000	10 000

Factors for the classification of farms in Mozambique (INE 2011)

[4] A household is a group of people living in the same housing, whether or not related by kin, which may occupy the entire or part of the housing and whose expenditures for the fulfilment of their essential needs are partially or totally borne together (INE 2011).

Considering the method of analysis adopted, only farms with information for all relevant variables (Table 2.1) were considered (Claus Köbrich 1997), therefore, the usable sample included only 27,805 farms.

2.2.2. Classification of farms by farming systems

Farming systems were derived based on a set of 42 computed variables, representing farmers' individual productive decisions (Table 2.1). Therefore, different farming systems reflect different combinations of farmers' decisions regarding agricultural land use, livestock composition and intensity, use of yield-raising and labour-saving inputs, i.e. farming system descriptors (endogenous to the farming system choice).

The variables in Table 2.1 were computed at the farm level, based on data extracted from the agricultural census (INE 2011) – see Table A1 in Appendix A. A farm refers to all parcels of land managed by the same household.

To correct for outliers, some variables were truncated: i) PermC: 200%; ii) LivDen: 10 standard livestock units per hectare of arable area; iii) MARKET: 100%; iv) EconInt: 200,000.00 MZN per hectare; v) LabProd: 40,000.00 MZN per labour unit; and, vi) Labour: 10 labour units per hectare of arable area. Threshold levels for truncation were defined based on histogram analysis and the authors' experience and knowledge of the context and nature of the data, considering possible errors due to simplification assumptions.

In the computation of variables, some data was transformed to allow further analysis or comparison between variables (see notes in Table A1). The Total Gross Product (TGP) of the farm, i.e. total output, was computed based on the gross product or output derived from crops – annual and permanent – (GPC) and livestock (GPLiv). GPC was based on the total harvested amount (extracted from CAP 2009-2010) and the median price computed for each crop (Table A1). In cases in which it was not possible to derive the total harvested amount, land productivity was used to estimate the farms' output (see notes in Table A1). Computation of GPLiv followed a similar approach – Table A1.

Table 2.1 Descriptive statistics of the variables considered in the classification of farms by farming systems (n=27,805)

Variable Code	Variable Description	Crop/Livestock[(1)]	mean	std.dev
Maize	Proportion of arable area with annual crop	Maize	0.26	0.27
Rice		Rice	0.07	0.22
Sorghum+		Sorghum+	0.06	0.16
Cassava		Cassava	0.23	0.30
SweetPotato		Sweet Potato	0.03	0.09
Cowpea		Cowpea (*Nhemba* bean)	0.08	0.14
Beans		Beans	0.07	0.14
Groundnut		Groundnut	0.08	0.16
Sesame		Sesame	0.01	0.08
Cotton		Cotton	0.01	0.08
Tobacco		Tobacco	0.01	0.07
Hort1		Horticultural crops 1	0.04	0.09
Hort2		Horticultural crops 2	0.02	0.12
Hort3		Horticultural crops 3	0.01	0.04
OtherAnC		Other annual crops	0.01	0.07
Mango	Proportion of … tree in total number of fruit tree stems	Mango	0.24	0.40
Cashew		Cashew	0.20	0.33
Coconut		Coconut	0.11	0.32
Citrus		Citrus	0.08	0.23
OtherFruits		Other fruit	0.20	0.17
PermC	Proportion of equivalent arable area with permanent crops		0.18	0.29
LivDens	Livestock density – number of standard livestock units per hectare of arable area		1.16	2.36
Bovine	Proportion of …. in total standard livestock units	Bovine	0.10	0.27
Goats		Goats	0.16	0.31
Swine		Swine	0.08	0.22
SmallLivestock		Small Livestock	0.42	0.46
Sheep		Sheep	0.01	0.06
GPAnBFC	Proportion of … output in total output (Total Gross Product – TGP[(2)])	Annual Basic Food Crops	0.45	0.44
GPHortC		Horticultural Crops	0.01	0.07
GPCashC		Cash Crops	0.03	0.12
GPCashew		Cashew	0.02	0.10
GPCoconut		Coconut	0.02	0.12
WGPLivestock		Livestock	0.44	0.44
EconInt	Economic Intensity – output (MZN) per hectare of arable area		38565	52297
Irrigation	Proportion of arable area with…	Annual irrigated crops	0.02	0.14
Pesticide		Pesticides	0.01	0.10
Fertilizer		Fertilizers	0.03	0.13
Manure		Manure	0.02	0.14
LabProd	Labour productivity – output (MZN) per labour unit		11652	13212
Labour	Labour intensity – labour units per hectare of arable area[(3)]		3.38	2.66
Traction	Bovine traction use indicator: 1 – if yes; 0 – otherwise		0.20	0.40
Tractor	Tractor use indicator: 1 – if yes; 0 – otherwise		0.02	0.15

[(1)] In cases in which the average total area of a crop represented, on average, less than 5% of the total annual arable area, these were aggregated based on similar agroecological conditions of the crops. Aggregated crops are Sorghum+, Beans, Horticultural Crops 1, 2 and 3 (Hort1, 2 and 3), Other annual crops (OtherAnC), Citrus and Other Fruits (OtherFruits). Regarding livestock, all small animals of the farm were aggregated into the category small livestock (SmallLivestock) (see Table A2 in the Appendix A, for crops and livestock in each category).
[(2)] TGP refers to the total output of the farm, including crops (annual and permanent) and livestock.
[(3)] The inverse of labour intensity is labour capacity, i.e. hectare of arable area per labour unit, representing the capacity of the labour units to explore the arable area.

Farming systems in Mozambique were identified using multivariate statistical methods: Principal Component Analysis (PCA), for dimension reduction, followed by Hierarchical Cluster Analysis (HCA) (Kansiime, Asten, and Sneyers 2018; C. Köbrich, Rehman, and Khan 2003; Claus Köbrich 1997; Kuivanen et al. 2016; Stylianou, Sdrali, and Apostolopoulos 2020).

A PCA was performed (using the statistical software R 3.6.2) based on a correlation matrix of the data including all variables presented in Table 2.1 for all farms in the usable sample; based on Kaiser's criteria, principal components (PCs) with eigenvalue greater than 1 were selected; then, a HCA (Ward method) was performed on the selected PCs. The best solution in terms of number of clusters was selected based on the evaluation of the dendrogram (Figure A1), and expert judgment about the appropriate level of heterogeneity that should be depicted at the national level, considering the authors' previous knowledge of agricultural diversity in the country. The clusters selected represent the main farming systems in Mozambique.

We used GIS software QGIS 3.14 for mapping farming systems. The spatial distribution of each farming system was represented at the district level (the third administrative level), based on the percentage of Total Agricultural Area (TAA) of each farming system in each district (see Figure A2 for spatial distribution of each farming system). For better representativeness and understanding of the spatial distribution of all farming systems in the country, a second HCA was performed at the district level based on the share of each farming systems' area in the TAA of the district (Figure A3 for cluster dendrogram). Each cluster represents a geographic area, i.e. a zone (representing a set of districts) with a similar composition of farming systems.

2.2.3. Socioeconomic and biophysical covariates of farming systems

To explore the applicability and potential of the proposed farming system approach in contributing to better policy design through the identification of the policy problem and policy options for food security and poverty alleviation, biophysical and socioeconomic covariates of farming systems were considered, i.e. market integration, rainfall and food security. To explore the association of these covariates with farming systems, scatter plots with confidence intervals for each farming system were drawn, using the "ggplot2" package in R 3.6.2.

Rainfall and market integration are both considered covariates of farming systems, meaning that there is a statistical association between them, therefore farming systems vary along gradients of these variables. In addition, rainfall may also be considered a driver of farming system choice, as it is exogenous to farmers' choice of farming system but affects this choice. Farmers are thus assumed to choose e.g., what crops to produce based on context, exogenous biophysical and socioeconomic variables e.g., farm location, soil conditions, water availability (rainfall and/or irrigation) and available infrastructure (roads, storage facilities, etc.).

On the other hand, market integration, at least as it was defined in this paper, i.e. as the proportion of output sold (Table A1), cannot be seen as an exogenous variable affecting the choice of farming system, but rather as a consequence of farming system choice. For example, if a farmer decides to produce tobacco, the consequence of selling a high proportion of output will follow. However, this choice of farming system and the resulting market integration level is only made possible because the farmer has access to the resources that enable this integration, e.g. markets, associated value chains, etc. – which are the relevant drivers of farming system choice, but were not explicitly computed and analysed in this paper. Market integration, therefore, is seen as a consequence of both the conditions (drivers) that lead to the choice of farming system, and the farming system choice itself.

Food security variables in this study refer to households' reports of and responses to food shortages, i.e. whether the household experienced a food shortage episode in a 12 months period, the main cause of that food shortage, and the main strategies adopted to address it. These variables were extracted from CAP 2009-2010. The data refers to the 12 months prior to the survey, therefore are very sensitive to the context and shocks that occurred only in this period (2009-2010). A household was considered food insecure if they experienced a food shortage at some point in the 12 months prior to the interview, and they could not consume the food that they usually do. Regarding coping strategies, CAP collected information regarding 14 different strategies adopted by farmers to alleviate food shortages (INE 2011). In this study, we focus on two coping strategies: i) reduce time dedicated to agricultural activities to devote it to other income-generating activities, and ii) sale of large animals (bovine, goats, and pigs).

Biophysical data, i.e. annual average rainfall (mm) for 1970-2000, was extracted from WorldClim 2.0 maps, with a spatial resolution of 2.5 minutes (Fick and Hijmans 2017).

3. RESULTS

3.1. Farming Systems in Mozambique

The PCA selected 16 PCs with eigenvalues greater than 1, retaining 62% of the overall variability in the data (Table A3). The analysis of the dendrogram output (Figure A1) from the HCA together with expert judgment led to select 16 clusters, interpreted as the main farming systems in Mozambique. Each farming system was named and characterized based on the analysis of the cluster means for the 42 background variables (Table A5).

For better interpretation of farming systems, these were aggregated into four broad categories, based on their specialization (Table 2.2); and farming systems' numbers were assigned based on this aggregation, not resulting from the numbers attributed in the initial cluster analysis. Category names were based on the terminology used in CAP 2009-2010.

Table 2.2 Aggregation of farming systems by broader categories

<table>
<tr><th>Category</th><th>Sub-category</th><th>Farming System</th></tr>
<tr><td rowspan="5">1. Annual Crops (AnC)</td><td rowspan="3">Cash Crops (CashC)</td><td>FS1 – Tobacco and Maize</td></tr>
<tr><td>FS2 – Cotton</td></tr>
<tr><td>FS3 – Sesame and Maize</td></tr>
<tr><td rowspan="2">Annual Food Crops (AnFC)</td><td>FS4 – Annual Food Crops – AnFC (Horticultural Crops, Maize and Sorghum+)</td></tr>
<tr><td>FS5 – Annual Basic Food Crops – AnBFC (Cassava, Maize and Beans)</td></tr>
<tr><td colspan="2" rowspan="2">2. Annual Food Crops (AnFC) and Livestock</td><td>FS6 – Mixed Livestock and Maize</td></tr>
<tr><td>FS7 – Bovine, Maize and Other AnFC</td></tr>
<tr><td colspan="2" rowspan="3">3. Mixed Crops (AnBFC & Permanent Crops – PermC)</td><td>FS8 – Roots (Cassava and Sweet Potato) and Mixed PermC</td></tr>
<tr><td>FS9 – Cashew and Mixed AnBFC</td></tr>
<tr><td>FS10 – Rice Mixed (PermC and Livestock)</td></tr>
<tr><td rowspan="6">4. Mixed Crops (AnFC & PermC) and Livestock</td><td rowspan="2">Livestock Specialization</td><td>FS11 – Small Livestock (SmallLiv) and Mixed Crops</td></tr>
<tr><td>FS12 – Swine and Mixed Crops</td></tr>
<tr><td rowspan="2">Some livestock density</td><td>FS13 – Sheep and Mixed Crops</td></tr>
<tr><td>FS14 – Goats and Mixed Crops</td></tr>
<tr><td rowspan="2">High livestock density</td><td>FS15 – Mixed Livestock, Horticultural and Mixed PermC</td></tr>
<tr><td>FS16 – Mixed Livestock, Coconut and Cassava</td></tr>
</table>

Table 2.3 presents the main characteristics of the farming systems identified (see Table A6 for the parameters for characterization); Farming Systems' numbers and names are presented in the first row. "Agricultural land use" refers to the predominance of annual or permanent crops (or both – "mixed") in the farming system. "Annual and Permanent Crops composition" refer to the annual/permanent crops that predominate (ordered by importance), based on the share of the area with each annual crop and the proportion of each fruit tree in total number of stems of permanent crops, respectively. "Livestock composition" refers to the predominant livestock types (ordered by importance), based on the proportion of each livestock in total livestock (in standard livestock units). "Farm specialization pattern" describes the focus of the overall farming system, based on the relative contribution of each type of agricultural activity (cash/food crops or livestock) in the total output. "Output intensity" refers to output per hectare of arable area. "Yield-raising input intensity" refers to the intensity in the use of yield-raising inputs, based on the share of the area with irrigation, pesticides, fertilizers, and manure in total arable area. "Labour and labour-saving inputs" refers to labour productivity and intensity and the use of labour-saving inputs represented by the level of mechanization, i.e. use of animal traction and tractors.

Table 2.3 Characterization of farming systems in Mozambique

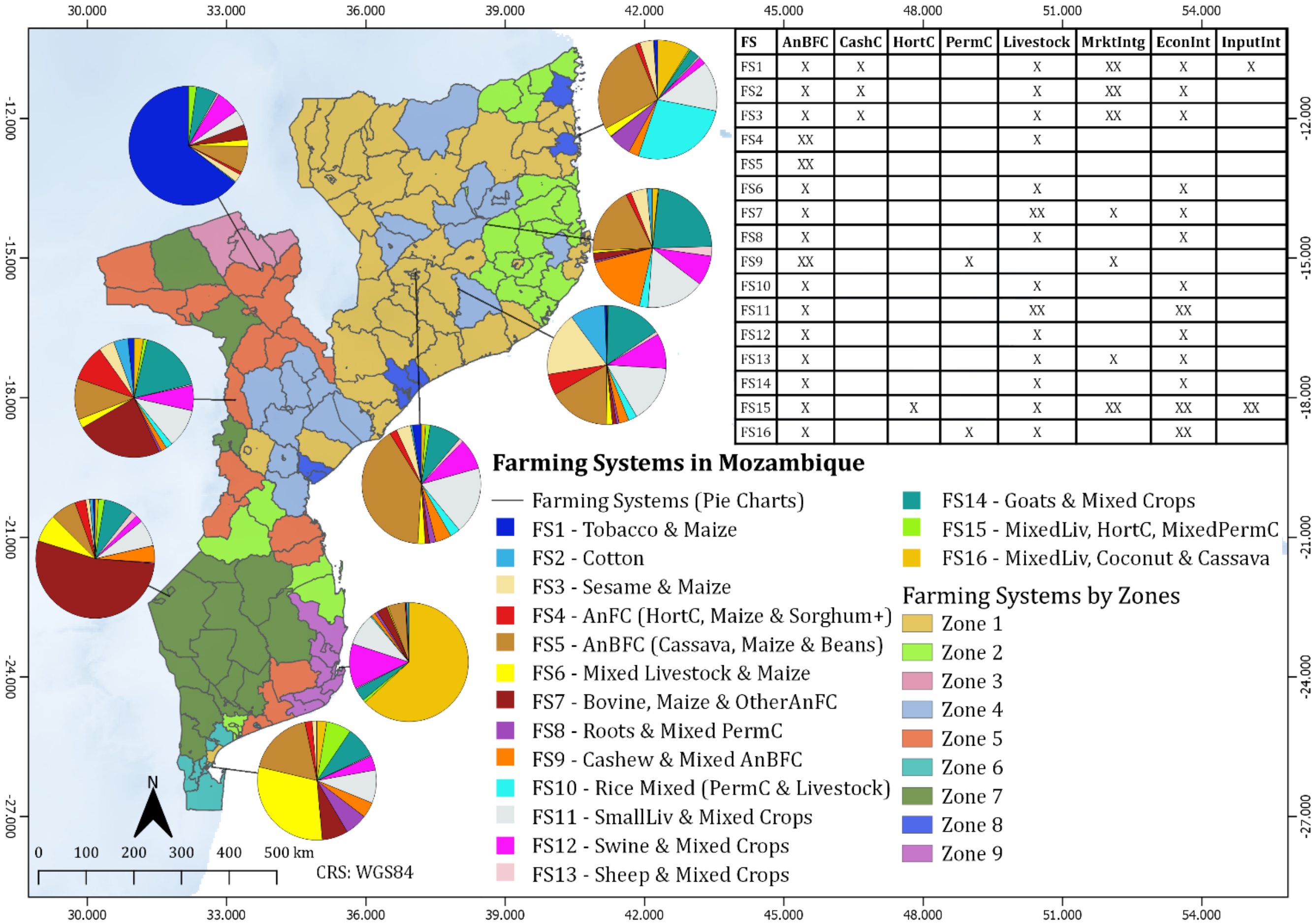
		FS1	FS2	FS3	FS4	FS5	FS6	FS7	FS8
FARMING SYSTEM		Tobacco & Maize	Cotton	Sesame & Maize	Annual Food Crops – AnFC(1) (Horticultural Crops, Maize & Sorghum+)	Annual Basic Food Crops – AnBFC(1)	Mixed Livestock & Maize	Bovine, Maize and Other AnFC	Roots & Mixed PermC
Agricultural land use		Annual	Annual	Annual	Annual	Annual	Annual	Annual	Mixed
Annual Crops (AnC) composition		Tobacco, Maize, Beans	Cotton, Maize, Sorghum+, Cassava	Maize, Sesame, Cassava, Sorghum+, Beans, Cowpea	Maize, Sorghum+, Hort1, Hort3, Cowpea, Cassava	Cassava, Maize, Beans, Groundnut Cowpea, Sorghum+	Maize, Cassava, Cowpea, Groundnut, Hort1, Rice	Maize, Hort1, Cowpea, Sorghum+, Groundnut	Sweet Potato, Cassava, Maize, Cowpea
Permanent Crops (PermC) composition									Mango, OtherFruits, Coconut
Livestock density		Low	Low	Low	None	None	High	High	Low
Livestock composition		Small Livestock, Goats	Small Livestock, Goats	Small Livestock, Goats	Small Livestock	Small Livestock	Small Livestock, Bovine, Goats	Bovine	Small Livestock
Farm specialization pattern (2)		Livestock, Cash Crops & Food Crops	Livestock, Food Crops & Cash Crops	Livestock, Food Crops & Cash Crops	Specialized Food Crops	Specialized Food Crops	Livestock & Food crops	Specialized Livestock	Food crops & Livestock
Output intensity	**Economic intensity**	Medium	Medium	Medium	Low	Low	Medium	Medium	Medium
Yield-raising input intensity	**Irrigation**	Low	Low	None	Low	Low	Low	Low	Low
	Pesticides	Medium	Medium	None	Low	None	None	None	None
	Fertilizers	High	Low	Low	Low	Low	Low	Low	Low
	Manure	Low	Low	Low	Low	Low	Low	Low	Low
Labour and labour-saving inputs	**Labour productivity**	High	Medium	Medium	Low	Low	High	High	Medium
	Labour intensity	Low	Low	Medium	Medium	Medium	Medium	Medium	High
	Animal traction	Medium	Low	Low	Low	Low	Medium	High	Low
	Motorization (Tractor)	Very Low	Very Low	None	None	None	Very High	None	Very Low

(1) AnBFC includes Maize, Rice, Sorghum+, Cowpea, Beans, Groundnut + Cassava and Sweet Potato (Roots); AnFC includes AnBFC + Horticultural crops (HortC).

(2) The term specialized is used when most of the gross product comes from a specific category (see Table A6 in Appendix A). It does not mean that the farming system is only dedicated to that specific activity.

Table 2.3. Characterization of farming systems in Mozambique (cont.)

		FS9	FS10	FS11	FS12	FS13	FS14	FS15	FS16
FARMING SYSTEM		Cashew & Mixed AnBFC	Rice & Mixed (PermC & Livestock)	Small Livestock & Mixed Crops	Swine & Mixed Crops	Sheep & Mixed Crops	Goats & Mixed Crops	Mixed Livestock, Horticultural & Mixed PermC	Mixed Livestock, Coconut & Cassava
Agricultural land use		Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Permanent
Annual Crops (AnC) composition		Cassava, Maize, Groundnut, Cowpea, Sorghum+, Beans	Rice	Maize, Cassava, Cowpea, Beans, Groundnut, Sorghum+	Cassava, Maize, Beans, Cowpea, Groundnut	OtherAnC[1], Cassava, Maize, Groundnut, Sorghum+, Beans, Cowpea	Maize, Cassava, Sorghum+, Groundnut, Cowpea, Beans, hort1	Hort2, Maize, Beans	Cassava, Cowpea, Groundnut, Maize, rice
Permanent Crops (PermC) composition		Cashew	Coconut, Mango, OtherFruits	Mango, Cashew, OtherFruits	Mango, Cashew, OtherFruits	Cashew, Mango	Cashew, Mango, OtherFruits	Mango, OtherFruits	Coconut, Cashew
Livestock density		None	Low	Low	Low	High	High	High	High
Livestock composition		Small Livestock	Small Livestock	Small Livestock	Swine, Small Livestock	Sheep, Small Livestock, Goats	Goats, Small Livestock	Small Livestock, Goats, Bovine	Bovine, Goats, Swine, Small Livestock
Farm specialization pattern		Specialized Food Crops	Food crops & Livestock	Specialized Livestock	Livestock & Food crops	Livestock & Food crops	Livestock & Food crops	Livestock, Food crops & Horticulture	Livestock, Coconut & Food crops
Output intensity	**Economic intensity**	Low	Medium	High	Medium	Medium	Medium	High	Medium
Yield-raising input intensity	**Irrigation**	None	None	None	Low	Low	Low	High	None
	Pesticides	None	None	None	None	None	None	High	None
	Fertilizers	Low	None	Low	Low	Low	Low	High	None
	Manure	Low	None	None	Low	Low	Low	High	None
Labour and labour-saving inputs	**Labour productivity**	Low	Medium	High	Medium	Medium	High	Medium	High
	Labour intensity	Low	High	Medium	Medium	Medium	Medium	High	Low
	Animal traction	Low	Low	Low	Low	Low	Low	Medium	High
	Motorization (Tractor)	Very Low	None	None	None	Very Low	None	Very Low	None



FS	AnBFC	CashC	HortC	PermC	Livestock	MrktIntg	EconInt	InputInt
FS1	X	X			X	XX	X	X
FS2	X	X			X	XX	X	
FS3	X	X			X	XX	X	
FS4	XX				X			
FS5	XX							
FS6	X				X		X	
FS7	X				XX	X	X	
FS8	X				X		X	
FS9	XX			X		X		
FS10	X				X		X	
FS11	X				XX		XX	
FS12	X				X		X	
FS13	X				X	X	X	
FS14	X				X		X	
FS15	X		X		X	XX	XX	XX
FS16	X			X	X		XX	

Note: The summary table reflects the main activities practiced in each farming system, as well as the level of market integration (MrktIntg or MARKET) – proportion of output sold, economic intensity (EconInt) – output per hectare of arable area and intensity in the use of yield-raising inputs (InputInt); X represents mildly weight and XX – high weight of the variable in the farming system, the absence of X means that the weight of the variable is very low or absent.

Figure 2.2 Spatial distribution of farming systems in Mozambique and summary table of farming systems characteristics

To represent the spatial distribution of farming systems in the country, 9 clusters from the second HCA were selected through dendrogram analysis. Each cluster corresponds to a zone, which represent a set of districts with a similar composition of farming systems (see pie charts in Figure 2.2).

The Cash Crops' farming systems, i.e. FS1 (Tobacco and Maize), FS2 (Cotton) and FS3 (Sesame and Maize) are concentrated in the Central and Northern regions of the country (see Figure A2). These farming systems are highly integrated in the market, use yield-raising inputs with some labour productivity.

FS4 (AnFC) is dedicated to annual food crops (mainly horticultural crops, maize and sorghum+) and occurs mainly in the Central region (Zone 5), and in less proportions in the North and South regions. This system is very rudimentary, being labour intensive, with low use of yield-raising and labour-saving inputs and is not market oriented. On the other hand, FS5 (Annual Basic Food Crops) is the most common system (representing ca. ¼ of sampled households) and occurs across the whole country, with emphasis to the Northern region. It is essentially a subsistence system, dedicated mostly to staple crops, i.e. cassava, maize and beans, with low yield-raising input use and economic intensity, and low level of market integration. Likewise, FS11 (Small livestock and Mixed Crops) and FS12 (Swine and Mixed crops) also occur across the country, mostly in the Center and North, with maize and cassava as the predominant crops. Both systems are dedicated to livestock, small livestock (mostly chickens) – FS11 and swine production – FS12. These systems have high and medium economic intensity, respectively, however both are mostly not market oriented (FS11 less than FS12).

FS6 (Mixed Livestock and Maize) predominates in the Southern region, mostly in Maputo Province (Zone 6); it is mainly dedicated to annual food crops (with particular emphasis to maize), with high livestock density (including small livestock, bovine and goats). FS6 is barely integrated in the market, however the use of labour-saving inputs is high, with emphasis to the use of tractors.

FS7 (Bovine, Maize and OtherAnFC) is characteristic of arid areas, occurring mainly in the South and Central inland regions (Zone 7 and 5). This farming system is mainly dedicated to livestock (bovine) and has high labour productivity and high use of labour-saving inputs (animal traction) with some market integration.

FS8 (Roots and Mixed Permanent Crops) occurs in small areas in the South (Zone 6) and Central and Northern regions (Zone 8). FS9 (Cashew and Mixed Annual Basic Food Crops) occurs mostly in the North, close to the coast; it is dedicated, among other crops, to cashew and has some integration in the market. FS10 (Rice Mixed) dedicated essentially to rice, is predominant in small areas in the North (Cabo Delgado and Niassa) and Center (Zambézia and Sofala) of Mozambique (Zone 8); this system does not use yield-raising inputs and is labour intensive, however has medium economic intensity.

FS13 (Sheep and Mixed Crops) occurs in a small proportion in the North and some parts of the Southern region (Figure A2). FS14 (Goats and Mixed Crops) is mostly predominant in the Central and Northern regions. Both FS13 and FS14 have high livestock density, with sheep and goats, being the predominant livestock species, respectively. Both farming systems use very low levels of yield-raising and labour-saving inputs. FS13 is slightly integrated in the market, while FS14 is not.

FS15 (Mixed livestock, Horticultural Corps and Mixed Permanent Crops) is mostly predominant in the Southern region. Horticultural crops are the predominant food crop in the system. FS15 is also the most irrigated with intensive use of yield-raising inputs and labour, and is highly integrated in the market.

FS16 (Mixed livestock, Coconut and Cassava) has a significant share of permanent crops, with emphasis to Coconut trees, occurring mainly along the coast, with particular emphasis to the South region (Inhambane Province – Zone 9). FS16 is also intensive in livestock, therefore is one of the systems with high use of animal traction and high labour productivity.

3.2. Socioeconomic and biophysical covariates of farming systems

This section explores the applicability of the proposed farming system approach by exploring the relationship between farming systems and biophysical and socioeconomic variables, i.e. market integration, rainfall and food security.

3.2.1. Farming systems and market integration

To analyse the distribution of farming system based on market integration, two variables were considered: 1) the proportion of horticultural (HortC) and cash crops (CashC) in total output (TGP); and, 2) yield-raising input intensity (including irrigation, pesticides, fertilizers and manure).

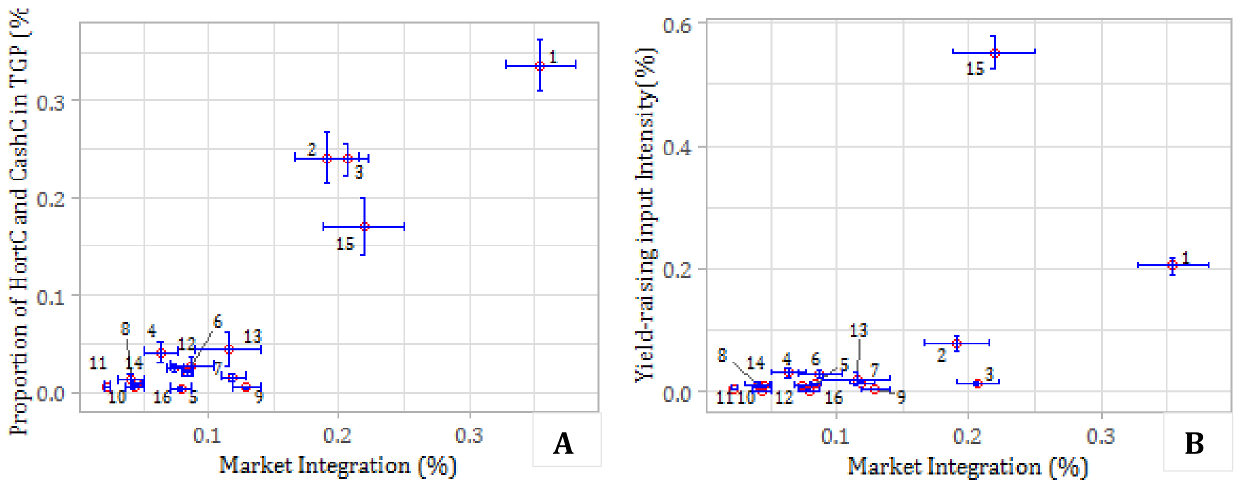


Figure 2.3 Contrasting market integration with the proportion of horticultural and cash crops in TGP (A) and yield-raising input intensity (B) by farming system

It was found a clear distinction between the 16 farming systems, in terms of the proportion of horticultural and cash crops and the level of market integration. FS1, FS2, FS3 and FS15 (dedicated to Tobacco, Cotton, Sesame and Horticultural crops, respectively) are market oriented. The other farming systems are subsistence, not being integrated or with low levels of integration in the market. Also, most of these farming systems do not use yield-raising inputs. The emphasis is on FS15 for the intensive use of yield-raising inputs (irrigation, fertilizers, pesticides, and manure). FS1 has some input intensity, with access to pesticides and fertilizers, while FS2 uses mostly pesticides.

3.2.2. Farming systems and biophysical drivers

To explore the distribution of farming systems along the gradient of rainfall, it was considered the proportion of annual basic food crops (AnBFC) and livestock (Bovine) in the TGP, showing the dependence of food and bovine oriented farming systems on rainfall.

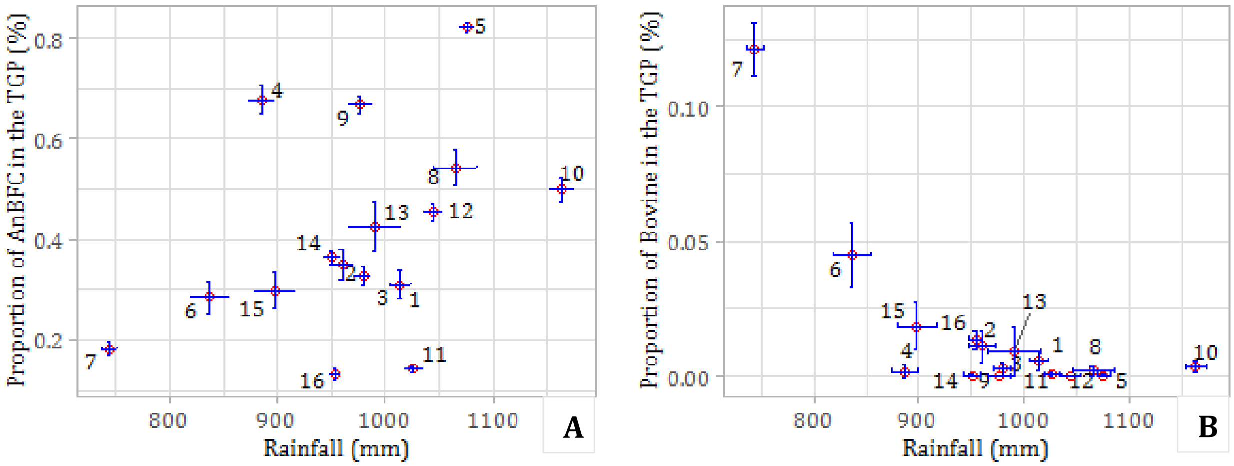
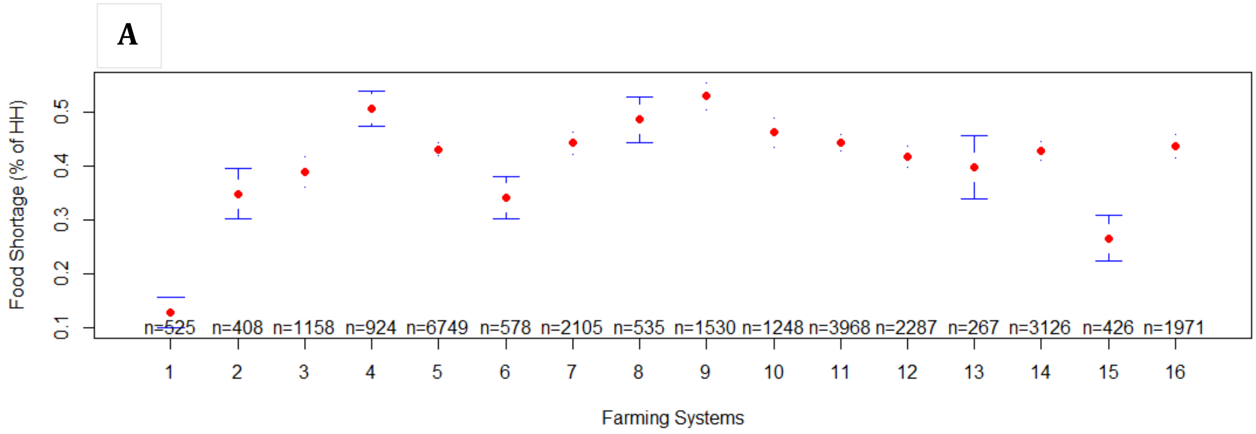


Figure 2.4 Contrasting rainfall (mm) with the proportion of annual basic food crops in TGP (A) and proportion of bovine in TGP (B), by farming system

Most farming systems in Mozambique are dependent on rainfall, being located in areas with levels of rainfall of at least 950mm, on average. Most of them obtain at least 30% of their total output from annual basic food crops (which excludes horticultural crops). On the other hand, most farming systems oriented towards bovine production, tend to be characteristic of arid areas. That is the case of FS7 (Bovine, Maize and OtherAnFC) specialized in livestock, specifically bovine; followed by FS6 (Mixed Livestock and Maize) and FS15 (Mixed Livestock, Horticultural Crops and Mixed Permanent Crops), which are also dedicated to livestock (including small livestock, bovine and goats) with a small proportion of annual basic food crops and horticultural crops, being mostly irrigated.

3.2.3. Farming systems and food security

To explore how farmers' vulnerability to food shortages and corresponding coping strategies vary across farming systems three variables were considered, referring to the proportion of households that reported: 1) food shortages; 2) lack of rain as the main cause of food shortage; and, 3) selected strategies adopted by households to face food shortage.



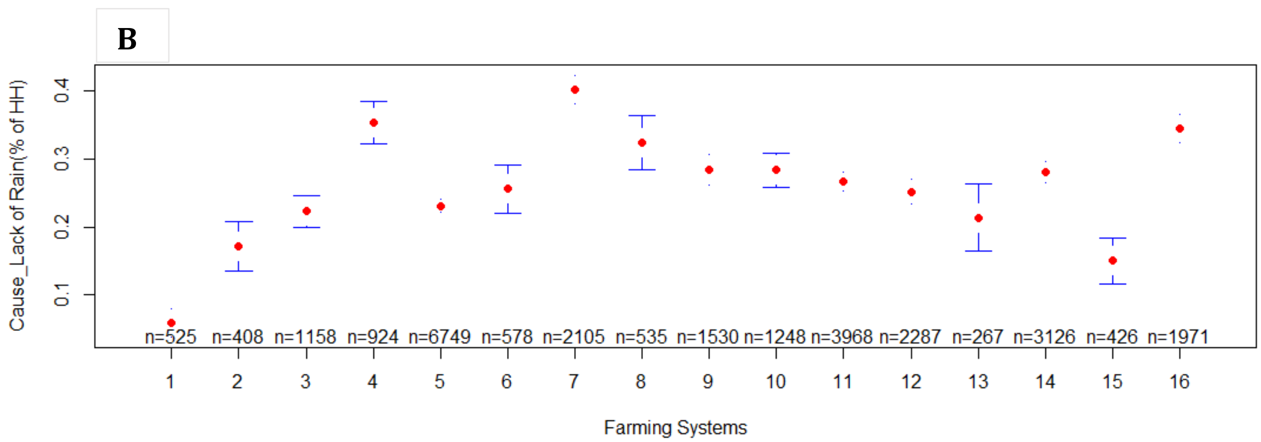


Figure 2.5 Proportion of households that reported food shortages (A) and lack of rain as the main cause of food shortage (B) by farming system

Regarding food shortage, results show that FS1 (Tobacco and Maize) is significantly different from the others and is assumed to be the most food secure (only 13% of households reported food shortages). Other farming systems considered food secure are FS15 (Mixed Livestock, Horticultural and Mixed PermC), FS6 (Mixed Livestock and Maize), FS2 (Cotton) and FS3 (Sesame and Maize), with less than 40% of the households reporting to have experienced food shortages.

The FS9 (Cashew and Mixed AnBFC) is considered the most food insecure, as more than half of the households reported food shortages. FS4 (AnFC – Horticultural Crops, Maize and Sorghum+) and FS8 (Roots and Mixed PermC) and FS10 (Rice Mixed) also reported significant food shortages (on average, almost 50% of households with food shortages).

FS5 (AnBFC – Cassava, Maize and Beans), FS11 (Small Livestock and Mixed Crops) and FS14 (Goats and Mixed Crops) are also considered relatively food insecure (ca. 43% of households reporting food shortages).

Most households, in all farming systems, referred to lack of rain as the main cause of food shortage, with particular emphasis to FS7 (Bovine, Maize and Other AnFC), followed by FS4, FS16 (Mixed Livestock, Coconut & Cassava) and FS8.

In order to face food shortage, farmers have adopted a set of strategies; we present two coping strategies: a) reduce time dedicated to agricultural activities to devote it to other income-generating activities; and, b) the sale of large animals, i.e. bovine, goats and pigs (Figure 2.6. A and B).

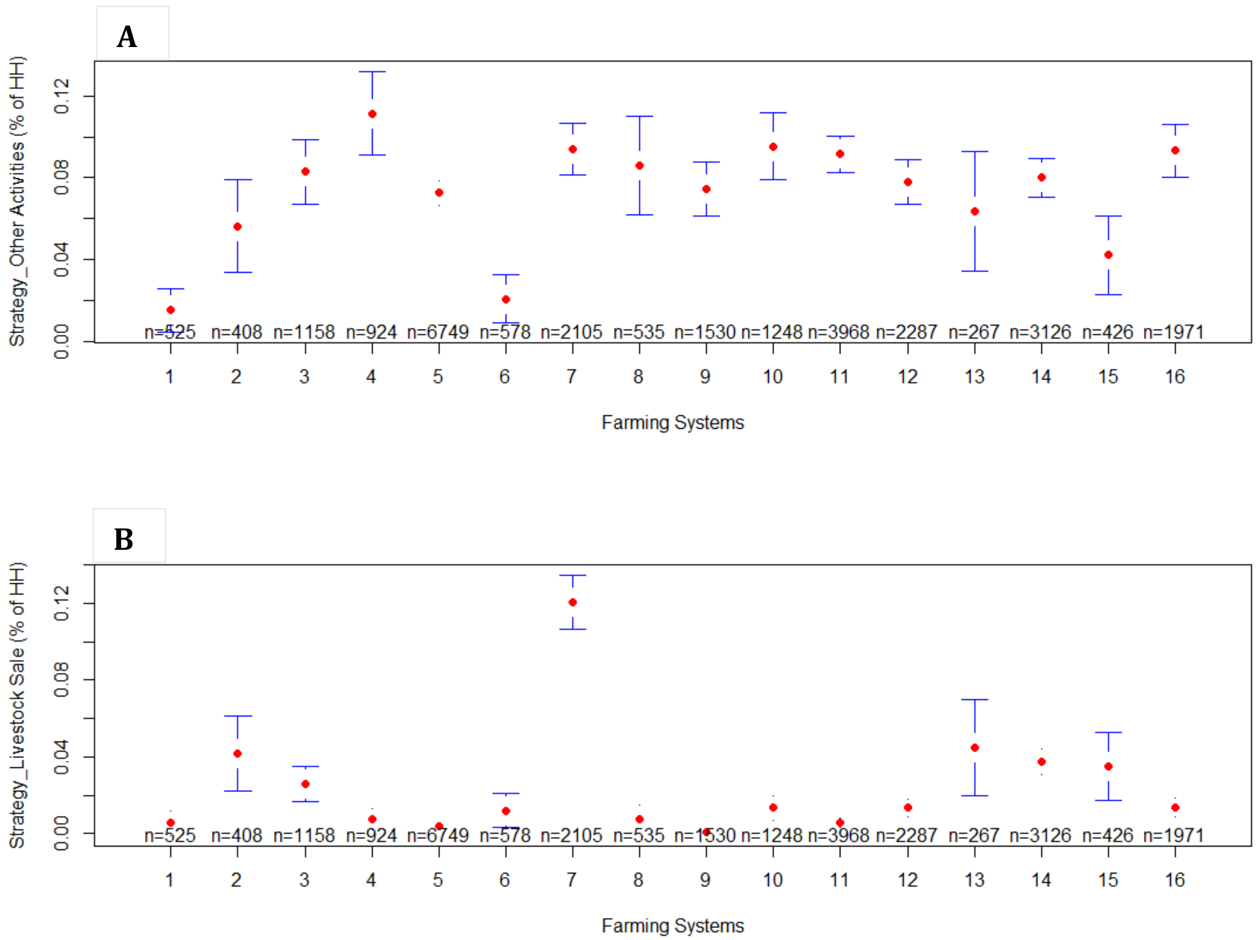


Figure 2.6 Strategies adopted by farmers to alleviate food shortages, based on CAP 2009-2010

To alleviate food shortages farmers decided to dedicate more time to other activities other than agriculture (Figure 2.6-A); this strategy was common among farmers in most farming systems, with particular emphasis to FS4 (AnFC). Other faming systems include FS10 (Rice Mixed), FS7 (Bovine, Maize and Other AnFC), FS16 (Mixed Livestock, Coconut and Cassava), FS11 (Small Livestock and Mixed Crops) and FS8 (Roots and Mixed PermC). FS1 (Tobacco and Maize) and FS6 (Mixed Livestock and Maize), on the other hand, rarely adopt this strategy.

On the other hand, the sale of livestock as a strategy to face food shortage is not very common among farmers (Figure 2.6-B), being predominant in FS7.

4. DISCUSSION

This section discusses the results obtained, focusing on the proposed methodological approach used to identify farming systems and explores possible applications of such an approach for policy design by illustrating how the results of the analysis may contribute to the identification of the policy problem and provide policy options for food security and poverty alleviation among small farmers in developing countries.

4.1. A census-based, countrywide farming system approach based on farmers' productive decisions

A faming system approach can be used to explore a multitude of issues, e.g. poverty, food security, etc. (Dixon, Gulliver, and Gibbon 2001; Massawe 2017), allowing to derive policy recommendations from the analysis. However, the range of policy impacts on farmers that can be addressed depends on the approach used to identify farming system types. For example, Dixon et al. (2001) identified farming systems based on available natural resource base, i.e. water, land, grazing areas and forest, climate, landscape, farm size and others (i.e. drivers of farming system choice) as well as dominant pattern of farm activities and household livelihoods, i.e. type of crops, livestock, trees, aquaculture, hunting and gathering, processing and off-farm activities, and technology used (i.e. farming system descriptors). Since Dixon et al. (2001) integrate what we call drivers into the analysis for the identification of farming systems, they cannot analyse the dependency relationships between these drivers and farming system choice, which hinders the analysis on the dynamics of farming systems as these drivers change in time or space. Our separation of the descriptors of farming system from the drivers of farming system choice, and the use of the former alone for the identification of farming system types, allow this analysis (C. Köbrich, Rehman, and Khan 2003; Claus Köbrich 1997; Silva et al. 2020). Since public policies may be seen as included in (or affecting) these drivers, the results of the analysis of how farming system choice responds to drivers may provide insights on how farming system choice will respond to policies.

The farming system approach presented is based on statistical data from the agricultural census, collected at the farm level for the entire country (covering all areas at the district level). The advantages of using this type of data are significant. First, it allows a detailed characterization of farming systems, based on the productive choices made by farmers in the field. Second, since the data covers the entire country, it allows to classify farms by farming systems at the country level and assess its spatial distribution. Third, in most developing countries, the agricultural census report is prepared periodically (e.g. usually every 10 years), and the database can be obtained upon request to the competent institutions, i.e. free of cost or at a reasonable price. Fourth, the fact that the agricultural census is carried out on a periodic basis allows, in the medium and long term, monitoring the evolution of farming systems over time (E Andersen et al. 2004).

Furthermore, this census-based approach can be applied in most developing countries, which usually lack alternative detailed, consistent, and continued data regarding the agricultural activity (e.g. studies that have collected their own data).

4.2. The applicability of the proposed approach: exploring links between farming system choice and its socioeconomic and biophysical covariates

To demonstrate the role of the drivers on farming systems choice, we explored the distribution of the farming systems along the gradients of two covariates: market integration and rainfall. The analysis presented is not intended to explore in depth all connections and relations between farming systems and these two covariates, but instead to develop a simple interpretation of results to illustrate how these may help describe the policy problem and explore policy options for food security and poverty alleviation.

Rainfall is expected to play a major role in the choice of farming system, as most farms in developing countries practice rainfed agriculture, and therefore are extremely dependent on rainfall (Biswas et al. 1987). Our results show that farming systems dedicated mostly to the production of annual basic food crops, e.g. maize, cassava and beans, are located in humid areas. On the other hand, farming systems oriented towards bovine production are more predominant in arid areas, with low levels of rainfall. This describes how the choice of farming system responds to rainfall levels, i.e. how farming systems vary along the precipitation gradient, which would allow to predict how future climate scenarios will affect farming system.

Regarding levels of market integration, there is a clear distinction between the 16 farming systems identified. Market integration is often associated with farmers' access to roads, storage facilities, associated value chains and others (Massawe 2017). Our results indicate that farming systems dedicated to the production of cash crops and horticultural crops tend to be more market oriented. For example, the horticultural system (FS15) is predominant in the south, in Maputo province (Figure 2.2), which has access to a developed road network and formal and informal markets (Paganini and Ouana 2019), therefore farmers tend to sell their products in markets close to their farms, or to wholesalers which then sell it to other small merchants (Paganini and Ouana 2019). For cash crops, market integration is related to the fact that tobacco and cotton production is mainly done by smallholders in a subcontracting system (Bruna 2014; Mosca 2019), i.e. concession large companies buy most of the production directly from the farmers at a fixed price established by the competent institutions. These companies are usually responsible for the supply of yield-raising inputs, credit and extension services (Bruna 2014), and also for transporting, storage, basic processing and selling. The considered developed value chain guarantees the supply of inputs and the subsequent purchase of the product, meaning that farmers producing these crops, located close to the areas in which these companies operate, are more likely to be integrated in the market, which influences positively on farmers' income.

Therefore, policy interventions focusing on farmers' risk reduction (production, prices and markets) can contribute to reduce farmers' impoverishment in rural areas. Further analysis of the drivers influencing farming system choice is recommended to better understand the relations between farming systems and these drivers.

4.3. A farming system approach to food security and poverty alleviation

In developing countries agricultural activity is mostly oriented towards subsistence, i.e. farmers' major concern is to guarantee their families' basic nutrition through food cropping. The most common system in developing countries is the mixed food crop (staples and legumes) system including some livestock production (e.g. poultry) (Etwire 2020 - Ghana; Maggio and Sitko 2018 - Zambia and Mozambique), which is supported by our results (Table 2.2). These systems are dedicated to basic food crops and use rudimentary production practices, with extremely low levels of yield-raising and labour-saving inputs (Maggio and Sitko 2018; MASA 2016) and low access to credit (INE 2011).

Based on our analysis, farming systems specialized mostly in food crops (FS9, FS4 and FS8), which are also labour intensive (except FS9), with very low use of yield-raising and labour-saving inputs, low labour productivity, with absence of any livestock besides small livestock (poultry) are the most food insecure. The absence of livestock is often associated with lack of access to animal traction and organic fertilizers, resulting in lower crop yields, which may contribute to food insecurity (Kuivanen et al. 2016). These systems usually concentrate farmers with lower incomes (Dixon, Gulliver, and Gibbon 2001), therefore they don't have sufficient income to buy yield-raising inputs and, in general, have difficult access to credit, which also contributes to lower access to inputs (Mosca 2019).

Farming systems concentrating most of the rural population, i.e. FS5, FS11 and FS14 (representing ca. 50% of the sampled households), are also considered relatively food insecure, being distributed across the country, with particular emphasis to the Central and Northern regions, which are the major food production regions. Areas with the highest shares of food production are also the ones more vulnerable to food insecurity (Abbas 2017b; Dixon, Gulliver, and Gibbon 2001; Massawe 2017), which can be related to difficult access to (input and output) markets, lack of off-farm work and low monetary incomes. These systems usually concentrate most of the rural poverty, i.e. low-income rural households, with small farms and highly dependent on agricultural incomes, which is closely related to hunger (Garrity, Dixon, and Boffa 2012; Mascarenhas et al. 1986). The lack of sufficient income to invest in productivity-enhancing technologies (yield-raising and labour-saving inputs) or to purchase food and other essential goods is a major factor contributing to food insecurity (Kansiime, Asten, and Sneyers 2018; Massawe 2017; Tittonell et al. 2010).

Results indicate that the most food secure farming systems, i.e. FS1, FS15, FS2, FS6 and FS3, are intensive in the use of yield-raising inputs, being also more integrated in the market. Commercial orientation in farming creates motivation and resources to increase productivity for most farming systems dependent on farm-income (Kansiime, Asten, and Sneyers 2018; Tittonell et al. 2010), contributing to increase crop yields which stimulates greater market integration, thus increasing farmers' income.

Increasing employment and *per capita* earnings are important factors contributing to the development of the agricultural sector (Mascarenhas et al. 1986). Overall, improved access to input and output markets is considered an important factor stimulating yields; access to roads and proximity to urban areas may increase access to off-farm opportunities contributing to increase farmers' income (Massawe 2017) and also positively drives adoption of more diverse systems (Maggio and Sitko 2018), contributing positively to food security. Usually farmers engaged in the production of cash crops, include some food crops in their systems, in order to meet the household food security (Lukanu et al. 2004; Maggio and Sitko 2018).

For example, FS6, which is relatively diversified and one of the most food secure systems, is predominant in a considerably urbanized area, showing the highest average of household members dedicated to off-farm activities; being also the system with the highest use of labour-saving inputs. Access to off/non-farm income promotes income diversification, being an alternative source of livelihood and a risk management strategy in small farms, allowing also farmers to enhance productivity in their farming systems (Stylianou, Sdrali, and Apostolopoulos 2020; Villano, Asante, and Bravo-Ureta 2019).

The search for off-farm activities is a common strategy adopted by households to alleviate poverty or to cope with food insecurity (Dixon, Gulliver, and Gibbon 2001; Massawe 2017; Stylianou, Sdrali, and Apostolopoulos 2020). According to our results, in Mozambique, when faced by food shortages most households tended to reduce the time dedicated to agricultural activity to devote it to other activities, i.e. off-farm activities.

In Sub-Saharan Africa food insecurity has been often associated, among other factors, with droughts (Dixon, Gulliver, and Gibbon 2001). In this study, the lack of rain has been considered the main cause of food shortage by most farmers, with particular emphasis to FS7 (Bovine) – in which 44% of households reported food shortages. The coping strategies adopted by farmers in this system are sale of livestock (e.g. cattle, goats and pigs), increase of off-farm activities, use of savings and reduce the diet quality. Dixon et al. (2001) also found similar coping mechanisms adopted in agropastoral systems.

Selling livestock is not a common strategy adopted in other farming systems; and when the decision is made is usually by men (ca. 56%). In many African countries, livestock has a cultural and social role in the communities, representing wealth and also a safety net or buffer against extreme shocks (Kuivanen et al. 2016), however households may avoid selling large livestock to face food shortage in the short run. The existing gender inequality also plays an important role, as even though women are responsible for most agricultural activities and food consumed by the household, they have limited ownership, control and access to assets that can be exchanged for food, i.e. livestock; which also makes female-headed households more likely to be food insecure (Massawe 2017). Our results corroborate that female-headed households are more food insecure (50%) compared to men-headed households (40%).

4.4. Contributing to policy design in targeting small food insecure farmers

Food insecurity and poverty affect most farmers in developing countries, especially the ones in less endowed farming systems. Climate, i.e. rainfall, influences farming system choice and appears to be an important source of vulnerability in most farming systems (Dixon, Gulliver, and Gibbon 2001) causing food shortages – which is supported by our results.

Nevertheless, farmers' vulnerability to food insecurity goes beyond climate shocks, being also influenced by socioeconomic variables, which frame the options available to farmers. Market integration and access to yield-raising and labour-saving inputs are important factors combating poverty and food insecurity (Dixon, Gulliver, and Gibbon 2001; Kansiime, Asten, and Sneyers 2018; Massawe 2017; Mosca 2019). Our results suggest that farming systems with access to markets and using yield-raising and labour-saving inputs, i.e. more integrated in the market, are the most food secure. Most food producers have limited access to such incentives (Mosca, Amreén, and Dadá 2014), and public policies usually benefit medium and large-scale farmers marginalizing the poor and food insecure small farmers (Mosca and Abbas 2016).

Farmers not having adequate access to financial resources, i.e. farm and/or off-farm income and credit, as well as agricultural resources are more vulnerable to food insecurity and external shocks. The limited access to credit which in one hand is caused by the high risk and vulnerability in agricultural activity, as well as the low yields and income generated from agriculture, prevents farmers to engage in yield-raising and labour-saving techniques which would lead to improve crop yields. This can stimulate labour productivity and farm income, if appropriate infrastructure is available, e.g. roads, storage and conservation facilities, allowing the integration of small farmers into the market. Overall, it is important to reduce farmers' risks, e.g. through price regulation, better access to yield-raising and labour-saving inputs and infrastructures. The greater the incentives for food production, the greater the farmers' capacity to escape poverty and food insecurity. Public policies have the leading role in making this happen. If adequate policies are implemented, even in the event of an external shock (e.g. climatic), farmers would be able to cope with food insecurity.

Based on the analysis, policies should focus on the most traditional farming systems dedicated essentially to food production, e.g. FS9, FS4, FS8, FS10, FS11, FS5 and FS14, as these concentrate the most poor and food insecure population; being also the crucial systems for guaranteeing food sovereignty in the long term. This is consistent with IAC (2004) which considers the maize mixed, cereal-root crop, irrigated and tree crop-based farming systems as priority systems, contributing to increase agricultural productivity and improve food security.

The results and analysis presented, are an example of the usefulness of the proposed farming system approach in exploring issues such as food security and poverty allowing for better policy design, with positive feedbacks to food insecure, poor farmers in developing countries. This approach can be used to identify which future changes in socioeconomic and biophysical drivers will more likely lead to the expected responses from farmers, in terms of production decisions that will lead to higher levels of food security and thus to higher policy effectiveness.

5. CONCLUSION

Our results suggest that a farming system approach that separates farming system description from the analysis of drivers (and other covariates) of farming system choice is a useful approach to explore the production decisions of small farmers in developing countries. Moreover, the use of a census-based approach provides a cost-effective way to access farm-level data that can be used by governments, policy-makers, research institutions and others, for policy analysis or to explore a range of issues affecting farmers in developing countries, thus contributing for the improvement of the lives of the most vulnerable.

The usefulness of this approach goes beyond the descriptive aspect of recognizing the diversity of farming systems. By classifying farms based solely on farmers' decisions regarding farm-level production, it enables the analyst to explore the factors that shape these decisions, which contributes to understand how changes in e.g., climate or other socioeconomic variables, will affect farmers' decisions and therefore contribute to achieve the desired policy outcomes. Our results support the idea that designing more effective policy requires the understanding of the diversity of farming systems, as well as the factors affecting how farmers choose their farming systems, respond, and adapt to external shocks, based on the resources available to them, and that a farming system approach such as the one developed in this study provides the right framework for such an understanding.

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APPENDIX A

Table A.1 Computation of variables used for the classification of farms by farming systems

Final variable (used in the analysis)				Variables extracted from CAP 2009-2010, used for the computation of the final variable			
Final Variable Code	**Final Variable name**	**Unit**	**Formula**	**Variable Code**	**Variable Name**	**Unit**	**Obs.**
AnC_i	Arable area with annual crop *i*	%	$(AAnC_i/AnCA)*100$	$AAnC_i$	Arable area with annual crop *i* (all parcels)	Hectare (ha)	Where *i* = Maize, Rice, Sorghum+, Cassava, Sweet Potato, Cowpea, Beans and Groundnut (AnBFC); Sesame, Cotton and Tobacco (CashC); Hort1, Hort2, Hort3 (HortC); and, Other annual crops (OtherAnC).
				AnCA	Total annual arable area (all parcels)	Ha	
$Tree_f$	Predominance of fruit tree *f*	%	$FTree_f/Ttree$	$Ftree_f$	Total number of fruit tree *f*	N	Where *f* = Mango, Cashew, Coconut, Citrus and Other Fruits (OtherFruits)
				TTree	Total number of fruit trees (all parcels)	N	
PermC	Area with permanent crops (in relation to annual crops)	%	APermC/AnCA	APermC	Area with Permanent Crops	Ha	APermC = ∑[(FTreef*ATreef)/10000];
				AnCA	Total annual arable area (all parcels)	Ha	ATreef - Average area per fruit tree *f* (m^2), based on Rehm & Espig (1991).
$Livestock_k$	Proportion of livestock *k* in total livestock	%	$(Liv_k/Tliv)*100$	Liv_k	Total livestock *k* in livestock unit (1)	N	Where *k* = Bovine, Goats, Sheep, Swine and Small Livestock
				TLiv	Total livestock in livestock unit	N	
LivDens	Livestock density	N/ha	TLiv/AnCA	-	-	-	-
WGP_g	Weight of group *g* in Total Gross Product	%	GP_g/TGP	GP_g	Gross Product for group *g*	MZN	Where *g* = AnBFC; CashC; HortC; Fruit; Cashew; Coc.
				TGP	Total Gross Product: TGP = GPC(2) + GPLiv(3)	MZN	GPC: Total Crop Gross Product (GPC = $\sum GP_i$) GPLiv: Total Livestock Gross Product (GPLiv = $\sum GPLiv_k$)
MARKET (4)	Market Integration	%	(TSale/TGP)*100	TSale	Total farm sales: TSale = CropSale + LivSale	MZN	CropSale: Total farm crop sales (all parcels) LivSale: Total livestock sales (all parcels)
				TGP	Total Gross Product	MZN	-
EconInt	Economic Intensity	MZN/ha	TGP/TAA	TGP	Total Gross Product	MZN	-
				TAA	Total Agricultural Area	ha	TAA = AnCA + APermC
Irrigation	Arable area with annual irrigated crops	%	(AIrrig/AnCA)*100	AIrrig	Total arable area with annual irrigated crops (all parcels)	ha	-
				AnCA	Total annual arable area (all parcels)	Ha	
Pesticide	Arable area with pesticides	%	(APest/AnCA)*100	APest	Total arable area with pesticide (all parcels)	ha	-
				AnCA	Total annual arable area (all parcels)	ha	

Table A1. Computation of variables used for the classification of farms by farming systems (Cont.)

Final variable (used in the analysis)				**Variables extracted from CAP 2009-2010, used for the computation of the final variable**			
Final Variable Code	**Final Variable name**	**Unit**	**Formula**	**Variable Code**	**Variable Name**	**Unit**	**Obs.**
Fertilizer	Arable area with fertilizers	%	(AFert/AnCA)*100	AFert	Total arable area with fertilizer (all parcels)	ha	-
				AnCA	Total annual arable area (all parcels)	ha	
Manure	Arable area with manure	%	(AManure/AnCA)*100	AManure	Total arable area with manure (all parcels)	ha	-
				AnCA	Total annual arable area (all parcels)	ha	
LabProd	Labour productivity	MZN/N	TGP/LU	TGP	Total Gross Product	MZN	-
				LU	Labour Unit [5]	N	
Labour	Total Labour intensity	N/ha	LU/TAA	LU	Labour Unit	N	-
				TAA	Total Agricultural Area	ha	-
Traction	Bovine traction use indicator	Dummy	0 - No	Extracted from CAP 2009-2010 database			
			1 - Yes				
Tractor	Tractor use indicator	Dummy	0 - No				
			1 - Yes				

[1] Livestock unit is a standard unit of equivalence used to compare and aggregate numbers of animals of different species or categories, taking into account animal species, age, live weight and productive vocation (Decree Law 214/2008, 10th November, Annex II, pg. 7848); the conversion to livestock units was based on the Equivalence Table provided by the Decree Law 214/2008, 10th November, Annex II 2nd, Table 2, pg. 7848.

[2] Crop Gross Products (GPC) was equal to the total harvested amount for each crop (extracted from CAP 2009-2010), multiplied by the median price computed for each crop. The median price for crops was obtained through CAP 2009-2010, as it provided the total quantity sold for each crop, as well as the total value received for the sale (in cases which different currencies were considered, it was used the average exchange rate for 2009 and 2010, obtained at Bank of Mozambique – http://www.bancomoc.mz/ to convert to the national currency – Metical, MZN), then the average price for each household was calculated. After calculating the price for each crop for each household, a percentile analysis was performed to obtain the median price for each crop. Harvested and sold quantities for each crop, are given in CAP 2009-2010 in different units of measure and different status – the status meaning, e.g. if the crop was harvested or sold fresh, in cob, in grain, shelled, dry, etc. Therefore, harvested and sold amounts were converted into the same measurement unit, kilograms (kg), using the conversion parameters provided by the Ministry of Agriculture and Food Security and the National Statistical Institute – institutions responsible for the design and realization of the survey and processing of information of CAP 2009-2010. However, the conversion factors did not covered all the existing units of measure. For those cases it was used the land productivity to estimate the farms' production. Land productivity was obtained through the arable land area and harvested quantity (in kg) for each crop (considering only the observations for which conversions were available) extracted from CAP 2009-2010. Conversion factors for horticulture and fruits was not available; also harvested amounts for these groups of crops were not available, therefore it was assumed that the gross product was equal to the sales (in Metical, MZN).

[3] The livestock gross product (GPLiv) was obtained by adding the slaughtered livestock (for consumption and sale) and the live animals sold and offered, multiplied by the average price. To obtain the price used in the analysis, three price categories were calculated: 1) Purchase price; 2) Sale price; and, 3) Sale price of meat, based on data extracted from CAP 2009-2010. The percentile was calculated for each of the categories, in order to obtain the median price; it was used the average of the three median prices obtained.

[4] Market Integration (MARKET) variable was not used for the classification of farming systems, however it was used to characterize farming systems and in the analysis.

[5] Labour units correspond to the sum of all units of labour employed in agriculture and livestock activity, including: i) family labour – weighted in 100% for those who had agricultural as their main activity, and 25% for those who have agriculture as their secondary activity; ii) full-time workers – considered to dedicate 100% of their time to agricultural activity; and, iii) temporary workers – assumed to spend 10% of their time on agricultural activity.

Table A.2 Aggregation of crops and livestock from CAP 2009-2010, based on statistical means, for classification of farms by farming systems

Crop/livestock aggregation name	**Crops/livestock included (ordered by importance)**	**Criteria**
Sorghum+	Sorghum and Millet	According to the literature and preliminary analysis, sorghum and millet are usually aggregated together, as they are tropical cereal species and are cultivated in the same agroecological zones (Taylor and Duodu 2017).
Beans	Pigeon peas, Jugo beans and Kidney beans	All beans with $WAnC_i$ (Mean) ≤ 5%,
Hort1	Pumpkin, Watermelon and Okra	Horticultures were aggregated considering their association and distribution among typologies of farming systems.
Hort2	Tomato, Kale, Onion, Potato, Lettuce and Cabbage	
Hort3	Cucumber, Yam, Green beans, Garlic, Carrot, Pepper and Eggplant	
OtherAnC	Other crops, Other beans, Peas, Sunflower, Soy, Sugar Cane, *Piripiri*, Other legumes, Wheat, Ginger and Paprika	Includes all annual crops (food and cash crops) that are not included in the other aggregated variables, with $WAnC_i$ (Mean) ≤ 0.5%.
Citrus	Orange, Lemon, Tangerine and Grapefruit	$WFTree_f$ (Mean) ≤ 10%
Other Fruits	Papaya, *Maçanica*, *Mafurra*, Guava, Avocado, *Jambalão*, Peach, Litchi and Apple	
Small Livestock	Chicken, Ducks, Bush chicken, Turkeys, Rabbits and Geese	All small livestock was aggregated together, considering that, separately, their importance on the farm was not significant.

Note: Annual crops were aggregated based on the weight of the area with a specific annual crop i on the farm (WAnCi). All annual basic food crops with mean values for WAnCi ≤ 5% were aggregated (considering the type of crop) except sweet potato, due to its importance for food security.

Table A.3 Eigenvalues of the Principal Components

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12
SS loadings	3.71	3.07	2.48	2.21	1.69	1.58	1.35	1.31	1.22	1.19	1.15	1.11
Proportion Var	0.09	0.07	0.06	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Cumulative Var	0.09	0.16	0.22	0.27	0.31	0.35	0.38	0.41	0.44	0.47	0.50	0.53
Proportion Explained	0.11	0.09	0.07	0.07	0.05	0.05	0.04	0.04	0.04	0.04	0.03	0.03
Cumulative Proportion	0.11	0.20	0.27	0.34	0.39	0.44	0.48	0.52	0.55	0.59	0.62	0.66

	PC13	PC14	PC15	PC16	PC17	PC18	PC19	PC20	PC21	PC22	PC23	PC24
SS loadings	1.07	1.04	1.02	1.01	0.99	0.98	0.95	0.94	0.94	0.92	0.88	0.87
Proportion Var	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Cumulative Var	0.55	0.58	0.60	0.62	0.65	0.67	0.69	0.72	0.74	0.76	0.78	0.80
Proportion Explained	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Cumulative Proportion	0.69	0.72	0.75	0.78	0.81	0.84	0.87	0.89	0.92	0.95	0.97	1.00

Table A.4 Principal Component Analysis loadings

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13	PC14	PC15	PC16
Maize	0.16	0.15	-0.46	-0.36	0.02	-0.06	-0.13	-0.31	-0.13	-0.10	0.31	0.05	0.01	-0.10	-0.03	0.00
Rice	-0.11	-0.03	0.11	0.15	-0.18	-0.39	0.03	0.48	-0.37	-0.21	0.08	0.12	-0.23	0.09	-0.02	0.17
Sorghum.	-0.02	0.05	-0.25	-0.06	0.02	0.13	-0.23	0.27	0.13	-0.25	-0.27	-0.35	-0.10	-0.01	0.02	0.03
Cassava	-0.24	-0.38	0.32	0.28	-0.05	0.09	0.20	-0.10	0.20	0.19	-0.24	-0.08	0.05	-0.30	0.23	-0.25
Sweet Potato	0.02	0.05	-0.04	0.08	-0.16	-0.15	0.10	0.09	0.11	-0.02	-0.01	0.38	0.26	-0.42	0.03	0.00
Cowpea	0.14	-0.30	0.16	-0.12	0.08	0.07	-0.19	-0.19	0.09	0.15	0.06	0.20	0.15	0.05	-0.32	0.02
Beans	-0.15	0.09	-0.14	0.11	-0.07	0.08	0.28	-0.38	0.02	-0.10	0.04	-0.29	0.00	0.23	-0.17	0.14
Groundnut	0.01	-0.21	0.11	-0.05	0.10	0.31	0.07	-0.07	-0.06	0.17	-0.07	0.17	-0.28	0.48	-0.23	-0.06
Sesame	0.01	0.07	-0.12	0.06	0.28	-0.03	-0.07	0.27	0.12	0.12	0.45	-0.13	0.35	0.20	0.13	-0.34
Cotton	0.00	0.12	0.02	0.04	0.34	-0.06	0.03	0.26	0.10	0.34	0.20	-0.33	-0.27	-0.29	-0.07	0.30
Tobacco	0.05	0.28	0.07	0.06	0.55	-0.20	0.16	-0.09	-0.08	-0.03	-0.40	0.27	0.04	0.07	-0.04	-0.07
Hort1	0.23	0.13	-0.23	-0.36	-0.07	0.00	-0.31	0.04	0.06	0.03	-0.20	0.10	0.19	-0.02	0.04	-0.03
	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**	**PC8**	**PC9**	**PC10**	**PC11**	**PC12**	**PC13**	**PC14**	**PC15**	**PC16**
Hort2	0.23	0.53	0.42	0.11	-0.27	0.14	-0.05	-0.03	0.00	-0.09	0.14	-0.09	0.03	-0.02	-0.03	-0.12
Hort3	0.12	0.23	-0.02	-0.11	-0.14	0.03	-0.35	0.12	0.20	-0.01	-0.30	-0.04	0.17	0.14	0.15	0.02
OtherAnC	-0.02	0.10	0.02	0.04	0.01	0.08	0.09	0.03	0.04	-0.03	0.00	0.16	0.19	0.23	0.54	0.51
PermC	0.20	-0.43	0.53	0.09	0.04	-0.04	-0.04	-0.04	0.02	-0.06	0.05	0.01	0.16	0.03	-0.03	0.02
Mango	-0.06	0.33	-0.26	0.12	0.05	-0.22	0.28	-0.26	-0.14	-0.32	0.08	-0.06	0.17	-0.04	-0.03	0.04
Cashew	-0.07	-0.32	0.20	0.07	0.23	0.64	-0.06	0.08	-0.27	-0.03	0.01	-0.01	0.08	-0.10	0.07	0.07
Coconut	0.07	-0.43	0.48	0.12	-0.06	-0.45	-0.08	0.05	0.02	-0.10	-0.02	-0.05	-0.02	0.06	0.01	-0.06
Citrus	0.10	-0.05	0.04	0.06	-0.07	-0.09	0.03	-0.26	0.27	0.25	0.19	0.17	-0.29	0.03	0.25	-0.15
Other Fruits	0.16	0.21	-0.21	-0.10	-0.21	-0.04	-0.21	0.20	0.28	0.30	-0.12	0.15	-0.08	0.12	-0.19	0.13
LivDens	0.66	-0.14	0.09	-0.40	-0.08	0.03	0.32	0.13	-0.05	0.04	-0.04	-0.10	0.07	-0.01	0.02	-0.02
Bovine	0.56	-0.10	0.04	-0.57	-0.05	-0.08	0.19	0.02	-0.24	0.13	-0.09	-0.18	0.01	-0.05	0.10	-0.06
Goats	0.19	-0.04	0.00	-0.04	0.23	0.25	0.08	0.23	0.37	-0.53	0.17	0.26	-0.19	-0.08	-0.13	-0.13
Swine	0.09	-0.16	0.18	0.03	0.07	-0.06	0.06	-0.23	0.46	-0.04	0.05	-0.15	0.13	0.07	-0.01	0.44
Small Livestock	-0.07	0.03	-0.23	0.62	-0.08	-0.07	-0.28	-0.13	-0.36	0.30	-0.08	-0.04	0.10	0.01	-0.01	-0.04
Sheep	0.02	-0.02	0.00	-0.04	0.05	0.13	0.10	0.08	-0.08	-0.07	-0.04	-0.04	-0.19	0.27	0.44	-0.16
GPAnBFC	-0.74	0.18	0.08	-0.29	-0.16	0.05	0.23	-0.01	0.07	0.05	-0.10	0.02	-0.05	-0.06	0.00	-0.06

GPHortC	0.08	0.30	0.22	0.01	-0.19	0.08	-0.18	-0.08	0.05	-0.02	0.14	-0.02	0.03	0.14	0.07	-0.06
GPCashC	-0.02	0.28	-0.01	-0.01	0.61	-0.18	0.07	0.17	0.04	0.18	0.17	-0.03	0.21	0.13	0.02	-0.09
GPCashew	-0.14	-0.16	0.25	-0.14	0.16	0.36	-0.20	0.01	-0.29	-0.03	0.11	0.14	0.19	-0.14	-0.04	0.22
GPCoconut	-0.03	-0.27	0.43	-0.04	0.00	-0.42	-0.19	0.01	-0.01	-0.13	0.07	-0.01	0.05	0.17	-0.07	0.04
GPLiv	0.76	-0.21	-0.28	0.36	0.01	0.03	-0.09	-0.04	-0.02	-0.05	-0.02	-0.05	-0.05	-0.02	0.01	0.02
EconInt	0.64	-0.02	-0.17	0.44	-0.11	0.11	0.25	0.13	0.02	0.04	-0.03	0.07	0.07	0.03	-0.07	0.03
Irrigation	0.27	0.59	0.47	0.08	-0.23	0.13	-0.06	-0.03	-0.02	-0.06	0.11	-0.05	0.00	-0.02	0.00	-0.05
Pesticide	0.19	0.50	0.35	0.07	0.28	-0.02	-0.03	0.01	-0.01	0.14	-0.08	-0.06	-0.22	-0.17	-0.04	0.11
Fertilizer	0.22	0.57	0.27	0.03	0.31	-0.06	0.00	-0.14	-0.05	-0.06	-0.27	0.15	-0.02	0.03	-0.01	0.00
Manure	0.16	0.48	0.37	0.08	-0.12	0.11	-0.08	-0.08	-0.04	-0.03	0.07	-0.10	-0.02	-0.03	-0.01	-0.04
LabProd	0.68	-0.16	-0.20	0.43	0.08	0.04	-0.01	-0.06	0.04	-0.09	-0.04	0.01	-0.08	-0.05	0.06	-0.02
Labour	0.07	0.20	0.04	0.08	-0.31	0.13	0.47	0.31	0.01	0.23	0.01	0.11	0.26	0.15	-0.22	0.05
Traction	0.55	-0.19	0.14	-0.45	0.03	-0.13	0.04	-0.14	-0.11	0.07	-0.05	-0.09	0.02	-0.05	0.03	-0.01
Tractor	0.16	0.08	-0.01	-0.10	-0.08	-0.03	-0.02	-0.07	-0.08	0.16	0.26	0.38	-0.26	-0.07	0.21	0.12

Table A.5 Identification of farming systems: Cluster Analysis output

FS	Total HH	Maize	Rice	Sorghum+	Cassava	Sweet Pot	Cowpea	Beans	Groundnut	Sesame	Cotton	Tobacco	Hort1	Hort2	Hort3
FS 1	525	0.300	0.002	0.014	0.023	0.017	0.034	0.059	0.043	0.003	0.000	0.390	0.041	0.039	0.008
FS 2	408	0.139	0.007	0.062	0.048	0.005	0.039	0.025	0.030	0.039	0.571	0.001	0.022	0.003	0.005
FS 3	1158	0.309	0.018	0.081	0.094	0.017	0.055	0.056	0.035	0.268	0.004	0.002	0.039	0.009	0.008
FS 4	924	0.259	0.007	0.183	0.061	0.021	0.065	0.027	0.032	0.010	0.000	0.000	0.177	0.029	0.117
FS 5	6749	0.273	0.034	0.046	0.290	0.021	0.075	0.112	0.087	0.001	0.000	0.000	0.026	0.022	0.003
FS 6	578	0.442	0.058	0.009	0.106	0.033	0.100	0.031	0.075	0.008	0.000	0.001	0.069	0.025	0.007
FS 7	2105	0.456	0.007	0.089	0.034	0.019	0.103	0.039	0.082	0.008	0.001	0.001	0.118	0.015	0.019
FS 8	535	0.088	0.036	0.004	0.290	0.455	0.053	0.018	0.007	0.002	0.000	0.000	0.021	0.025	0.002
FS 9	1530	0.185	0.025	0.069	0.396	0.006	0.098	0.066	0.119	0.001	0.000	0.000	0.022	0.003	0.002
FS 10	1248	0.017	0.932	0.006	0.021	0.004	0.003	0.002	0.002	0.000	0.000	0.000	0.002	0.004	0.001
FS 11	3968	0.299	0.023	0.066	0.269	0.018	0.094	0.083	0.080	0.003	0.000	0.000	0.036	0.008	0.006
FS 12	2287	0.225	0.013	0.058	0.253	0.024	0.088	0.111	0.084	0.007	0.001	0.001	0.028	0.014	0.007
FS 13	267	0.145	0.025	0.069	0.185	0.013	0.054	0.064	0.099	0.011	0.003	0.002	0.020	0.014	0.006
FS 14	3126	0.294	0.010	0.145	0.186	0.022	0.081	0.071	0.104	0.003	0.001	0.001	0.049	0.014	0.011
FS 15	426	0.115	0.038	0.000	0.013	0.016	0.025	0.049	0.008	0.000	0.001	0.000	0.035	0.658	0.032
FS 16	1971	0.091	0.062	0.004	0.493	0.010	0.195	0.026	0.100	0.001	0.000	0.000	0.009	0.004	0.001

FS	Other AnC	PermC	Mango	Cashew	Coconut	Citrus	Other Fruits	Liv Dens	Bov	Goats	Swine	Small Livestock	Sheep	GP AnBFC	GP HortC
FS 1	0.024	0.016	0.582	0.017	0.003	0.035	0.176	0.598	0.092	0.223	0.082	0.411	0.004	0.306	0.013
FS 2	0.005	0.032	0.205	0.153	0.030	0.075	0.251	0.884	0.139	0.193	0.081	0.418	0.003	0.345	0.000
FS 3	0.007	0.065	0.308	0.181	0.033	0.062	0.188	0.553	0.018	0.213	0.032	0.515	0.000	0.321	0.005
FS 4	0.017	0.040	0.139	0.059	0.018	0.018	0.417	0.204	0.009	0.017	0.015	0.470	0.000	0.676	0.028
FS 5	0.003	0.077	0.280	0.075	0.083	0.098	0.188	0.140	0.008	0.014	0.004	0.411	0.000	0.821	0.015
FS 6	0.016	0.090	0.220	0.113	0.051	0.174	0.324	2.400	0.270	0.159	0.053	0.348	0.005	0.279	0.019
FS 7	0.007	0.081	0.189	0.170	0.032	0.073	0.273	6.124	0.834	0.098	0.022	0.021	0.008	0.176	0.005
FS 8	0.003	0.227	0.266	0.112	0.162	0.085	0.212	0.784	0.025	0.095	0.023	0.533	0.001	0.539	0.002
FS 9	0.002	0.274	0.087	0.791	0.033	0.023	0.060	0.183	0.009	0.047	0.014	0.435	0.000	0.668	0.001
FS 10	0.006	0.170	0.242	0.134	0.242	0.049	0.154	0.757	0.038	0.123	0.024	0.436	0.001	0.498	0.001
FS 11	0.003	0.142	0.281	0.220	0.090	0.061	0.211	0.320	0.002	0.009	0.004	0.976	0.000	0.131	0.001
FS 12	0.080	0.179	0.262	0.228	0.101	0.093	0.181	0.872	0.004	0.084	0.537	0.282	0.000	0.449	0.004
FS 13	0.288	0.199	0.211	0.411	0.074	0.088	0.131	1.455	0.047	0.175	0.037	0.197	0.455	0.417	0.006
FS 14	0.004	0.122	0.228	0.279	0.038	0.071	0.209	1.279	0.008	0.763	0.033	0.164	0.001	0.356	0.002
FS 15	0.009	0.271	0.343	0.072	0.057	0.081	0.302	2.949	0.165	0.221	0.063	0.327	0.004	0.295	0.116
FS 16	0.001	0.880	0.059	0.193	0.516	0.111	0.096	2.538	0.255	0.224	0.212	0.199	0.001	0.124	0.001

Table A5. Identification of farming systems: Cluster Analysis output (cont.)

Farming System	GP CashC	GP Cashew	GP Coconut	GP Liv	EconInt	Irrigation	Pesticide	Fertilizer	Manure	Lab Prod	Labour	Traction	Tractor
FS 1	0.322	0.001	0.000	0.344	41,284	0.054	0.139	0.546	0.077	15,645	2.815	0.310	0.010
FS 2	0.237	0.007	0.001	0.398	33,230	0.007	0.227	0.047	0.035	11,618	2.909	0.169	0.012
FS 3	0.233	0.011	0.001	0.414	35,544	0.003	0.004	0.028	0.022	11,810	3.195	0.052	0.004
FS 4	0.012	0.004	0.001	0.199	15,055	0.041	0.005	0.051	0.029	4,812	3.081	0.110	0.004
FS 5	0.004	0.006	0.007	0.094	14,391	0.013	0.001	0.011	0.027	3,804	3.602	0.064	0.000
FS 6	0.007	0.007	0.012	0.621	54,913	0.059	0.003	0.031	0.024	15,940	3.544	0.429	0.958
FS 7	0.009	0.017	0.001	0.765	55,705	0.015	0.003	0.030	0.010	16,677	3.531	0.873	0.000
FS 8	0.009	0.009	0.015	0.399	54,339	0.023	0.002	0.010	0.011	12,394	4.630	0.095	0.006
FS 9	0.003	0.238	0.004	0.073	8,953	0.002	0.001	0.007	0.006	3,646	2.752	0.072	0.008
FS 10	0.003	0.009	0.009	0.367	42,408	0.002	0.000	0.000	0.003	9,580	4.145	0.047	0.002
FS 11	0.003	0.003	0.003	0.838	67,254	0.002	0.000	0.014	0.004	19,604	3.334	0.108	0.000
FS 12	0.019	0.016	0.012	0.480	39,716	0.006	0.002	0.021	0.013	12,876	3.268	0.176	0.002
FS 13	0.036	0.039	0.011	0.446	39,187	0.032	0.004	0.038	0.012	12,035	3.596	0.127	0.052
FS 14	0.005	0.012	0.001	0.601	51,319	0.008	0.002	0.022	0.009	15,669	3.293	0.111	0.000
FS 15	0.053	0.010	0.020	0.445	87,190	0.864	0.367	0.435	0.542	13,580	6.739	0.319	0.061
FS 16	0.002	0.031	0.248	0.578	37,771	0.003	0.000	0.003	0.003	17,016	2.127	0.605	0.001

Table A.6 Parameters for characterization of farming systems, based on data analysis

Indicator	Variable	Criteria	Classification
Agricultural land use	PermC	< 1%	Annual
		[1%, 8%]	Mixed
		> 8%	Permanent
Annual Crops (AnC) composition	AnC_i	≥ 5%	Order by importance
Permanent Crops (PermC) composition	$FTree_f$	≥ 15%	Order by importance
Livestock density	LivDens	< 0.2	None
		[0.2, 1]	Low
		> 1	High
Livestock composition	$Livestock_k$	≥ 15%	Order by importance
Farm specialization pattern	WGP_{cg}	≥ 67%	Specialized in one sector
		< 67%	Mixed (order by importance)
		< 10%	Not included
Output intensity	EconInt	< 30,000	Low
		[30,000; 60,000]	Medium
		> 60,000	High
Yield-raising input intensity	Irrigation, Pesticide, Fertilizer and Manure	0%	None
		[1%, 10% [	Low
		[10%, 30% [	Medium
		≥ 30%	High
Labour and labour-saving inputs	LabProd	< 9,000	Low
		[9,000; 15,000]	Medium
		>15,000	High
	Labour	<3	Low
		[3, 4]	Medium
		>4	High
	Traction	<0.3	Low
		[0.3, 0.55]	Medium
		>0.55	High
	Tractor	0	None
		[0.01, 0.1]	Very low
		>0.9	very High

Table A.7 Aggrupation of farming systems by zones (% of the Total Agricultural Area – TAA)

ZONES	FS1	FS2	FS3	FS4	FS5	FS6	FS7	FS8	FS9	FS10	FS11	FS12	FS13	FS14	FS15	FS16
1	0.024	0.005	0.040	0.020	0.402	0.020	0.012	0.017	0.043	0.028	0.183	0.084	0.011	0.088	0.012	0.011
2	0.000	0.015	0.044	0.014	0.183	0.007	0.021	0.005	0.175	0.024	0.158	0.082	0.026	0.229	0.002	0.015
3	0.644	0.003	0.023	0.008	0.071	0.019	0.040	0.000	0.000	0.000	0.043	0.064	0.005	0.058	0.022	0.000
4	0.005	0.096	0.174	0.057	0.166	0.017	0.011	0.007	0.027	0.024	0.157	0.095	0.009	0.152	0.002	0.002
5	0.017	0.039	0.043	0.099	0.112	0.024	0.237	0.006	0.016	0.018	0.105	0.069	0.004	0.177	0.010	0.025
6	0.000	0.001	0.013	0.019	0.181	0.301	0.071	0.061	0.042	0.000	0.090	0.039	0.003	0.085	0.068	0.026
7	0.006	0.009	0.011	0.030	0.070	0.076	0.535	0.003	0.046	0.000	0.072	0.020	0.017	0.080	0.017	0.008
8	0.011	0.000	0.037	0.013	0.269	0.025	0.001	0.063	0.028	0.272	0.135	0.020	0.005	0.028	0.004	0.089
9	0.000	0.007	0.001	0.003	0.047	0.004	0.028	0.008	0.011	0.003	0.088	0.122	0.003	0.035	0.008	0.632

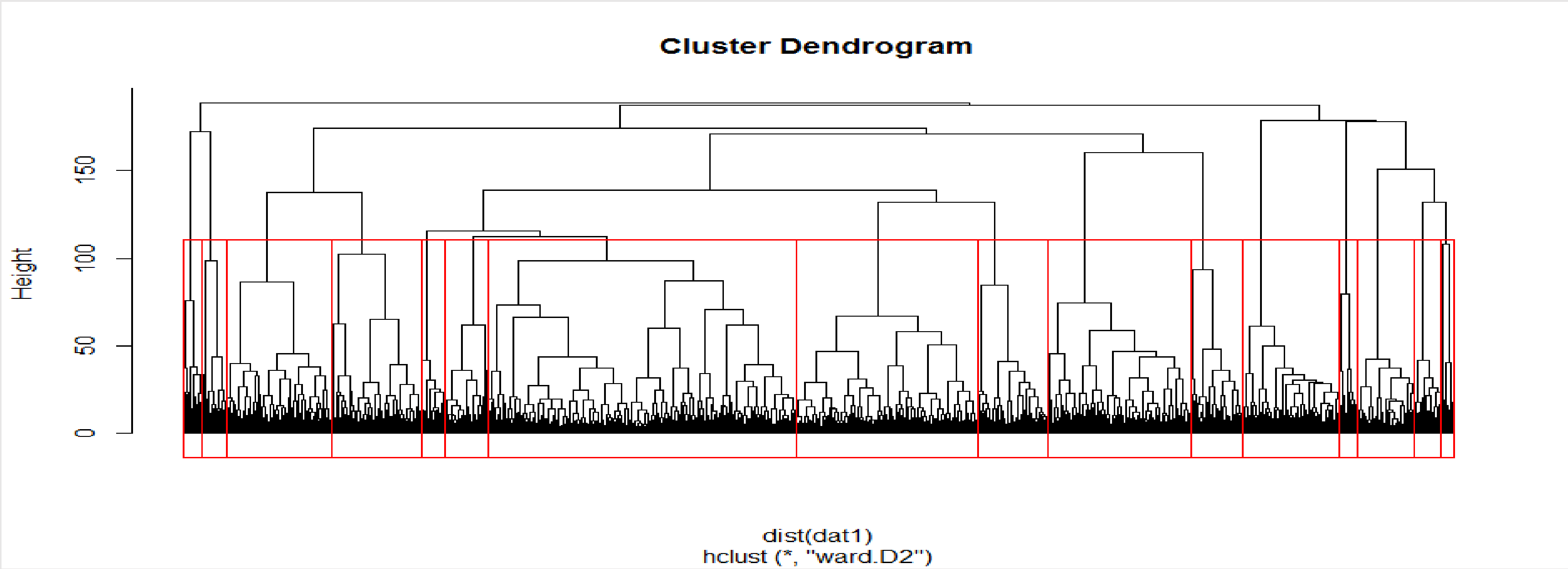
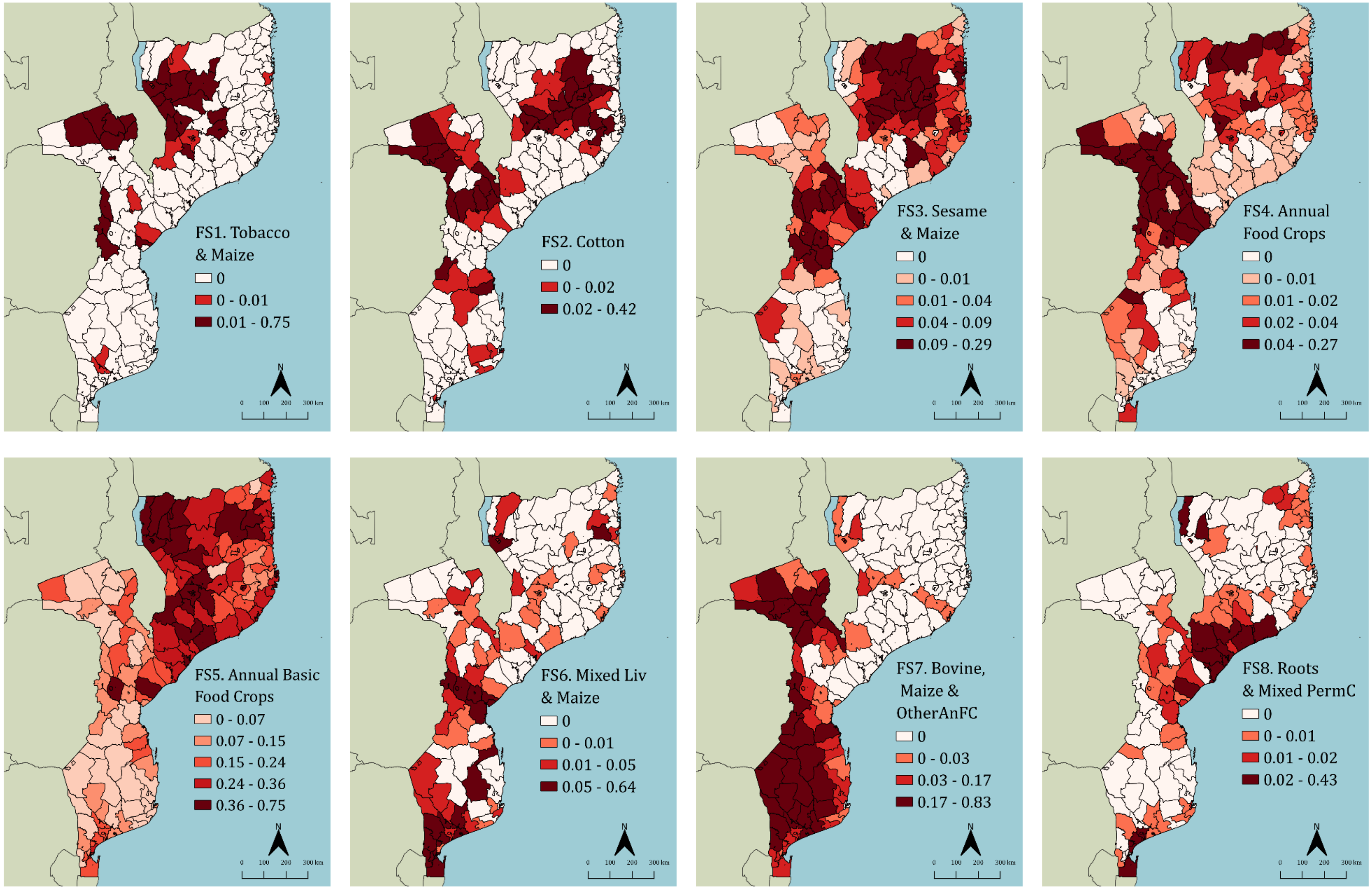


Figure A.1 Dendrogram: identification of farming systems


FS1. Tobacco & Maize
0
0 - 0.01
0.01 - 0.75
FS2. Cotton
0
0 - 0.02
0.02 - 0.42
FS3. Sesame & Maize
0
0 - 0.01
0.01 - 0.04
0.04 - 0.09
0.09 - 0.29
FS4. Annual Food Crops
0
0 - 0.01
0.01 - 0.02
0.02 - 0.04
0.04 - 0.27
FS5. Annual Basic Food Crops
0 - 0.07
0.07 - 0.15
0.15 - 0.24
0.24 - 0.36
0.36 - 0.75
FS6. Mixed Liv & Maize
0
0 - 0.01
0.01 - 0.05
0.05 - 0.64
FS7. Bovine, Maize & OtherAnFC
0
0 - 0.03
0.03 - 0.17
0.17 - 0.83
FS8. Roots & Mixed PermC
0
0 - 0.01
0.01 - 0.02
0.02 - 0.43
N

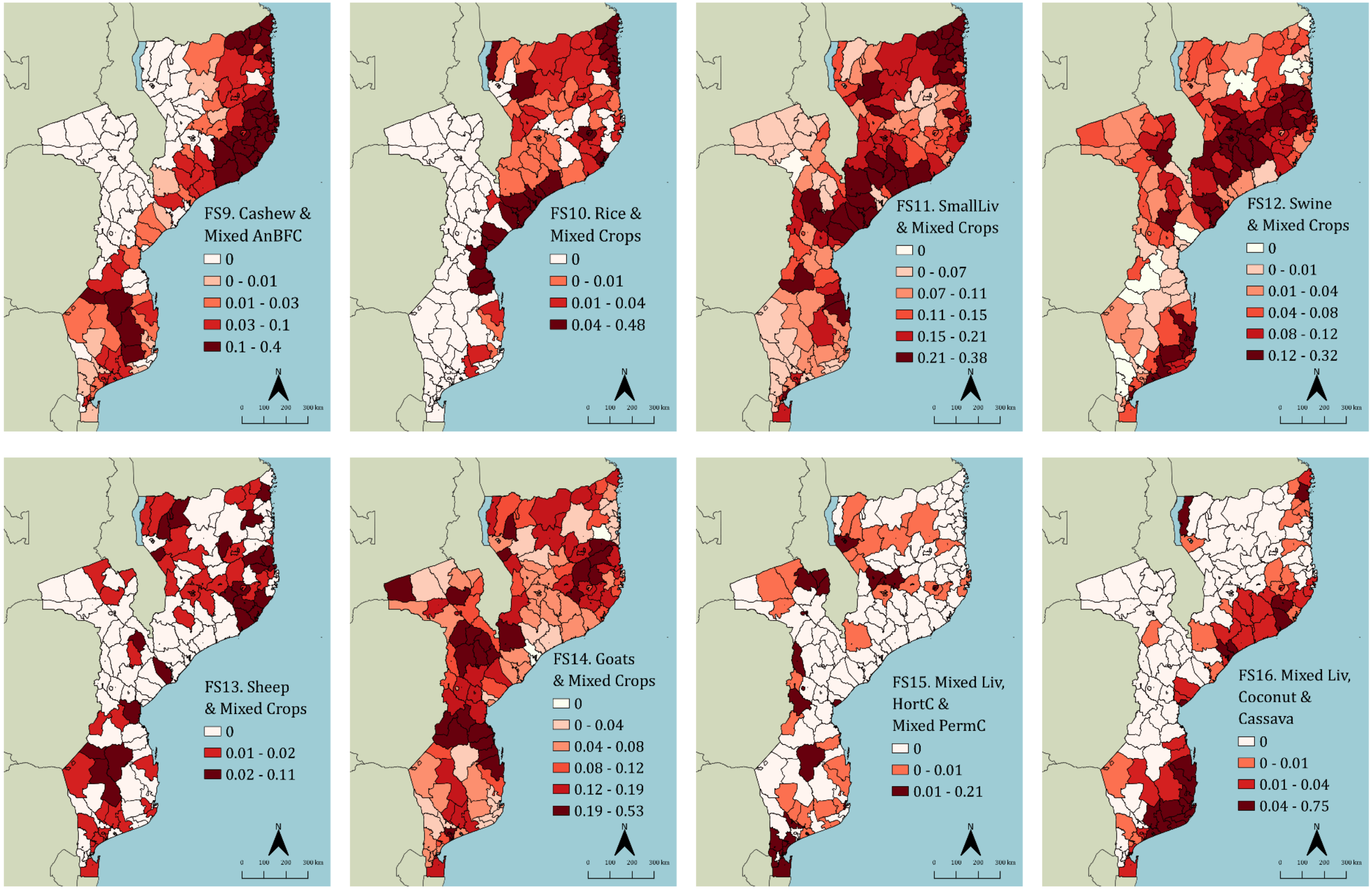


Figure A.2 Spatial distribution of farming systems in Mozambique (% of Total Agricultural Area)

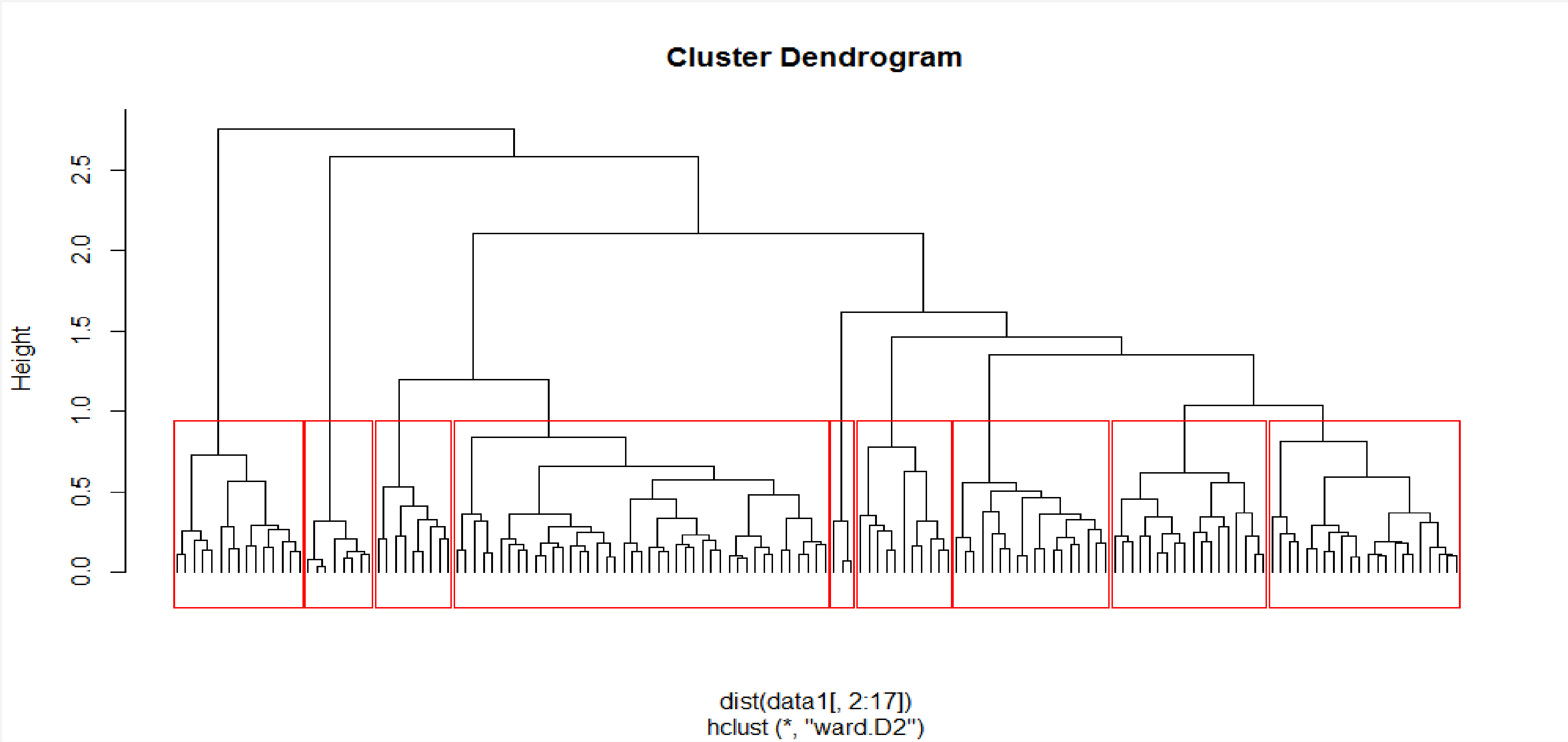


Figure A.3 Cluster dendrogram: identification of zones with similar composition of farming systems

CHAPTER 3

CLIMATE AND SOCIOECONOMIC DRIVERS OF FARMING SYSTEM CHOICE IN DEVELOPING COUNTRIES: A FRAMEWORK TO ASSESS POLICY AND CLIMATE CHANGE SCENARIOS

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Climate and socioeconomic drivers of farming system choice in developing countries: a framework to assess policy and climate change scenarios

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ABSTRACT

Governments in developing countries have been criticized for the ineffectiveness of their policies in addressing the effects of climate change. These policies usually do not account for the heterogeneity of farmers. Increasing knowledge on the factors affecting farmers' choices enhances policies tackling the challenges posed to farmers. In this sense, this paper aims to develop a framework, based on a farming system approach, that allows modelling the biophysical and socioeconomic drivers of farming system choice and its potential for estimating the effects of policy and climate scenarios at the country level, contributing to food security. The framework is applied to Mozambique, using the random forest model. The results indicate that both biophysical and socioeconomic drivers play an important role in explaining farming system choice. Climate variables (rainfall, temperature, and aridity) are emphasized, as they influence significatively farming system choice and are expected to change in time due to climate change, diverting farmers' decisions in the choice of farming systems, with potential impacts on food security. Based on the proposed framework, better knowledge on the effects of socioeconomic drivers can be used to inform policy options aimed at adaptation to climate change and reducing its negative impact on food security among small farmers in developing countries. A significant advantage of the proposed approach, is that it can be easily replicated in other parts of the world, including developing countries, as it relies mostly on agricultural census data (an available and cost-effective source of information) and on worldwide climate data publicly available.

Keywords: biophysical and socioeconomic drivers, farming system choice, climate change, food security, developing countries.

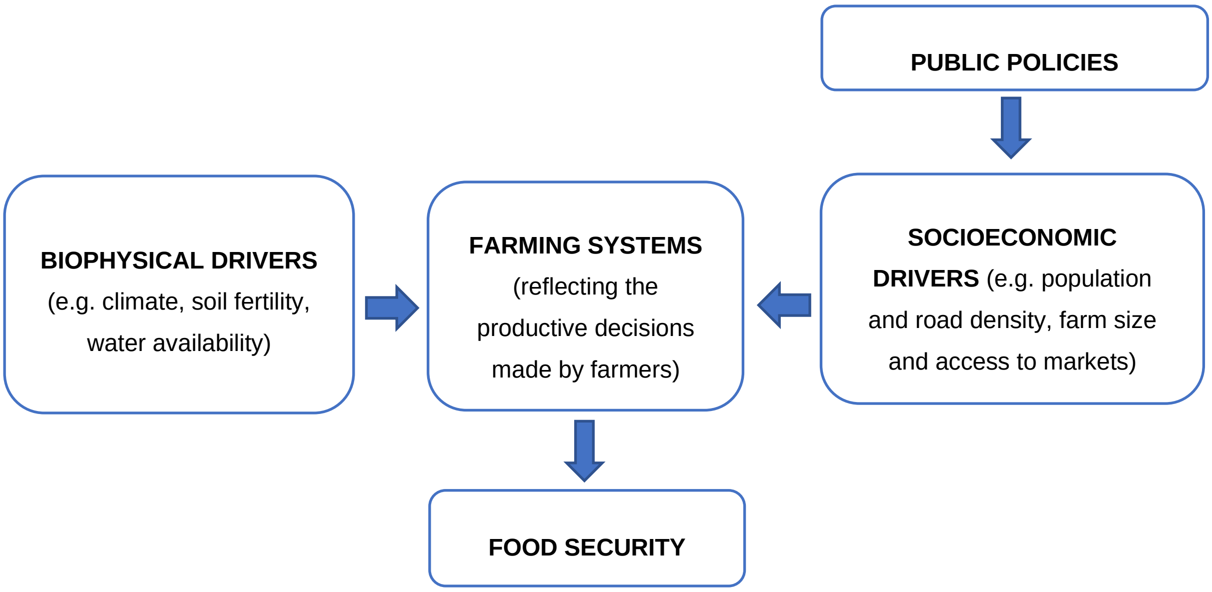
1. INTRODUCTION

Developing countries are among the most vulnerable to climate change, due to the high dependence of livelihoods on natural resources and its limited adaptive capacity to cope with the impacts of climate change (Warner et al. 2016; World Bank 2010). Governments have been criticized due to the ineffectiveness of their policies and failure to address the needs of the rural population (Kansiime, Asten, and Sneyers 2018). Food security is one of the relevant issues concerning policymakers in developing countries, as it is going to be considerably affected due to changes in farming practices driven by changes in climate, especially among the most vulnerable and poor population (Etwire 2020; Ouédraogo et al. 2017).

Increasing knowledge on adaptation methods and factors affecting farmers' choices enhances policies tackling the challenges posed to farmers in developing countries by climate change (Deressa et al. 2009), considering that farmers' choice of farming practices and their responses to climate change is influenced by a set of socioeconomic and biophysical factors. In this regard, some studies have focused on factors influencing farmers' choice of cropping systems (e.g. Amare, Mavrotas, and Edeh 2018; Greig 2009; Lukanu et al. 2004) and the impact of these choices on crop yields and productivity (e.g. Maggio and Sitko 2018). Other studies have attempted to analyse the factors affecting farmers' choices of adaptation methods to climate change at the country (e.g. Deressa et al. 2009; Mugi-Ngenga et al. 2016) and regional level (e.g. Hassan and Nhemachena 2008; Ouédraogo et al. 2017). However, these studies often present an important limitation, as in most cases they are applied to specific crops or consider a limited set of cropping systems, with disregard to permanent crops and, to some extent, livestock, which are important components contributing to food security in developing countries, through income, diversification and wealth (safety net) (Etwire 2020; Massawe 2017).

Therefore, it is important to consider a broader approach e.g., instead of focusing on the factors influencing the choice to produce more maize or adopt a different variety of maize, the focus would be on the drivers explaining the choice of a farming system as a whole. A farming system approach allows to understand the rationality behind farmer's decisions at the farm-level, which provides the basis for understanding how government policies affect farmers' management and decision making (Mascarenhas et al. 1986; Santos et al. 2020). This knowledge can be used to inform policymakers, which would allow to design and evaluate policies in a way that it meets the food security objectives for rural poor small farmers in developing countries (Figure 3.1).

The farming system approach adopted in this study reflects only the farmers' productive decisions regarding agricultural land use/cover (LUC), livestock density and composition, use of yield-raising and labour-saving inputs, i.e. descriptors of farming system (Santos et al. 2020; Silva et al. 2020). In this paper, this approach was applied to Mozambique, with the use of the random forest algorithm to model the drivers influencing farming system choice. Nevertheless, due to its use of statistical data from the agricultural census (a cost-effective available source of information) and publicly available worldwide climate and spatial data, the study can be easily replicated elsewhere, including developing countries.



The farmer is the centrepiece of this framework, making decisions on what and how to produce – i.e. choosing the farming system – based on the biophysical and structural features of the farm, and its socioeconomic context, to achieve a satisfactory level of food security. Public policies are society's gateway to this process, influencing farmer's productive decisions to achieve societal goals.
Figure 3.1. A farming system framework: from public policies to food security

In general, this study aims at: i) modelling the drivers of farming system choice, as opposed to multiple production decisions by farmers; ii) understanding whether the current spatial distribution of farming systems can be explained by drivers that are expected to change in time due to climate change, such as aridity, rainfall or temperature, using "space for time" modelling strategies; iii) understanding how much space is left for policies aimed at countering the negative effects of climate change on agriculture and food security, given the prevailing biophysical and socioeconomic factors constraining agricultural management.

2. MATERIALS AND METHODS

2.1. Study area

The research focuses on Mozambique, an extremely vulnerable (to climate change), poor and food insecure country, located in the South Eastern coast of Africa (Figure 3.2). The climate is tropical to sub-tropical climate, although semi-arid regions occur in the southwest and the upper Zambezi Valley within the country (see Figure B1 in Appendix B).

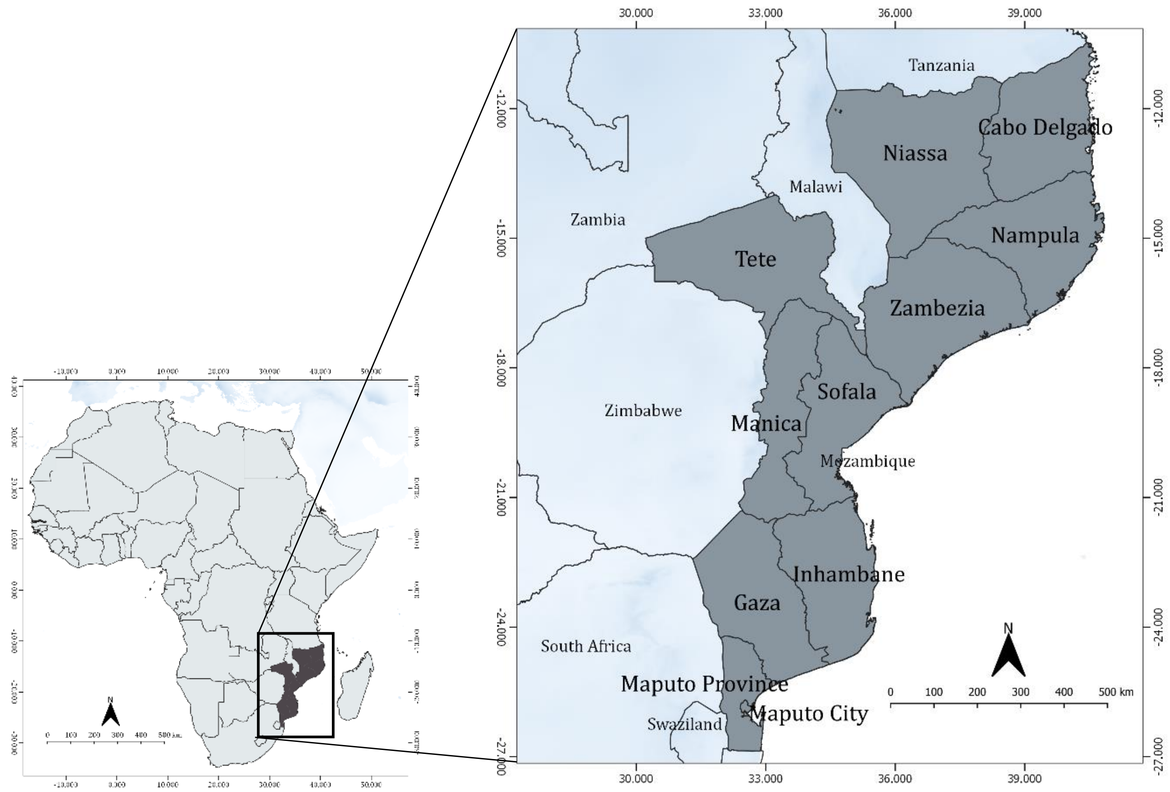


Figure 3.2. Location of the study area: Mozambique

The country is characterized by lowlands in the east and is more mountainous in the west (MFA Netherlands 2018). There are seasonal temperature and rainfall variations across the year, with a cool and dry season from May to September and a hot and humid season between October and April (Marques et al. 2009). The average temperature tends to be higher along the coast, with emphasis to the central and northern regions as well as in the lowlands along the valleys of the Zambezi river and lower in high altitude inland regions (Figure B2). The rainfall distribution follows an east-west gradient, with higher rainfall levels (annual average between 800mm and 1200mm) along the coast and in inland high-altitude areas in north and central regions; the inland central and south regions are the driest (400-800mm) – Figure B3.

Due to the unequal distribution and changes in temperature and rainfall patterns, the occurrence of extreme events in the south and coastal regions have been more frequent in the last decades, with the south experiencing more persistent droughts and the coastal areas facing more floods (MFA Netherlands 2018). The country is also frequently affected by tropical cyclones, occurring mainly in the hot humid season. Mozambique is considered one of Africa's most vulnerable countries to climate change and one of the least ready to address its effects (MFA Netherlands 2018).

Mozambique is essentially an agricultural country, with about 70% of the population dedicated to agriculture. The country's agroecological potential for agriculture is heterogeneous, encompassing ten agroecological zones with different aptitudes, defined as homogeneous agricultural regions in terms of climate, terrain, and soils and with similar farming systems (MASA, 2016). Nevertheless, these agroecological zones are also constrained by several socioeconomic factors (e.g. infrastructures such as roads, etc.) (MASA 2016).

Agriculture is mainly carried out by smallholders, who represent 99% of farms. The average size of households is about 5 people, being mostly headed by men; average small-holding size is typically less than 1 hectare (INE 2011; MASA 2016). Agriculture is mostly rainfed (in 98% of the farms), thus being extremely dependent on rainfall. Most of the domestic food production (ca. 95%) is produced by small farmers, being dominated by roots and tubers (especially cassava), cereals (maize, millet, sorghum, and rice), groundnuts, legumes, and horticultural crops. Basic food crops are mostly produced for the household's own consumption, and usually only marginal surpluses are sold in local markets (World Bank 2011). Important cash crops are tobacco, cotton, sugar cane, sesame and, in recent years, soybean (Mosca and Nova 2019).

2.2. Farming systems typology in Mozambique

Farming systems were identified based on farmers' individual productive decisions regarding agricultural land use/cover, livestock density and composition, use of yield-raising (e.g. fertilizer) and labour-saving (e.g. mechanical or animal traction) inputs, i.e. farming system descriptors (Table B1 in appendix B).

Data for the classification of farms by farming system were extracted from the Mozambican agricultural census, referring to the 2009/2010 agricultural season (INE 2011). Only small and medium farms were included in the analysis, which are subject to a specific survey in national agricultural censuses, accounting for about 99% of total farms in Mozambique (INE 2011). Data was analysed at the farm-level, including a usable sample of 27,805 farms, which represents about 1% of total small and medium farms in the country, corresponding to a fixed sample of 10 households/farms in each enumeration area defined by CAP, in all districts (third administrative division) (see INE 2011 for more details). A farm refers to all parcels of land managed by the same household.

To identify the farming systems, a Principal Components Analysis (PCA) was firstly performed on a correlation matrix of 42 farm characterization variables (Table B1) for dimension reduction. Principal components (PCs) with eigenvalues greater than 1 (Kaiser's criteria) were selected to enter a Hierarchical Cluster Analysis (HCA), from which a set of clusters representing the main farming systems was selected based on dendrogram analysis and experts' knowledge.

2.3. Biophysical and socioeconomic drivers

To identify the main drivers influencing farming system choice in Mozambique, a set of biophysical and socioeconomic variables were considered (Table 3.1). Biophysical data included climatic variables (temperature, rainfall and an aridity index), slope classes, soil fertility – extracted from maps and computed at the administrative post level (fourth administrative level division) – and an indicator of proximity to water courses, which is usually linked to valley bottom locations (variable LOWAREA, representing the proportion of the farm with this particular location), extracted from the agricultural census (INE 2011) and computed at the farm-level. Socioeconomic data included context variables, i.e. population and road density – computed at the administrative post level – and market integration and household/farm structure variables, i.e. household and farm size, share of the farm that is managed by women and share of paid work – extracted from the agricultural census at the farm level. Biophysical and socioeconomic data for each administrative post, were computed using GIS tools in QGIS 3.14 and R software 4.0.2. Farms belonging to the same administrative post were assigned the same value for these variables. Farms with missing values for one or more variables were discarded; hence, the sample used to perform the analysis included 26,421 farms.

Table 3.1. Descriptive statistics for the biophysical and socioeconomic drivers (n = 26,421)

Variables	Description	mean (min-max) s.d.
Biophysical variables		
MINTEMP	Average minimum temperature in the coldest month 1970-2000 (℃)	13.7 (7.5-18.5) 2.1
AVGTEMP	Average annual temperature 1970-2000 (℃)	23.8 (18.5-26.5) 1.4
RAINFALL	Average annual rainfall 1970-2000 (mm)	994 (413-1877) 224
ARIDITYINDEX	Aridity Index	0.78 (0.29-1.68) 0.22
SLOPE5	Proportion of administrative post area with smooth slopes (<5%)	0.54 (0-1) 0.32
SLOPE10	Proportion of administrative post area with steep slopes (>10%)	0.46 (0-1) 0.32
HIGHFERT	Proportion of administrative post area with high fertility	0.17 (0-1) 0.26
LOWAREA	Proportion of the farm area in lower, valley bottom locations (1)	0.33 (0-1) 0.46
Socioeconomic variables		
Administrative post- level		
POPDENS	Population density (inhabitants/km^2)	122 (0.1-6735) 442
ROADDENS	Road density (km/km^2)	0.1 (0-2) 0.1
Farm-level		
HOUSEHOLD	Household size	5 (1-90) 3
FARMSIZE	Farm size (ha)	1.2 (0.0001-45) 1.4
WOMEN	Proportion of farm area managed by women	0.36 (0-1) 0.48
MARKET	Market integration	0.09 (0-1) 0.19
PAIDWORK	Proportion of hired labour in total labour units (LU) (2)	0.13 (0-1) 0.24

(1) Lower zones are usually located close to rivers or in their basins, valleys, lakes, or in areas with high levels of groundwater and humidity, and where water-demanding crops are practiced, e.g. horticultural crops, banana, rice, sweet potatoes, etc. during the dry season (MASA 2016).

(2) Labour units correspond to the sum of all units of labour employed in agriculture and livestock activity (see notes in Table B1).

Climate data, i.e. temperature and rainfall for 1970-2000, were collected from WorldClim 2.1, with spatial resolution of 2.5 minutes (Fick and Hijmans 2017). Another, more synthetic, climate variable is the aridity index, which reflects long-term climatic water deficits (Cherlet et al. 2018). The United Nations Environment Programme (UNEP) formula was adopted to compute the aridity index; aridity is thus quantified as a ratio between the average annual precipitation and the long-term climatic water demand, i.e. potential evapotranspiration (PET) – computed using the Thornthwaite method (Pascual-ferrer and Candela 2015) – Table B2.

Other biophysical variables included the proportion of the administrative post area in diverse slope and soil fertility classes, and the proportion of the farm area located in lower zones. Slope classes were computed from a slope map extracted from the 30 meters Digital Elevation Model (DEM) from Shuttle Radar Topography Mission (SRTM) for Mozambique, obtained at RCMRD GeoPortal (http://geoportal.rcmrd.org/). Slope classes representing smooth (<5%) and steep (>10%) slopes were considered. For soil fertility, areas with intermediate to high and very high fertility were merged into a single class: areas with high soil fertility. Spatial data on soil types and soil fertility were provided in person by the Agricultural Research Institute of Mozambique.

Regarding socioeconomic variables, the average population and road densities were both calculated at the administrative post level. Population – referring to the Population and Housing Census 2007 – and administrative post area data were obtained from the National Statistics Institute. Road density was computed based on road length data extracted from the RCMRD GeoPortal.

Unlike the biophysical and the other socioeconomic variables, market integration as defined in this paper, i.e. the proportion of output sold (Table B2), is subject to change over a short period of time, as it is very sensitive to the context and shocks that may have occurred in the period for which the data was collected (2009/2010). Market integration was used, in this study, as a proxy for access to markets, based on the assumption that the proportion of output sold in a particular farm was only made possible because the farmer had access to the resources that enabled this level of market integration, e.g. accessible markets, associated value chains, storage and conservation facilities, distance of the farm to a proper road, etc. – which are relevant drivers of farming system choice (Ribeiro et al. 2018), but were not explicitly computed and analysed in this paper due to lack of data.

2.4. The Random Forest Model

The Random Forest (RF) algorithm was applied to model the drivers of farming system choice in Mozambique. This analysis allowed us to understand the most important factors, i.e. drivers, influencing farming system choice, which would enable us to understand how farmers would respond to changes in these drivers across time and space.

RF is an ensemble machine learning technique that uses a bagging-based approach (random sampling with replacement) to build a forest of classification trees; it is considered an effective tool in prediction, and an accurate classifier with high tolerance to outliers and noise (Breiman 2001; Vintrou et al. 2012). RF has been widely used in agricultural research, e.g. to predict crop yields (Everingham et al. 2016; Jeong et al. 2016; Prasad, Patel, and Danodia 2020), farmers' decisions (Mwanga et al. 2020), spatial patterns of agricultural systems (Debats et al. 2016; Vintrou et al. 2012), forest fires (Su et al. 2018), among others.

The biophysical and socioeconomic variables presented in Table 3.1 were used as predictors, or independent variables, and the set of clusters selected from the HCA, representing the main farming systems in Mozambique, as the dependent categorical variable. The RF classification model was built using the statistical software R version 4.0.2, and the "randomForest" package with 500 trees, and the number of descriptors that are randomly selected to split each node (mtry) was set to 5. Two analytical tools were used to explore the influence of each driver on each farming system, i.e. variable importance (based on mean decrease in accuracy) and partial dependence plots. The variable importance provides a measure of the usefulness of the different variables in distinguishing between different classes, i.e. the mean decrease in accuracy allows to assess the importance of each predictor variable; the higher the value, the more important the variable is to the classification (Vintrou et al. 2012). On the other hand, partial dependence plots show how the RF model predictions of a particular farming system are influenced by each predictor variable, when all of the other predictors in the model are held constant at their average levels (Jeong et al. 2016). A partial dependence plot analysis can show whether the relationship between the dependent and a predictor variable is linear, monotonic, or more complex. Based on a visual analysis of these plots, the shape of the fitted function for each predictor variable (for each farming system) was observed to infer the positive or negative effect of the predictor on the probability of selecting that particular farming system (Table B3).

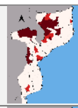
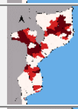
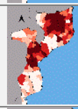
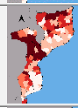
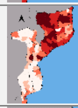
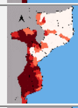
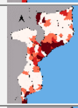
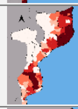
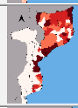
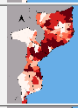
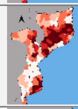
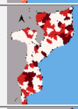
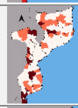
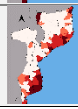
3. RESULTS

3.1. Farming system typology in Mozambique

A solution of 16 clusters, representing the main farming systems in Mozambique was selected from the HCA. The farming systems identified are mostly mixed (crop-livestock), with some being more crop-oriented and others livestock-oriented (Table 3.2). Farming systems were named based on their orientation regarding crop-livestock integration, analysed through the cluster means for the background variables (Table B4).

The farming systems are unevenly distributed across the country. Most of the food production is concentrated in the central and northern regions of the country, while livestock systems, with emphasis to bovine production, are located mainly in the arid southern and central inland regions. Cash crop systems are also concentrated in specific areas in the central and northern regions.

Table 3.2. Farming Systems in Mozambique

Category	Sub-category	Farming System	Description	Spatial distribution [1]
Annual Crops	Cash Crops	FS1 – Tobacco and Maize	Intensive use of inputs (pesticides, fertilizers, and animal traction). Medium economic intensity (output/ha).	
		FS2 – Cotton	Pesticide-input user. Medium economic intensity.	
		FS3 – Sesame and Maize	Labour intensive (labour unit/ha). Medium economic intensity.	
	Annual Food Crops	FS4 – Annual Food Crops – AnFC[2] (Horticultural Crops, Maize and Sorghum+)	Labour intensive.	
		FS5 – Annual Basic Food Crops – AnBFC[2] (Cassava, Maize and Beans)	Labour intensive.	
Annual Food Crops and Livestock		FS6 – Mixed Livestock and Maize	Intensive use of labour-saving inputs (animal traction and tractor). Medium economic intensity.	
		FS7 – Bovine, Maize and Other Annual Food Crops	High use of animal traction. Medium economic intensity.	
Mixed Crops (Annual Food Crops and Permanent Crops)		FS8 – Roots (Cassava and Sweet Potato) and Mixed Permanent Crops	Labour intensive. Medium economic intensity.	
		FS9 – Cashew and Mixed Annual Basic Food Crops		
		FS10 – Rice Mixed (Permanent Crops and Livestock)	Highly labour intensive.	
Mixed Crops and Livestock	Livestock specialization	FS11 – Small Livestock and Mixed Crops	High output per hectare (economic intensity).	
		FS12 – Swine and Mixed Crops		
	Some livestock density	FS13 – Sheep and Mixed Crops		
		FS14 – Goats and Mixed Crops		
	High livestock density	FS15 – Mixed Livestock, Horticultural and Mixed Permanent Crops	Irrigated with intensive use of yield-raising inputs and animal traction. High output per hectare.	
		FS16 – Mixed Livestock, Coconut and Cassava	High use of animal traction.	

[1] The spatial distribution of each farming system is represented at the district level, based on the share of the total agricultural area in each district occupied by the farming system (the color gradient is supposed to be dimensionless and self-explanatory) – see detailed maps for farming systems spatial distribution in Figure B4 in Appendix B.
[2] AnFC = AnBFC + Horticultura Crops. AnBFC includes Maize, Rice, Sorghum+, Cowpea, Beans, Groundnut + Roots (Cassava and Sweet potato).

3.2. Biophysical and socioeconomic drivers of farming system choice

The RF model used to identify the main drivers of farming system choice by small-medium farmers in Mozambique returned a classification error rate of 60.4% for the overall model. This should be considered a positive result considering the high number of classes in the dependent variable: the 16 farming systems. The classification error for each farming system ranged from a minimum of 22.4% (FS16 – Mixed Livestock, Coconut and Cassava) to a maximum of 97.3% (FS13 – Sheep and Mixed Crops) – Figure 3.3.

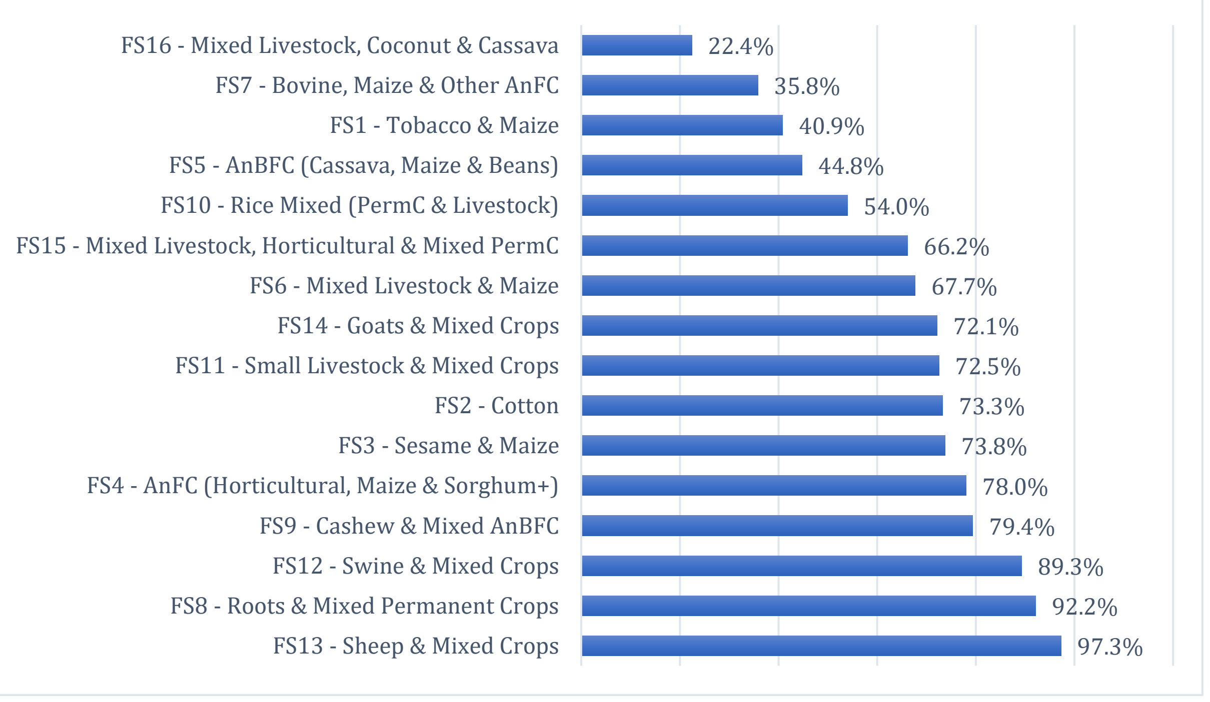


Figure 3.3. Out-of-bag (OOB) estimate and classification error rates for the 16 farming systems

The variable importance for the overall model, analysed through the mean decrease in accuracy (Table 3.3 – second column), showed that both biophysical and socioeconomic variables play an important role in explaining why farmers choose a particular farming system. Among the ten most important variables, four are socioeconomic, with market integration (MARKET) – understood in this research as a proxy for access to markets – standing out as the most relevant variable influencing farming system choice; and six are biophysical, with emphasis to climatic variables. Proximity to water courses (LOWAREA) and the dimension of the farm (FARMSIZE) are both, almost equally, important variables shaping farming systems choice, followed by other biophysical variables, i.e. the minimum average temperature in the coldest month (MINTEMP), high fertility soils (HIGHFERT) and average rainfall (RAINFALL). The household size (HOUSEHOLD) and the level of aridity (ARIDITYINDEX) also play an important role in explaining farming system choice, followed by the proportion of hired labour (PAIDWORK) and the average temperature (AVGTEMP). The least, but still important variable is the proportion of the farm area that is managed by women (WOMEN). Slope is an important driver of farming system choice, however, in this study this variable was offset by the variable expressing the proximity to water courses (LOWAREA) which is usually linked to flat areas, and it is calculated at the farm level rather than at the post administrative level (as the slopes), and therefore is more accurate.

The variable importance analysis for each farming system (Table 3.3) shows that there are clear differences regarding the most relevant drivers influencing the choice of each farming system. The analysis of the partial dependence plots (Table B3) allowed to identify the type of marginal relationship: positive (+), negative (-), U-shaped (-/+), inverted U-shaped (+/-) or more complex/undetermined (**), between each driver and the probability of choosing a particular farming system (Table 3.3). These were identified based on the observed trends where the largest part of the observations was concentrated. Special attention should be paid when interpreting the ARIDITYINDEX, as a negative sign means that the farming system is positively associated with aridity, i.e. decreases with humidity, and increases with aridity.

Market integration (MARKET) is one of the most important variables explaining the choice of cash crop farming systems, i.e. FS1 (Tobacco and Maize), FS2 (Cotton) and FS3 (Sesame and Maize), highlighting a positive relationship, i.e. the probability of choosing these systems increases as the level of market integration increases. The choice of FS1 also increases with farm size and average rainfall (RAINFALL). The average minimum temperature in the coldest month (MINTEMP) and the average annual temperature (AVGTEMP) are also important climatic drivers of farmer’s choice for this farming system, which tends to increase with lower temperatures and steep areas. Rainfall is a relevant predictor for the choice of FS2 and FS3, i.e. rainfall levels above 1100 mm discourage the choice of both systems. The probability of choice of both systems is also negatively influenced by highly populated areas (POPDENS).

Regarding the Annual Food Crops (AnFC) systems, FS4 (AnFC – Horticultural Crops, Maize and Sorghum) has a non-monotonic, U-shaped relation with market integration (MARKET), MINTEMP and aridity levels (ARIDITYINDEX). Market integration levels above 25% have a positive influence on the probability of choice of this system, which tends to decrease with dry-humid climate, slightly increases with humid climate, and decreases in highly populated areas (POPDENS). On the other hand, the probability of choosing the Annual Basic Food Crop system, FS5 (AnBFC – Cassava, Maize and Beans), is negatively related to high market integration and large farm sizes, and positively influenced by higher minimum temperatures in the coldest month (MINTEMP). The preference for this system increases with dry-humid climate and decreases in humid climate.

Biophysical variables are the most associated to the probability of choosing the Mixed Livestock and Maize system (FS6), which is negatively affected by higher temperatures (MINTEMP and AVGTEMP) and rainfall levels (RAINFALL) and is favoured by areas with high fertility (HIGHFERT) and higher population density. The choice of the Bovine, Maize and other Annual Food Crops system (FS7) is strongly related with larger household and farm sizes, as well as higher proportions of hired labour (PAIDWORK). The choice of this system is also favoured by lower temperatures in the coldest month (MINTEMP) and semi-arid areas, that is, those areas with low levels of the aridity index (ARIDITYINDEX).

Higher precipitation levels (RAINFALL) and high fertility soils (HIGHFERT) positively affect the probability of choice of FS8 (Roots and Mixed Permanent Crops), which is also associated with smaller farms. The choice of FS9 (Cashew and Mixed AnBFC) is associated to warmer cold seasons

(MINTEMP), increasing market integration, areas with low fertility soils and dry-humid climate. Farmer's choice of the Rice Mixed system (FS10) is mostly driven by the proximity to water courses (LOWAREA), high levels of rainfall and high fertility soils; it is also favoured by sparsely populated areas (POPDENS) and smaller farms (FARMSIZE).

The choice of farming systems dedicated to Mixed Crops (permanent and annual) and Livestock, i.e. FS11 (Small Livestock), FS12 (Swine), FS13 (Sheep) and FS14 (Goats), is mostly influenced by climatic variables. All four systems are positively associated to intermediate levels of humidity and discouraged by high humidity (RAINFALL and ARIDITY). FS11 (Small Livestock) and FS12 (Swine) are favoured by warmer cold seasons (MINTEMP). FS13 (Sheep) is characterized by lower soil fertility. FS11 and FS14 (Goats) are both negatively associated with market integration, and positively with population density, as it is also the case with FS12.

FS15 (Mixed Livestock, Horticultural Crops and Mixed Permanent Crops) is favoured by smaller farm sizes, lower average temperature and rainfall levels. The choice of this system is also positively related with high soil fertility. On the other hand, the choice of FS16 (Mixed Livestock, Coconut and Cassava) is preferred in populated areas (POPDENS), not close to water courses (i.e. rivers, lakes, lagoons, valleys, etc), as shown by the negative effect of LOWAREA.

Table 3.3. Variable importance and Partial Dependence Plots (PDP) interpretation for the overall model and for each farming system

		MDA Overall Model	FS1 - Tobacco & Maize		FS2 - Cotton		FS3 - Sesame & Maize		FS4 - AnFC		FS5 - AnBFC		FS6 - MixedLiv & Maize		FS7 - Bovine & Maize		FS8 - Roots & Mixed PermC	
BIOPHYSICAL	MINTEMP	73.5	38.9	-	43.4	**	31.5	-/+	27.4	-/+	46.9	+	41.8	-	47.4	-	22.9	**
	AVGTEMP	57.8	24.4	-	31.9	+/-	37.9	+	27.2	+	44.7	-/+	40.4	-	38.0	-/+	22.5	-/+
	RAINFALL	63.7	42.7	+	42.4	**	42.7	+/-	32.5	**	50.6	**	47.6	-	45.1	-	27.8	+
	ARIDITYINDEX	60.4	24.4	+	35.9	**	37.7	-	36.8	-/+	46.4	+/-	31.9	-/+	45.2	-	18.5	+
	SLOPE5	39.8	23.9	-	27.9	**	32.5	**	19.9	-	30.3	**	21.9	-/+	24.3	-/+	17.4	-/+
	SLOPE10	39.1	23.6	+	29.2	**	32.5	**	19.7	+	31.6	**	20.8	-/+	23.5	-/+	15.5	-/+
	HIGHFERT	65.2	17.0	+/-	30.5	-/+	30.2	-/+	19.1	-/+	23.6	-	33.0	+	31.9	+	21.0	+
	LOWAREA	89.7	3.3	-	0.3	**	2.8	-/+	6.6	+	5.2	-/+	9.8	**	14.0	**	6.8	+
SOCIOECONOMIC	ROADDENS	47.0	17.1	-	27.1	-	30.7	-	24.4	-	32.7	+	30.6	+	32.5	+	12.3	+
	POPDENS	57.0	22.7	-	33.0	-	38.2	-	28.4	-	34.2	+	33.5	+	29.5	-	11.4	+
	HOUSEHOLD	62.2	17.1	-	2.2	-	-1.4	-	7.4	-	25.1	-	12.7	+	85.7	+	-0.1	-
	FARMSIZE	88.9	51.7	+	19.0	+	11.1	+	11.2	+	45.0	-	15.1	+	53.2	+	18.8	-
	WOMEN	19.6	12.4	-	12.4	+/-	7.8	-/+	8.4	+	-1.8	-/+	6.5	**	14.8	**	1.7	-/+
	MARKET	143.8	88.4	+	36.8	+	67.9	+	49.1	-/+	61.0	-	2.8	**	30.2	+	8.9	**
	PAIDWORK	58.9	11.7	**	5.6	+/-	-2.1	**	18.3	-	30.7	-	26.2	+	51.7	+	-2.4	**

		FS9_Cashew & Mixed AnBFC		FS10_Rice Mixed		FS11_SmallLiv & MixedC		FS12_Swine & MixedC		FS13_Sheep & MixedC		FS14_Goats & MixedC		FS15_MixedLiv, HortC & MixedPermC		FS16_MixedLiv, Coconut & Cassava	
BIOPHYSICAL	MINTEMP	67.8	+	31.5	+	28.7	+	34.9	+	19.2	**	43.6	+	41.7	-	56.6	+/-
	AVGTEMP	36.0	+/-	29.1	+	22.5	+/-	28.4	**	18.0	-/+	33.2	+/-	31.6	-	43.3	+/-
	RAINFALL	44.1	-/+	44.8	+	31.6	+/-	44.6	+/-	21.9	+/-	30.4	+/-	35.0	-	32.6	**
	ARIDITYINDEX	38.3	+/-	32.0	+	25.7	+/-	33.3	+/-	18.8	+/-	26.0	+/-	28.8	-/+	29.7	+/-
	SLOPE5	34.4	-/+	25.6	**	24.5	**	25.0	**	13.9	-	29.6	**	22.4	-	20.0	-/+
	SLOPE10	34.9	+/-	26.7	**	24.2	**	23.6	**	12.2	+	29.3	**	21.9	-/+	20.0	-/+
	HIGHFERT	36.3	-	35.1	+	18.6	-	18.5	-	16.8	-	29.9	-	19.1	**	23.5	+/-
	LOWAREA	4.2	-	97.3	+	19.0	-	9.1	-	9.5	**	10.8	-	55.8	+	58.3	-
SOCIOECONOMIC	ROADDENS	28.7	+	23.7	-	20.9	+	22.5	+	9.5	+	23.6	-	19.0	+	13.0	+
	POPDENS	33.2	+	34.6	-	23.4	+	26.9	+	16.1	-	38.7	+	25.8	+	38.0	+
	HOUSEHOLD	21.8	-	4.6	-	4.7	-	-2.6	-	-2.4	+	10.6	-	4.6	+	13.1	+
	FARMSIZE	8.4	-	34.0	-	8.9	-	7.6	+	-0.8	+	11.4	+	70.5	-	0.9	+
	WOMEN	2.6	-/+	0.2	+/-	16.7	-/+	14.7	**	3.0	**	1.3	**	3.6	-/+	-2.2	-/+
	MARKET	38.2	+	30.6	-	83.4	-	12.5	-	0.5	+/-	45.7	-	6.0	+	11.3	+/-
	PAIDWORK	16.1	-	-3.4	+/-	4.7	-	6.9	-	5.5	+	10.8	-	4.9	+	18.7	**

Note: (+) means a positive relation; (-) negative relation; (+/-) means that an increase in the value of the variable positively influences the farming system, to a certain extent, for which values above that point have a negative influence; (-/+) the opposite takes place; (**) indetermined.

4. DISCUSSION

4.1. The biophysical and socioeconomic drivers of farming system choice

Our findings indicate that both biophysical (e.g., climate) and socioeconomic (e.g., market integration, and farm and household characteristics) drivers are important determinants of farming system choice. Some studies evidenced the role of climate variables in explaining the choice of farming systems and driving change in farming practices in developing countries (e.g. Etwire 2020 - Ghana; Greig 2009 - Tanzania; Ouédraogo et al. 2017 - West Africa), while other studies consider that market-related variables (e.g. yields, market opportunities and labour) have been stronger drivers of change (Bhatta et al. 2016 - India, Nepal and Bangladesh; Epule et al. 2018 - Uganda).

From our results, biophysical variables proved to be important determinants of farming system choice: among the ten most important drivers, six are biophysical, with emphasis to climate. Among the climate drivers, rainfall and minimum temperature in the coldest month, are the most important. From one side, both the choice of some cash (e.g. FS2) and food crop systems (e.g. FS5, FS9 and FS10) is determined, among other factors, by rainfall. Rainfall is considered an important determinant of agricultural activity, especially in developing countries where irrigation is precarious and agriculture is mainly rainfed (Biswas et al. 1987). Livestock-oriented systems (e.g. FS6, FS7 and FS15), with emphasis to bovine, are mostly predominant in arid areas. On the other hand, the choice of mixed systems, i.e. dedicated mostly to food crops with small livestock production (mostly poultry) (e.g. FS5, FS9, FS10, FS11, FS12 – including swine and FS14 – goats), is favoured by warmer winters. Many studies, have found that warmer temperatures promote crop diversification and mixed farming (Aouadi et al. 2015; Etwire 2020; Hassan and Nhemachena 2008). However, further increases in temperature discourage the choice of mixed tree-crop systems (e.g. cashew – FS9, and coconut – FS16); which is in accordance with Etwire (2020).

On the other hand, the choice of cash crop (e.g., FS1, 2 and 3) and livestock-oriented systems (e.g., FS7) seems to be mostly determined by socioeconomic drivers, such as market integration or farm and household size, as opposed to farming systems dedicated to staple food crops (e.g., maize, cassava, sorghum, and rice - represented by FS5, FS11, FS14 and FS10). Poor farmers usually prefer to grow staple food crops (e.g. maize, cassava, sorghum and rice) or legumes (e.g. beans) to secure their families' basic nutrition, and only seldom they grow cash crops (Lukanu et al. 2004). Adopters of cash crop systems are mostly influenced by the existence of developed value chains that enable access to input and output markets (Lukanu et al. 2004; Maggio and Sitko 2018). Market-oriented and/or with large herd size and labour input systems also tend to be associated with large farm size (Stylianou, Sdrali, and Apostolopoulos 2020).

4.2. A farming system framework to assess policy and climate change scenarios

Given the importance of climate drivers in farming system choice, evidenced by our results, the fact that these are subject to changes in time will affect farmers' decisions regarding their agricultural practices. Changes in climate in the short-term may not affect significantly the fundamental basis of farming systems, as farmers, in their adaptation strategies, tend to first change varieties, and only later crops

(Ouédraogo et al. 2017). However, in the long term, changes in farming practices, due to climate change, will lead farmers to switch from vulnerable farming systems to others less susceptible to climate change (Etwire 2020).

Our results showed that farming systems whose choice is dependent on climate drivers are also the ones that are already vulnerable to climate change, either due to their location, i.e. along the coast and/or in densely populated areas (e.g. permanent crop systems – FS9 and FS16), or due to their lack of resources, i.e. poor and rudimentary (low use of yield-raising and labour-saving inputs) systems dedicated to staple food crops (e.g. FS5, FS10 and FS11). In many developing countries, tree-crops although considered an important source of income, are usually located in environmentally sensitive areas (e.g. coastal areas), which poses challenges to farmers' food security due to climate change (Etwire 2020; Souissi et al. 2018).

Mixed crop-livestock farming systems (e.g. FS6), on the other hand, although determined by climate drivers, are considered less vulnerable. Mixed or livestock-oriented systems are considered to tolerate better changes in climate, compared to food-crop systems, as the former are already produced under harsh and variable environments largely unsuitable for other uses (Etwire 2020). Moreover, diversified systems tend to be more innovative, i.e. more prone to make farming changes, and therefore are able to deal with the challenges posed by climate change (Bhatta et al. 2016).

Effective policies must look at the long run and develop appropriate strategies for farmers to adapt to climate change and meet their food security requirements without deepen impoverishment in rural areas. A farming system approach provides a useful tool to address the issue of food security in the context of climate change, as farmers respond to environmental and socioeconomic challenges differently according to their context (Ouédraogo et al. 2017). By understanding the drivers that influence farming system choice, this framework allows to understand how farmers would respond if these drivers (biophysical and socioeconomic) change across time, allowing to identify priority areas for policy support. The strong link between the spatial distribution of farming systems and the climate drivers demonstrated in this paper, enables us to propose our farming systems approach as a framework to map farming system dynamics under different climate change scenarios using a "space for time" modelling strategy, and use it to assess food security options in developing countries. Increasing knowledge on the factors affecting farmers' choices, enhances the design of appropriate policies that will lead to the expected outcomes regarding food security, thus smoothening the transition from one farming system to another.

4.3. The role of socioeconomic drivers in climate change adaptation policy options for food security

Our results showed that among the top-ten drivers of farming system choice, four are socioeconomic, which is in line with findings from previous works (e.g. Bhatta et al. 2016; Maggio and Sitko 2018; Stylianou, Sdrali, and Apostolopoulos 2020). Market-related factors seem to be associated with diversification within the farming system, i.e. cash-food crop systems (e.g. FS1), and crop-livestock systems (e.g. FS6 and FS7). Crop diversification, e.g. food-cash crops/food-livestock/food- cash-livestock systems, is an important factor for food security, as it helps to lower income volatility and provide food diversity (Lukanu et al. 2004; Maggio and Sitko 2018). It is also considered that larger farms are more likely to adopt diversified systems (e.g. FS7), use yield-raising and labour-saving inputs, and to be more food-secure (Kuivanen et al. 2016; Maggio and Sitko 2018; Massawe 2017). As agricultural land is a scarce resource, policies supporting land access and protecting land rights of smallholder farmers, as well as policies aimed at improving farmers' access to markets, i.e. investments in market infrastructures (e.g. roads) and price regulation, may be crucial to stimulate crop diversification and increase yields (Maggio and Sitko 2018), which are important factors contributing to improve food security, especially in the context of climate change.

Therefore, climate change adaptation policies aimed at reducing its negative effects on farmers' livelihoods and improving food security, should also focus on socioeconomic drivers that can be managed by policymakers, to create a more resilient environment that can produce the desired outcomes among rural farmers in developing countries.

5. CONCLUSION

This study focused on modelling the effects of biophysical and socioeconomic drivers in determining farming system choice in developing countries, and its potential for estimating the effects of policy and climate scenarios, contributing to food security. The results confirmed that both biophysical and socioeconomic drivers play an important role in influencing farmers' productive decisions, therefore in determining farming system choice. Climate drivers are of particular importance, as these are among the most important drivers influencing the choice of most farming systems, and are expected to change over time, diverting farmers choices from their original farming system. Given the strong link between the farming systems choice and the climate drivers, the farming system approach can be used as a framework to map farming system dynamics under different climate scenarios, to assess the impacts on farmers' livelihoods and food security. Moreover, given the important role of socioeconomic drivers in improving farmers' resilience and contributing to food security, increased knowledge on the impacts of these drivers on farming systems can be used to inform adaptation policies for food security. Future research should focus on the effects of climate change on farming system choice, and on priority areas for policy intervention, that will be under higher stress for change affecting food security and farmers' livelihoods.

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APPENDIX B

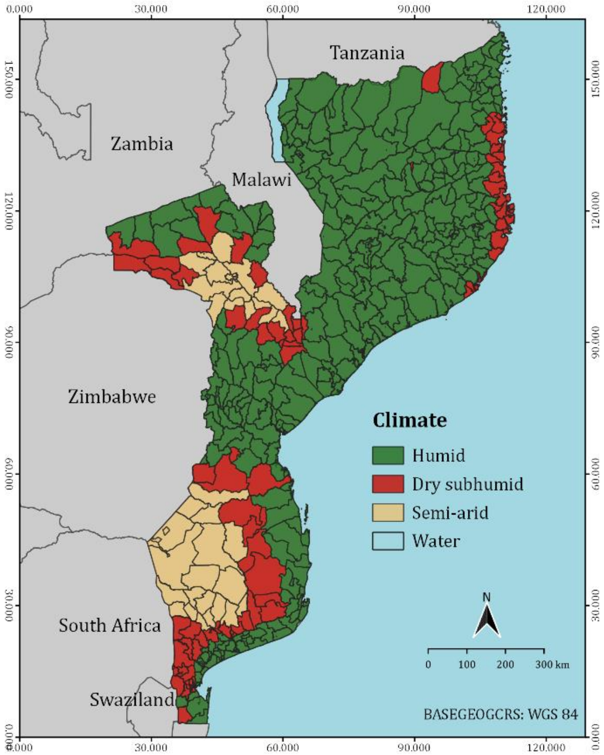


Figure B.1. Mozambique climate type based on the aridity index

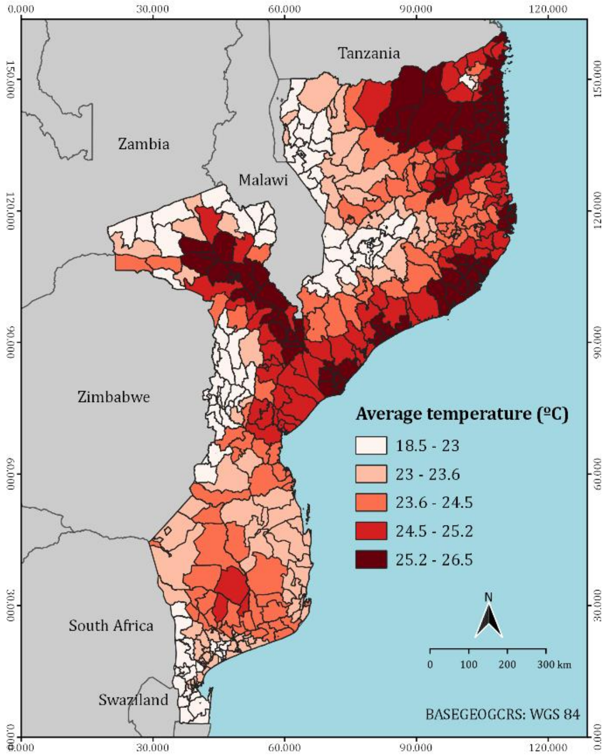


Figure B.2. Average temperature (1970-2000) for Mozambique

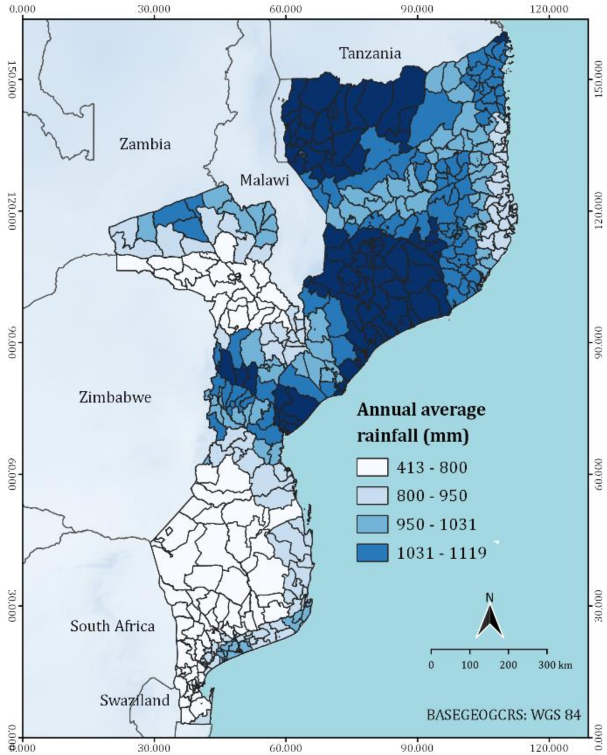


Figure B.3. Annual average rainfall (1970-2000) for Mozambique

Table B.1. Summary of the variables considered for the classification of farms by farming systems (n=27,805)

Variables			Crops/Livestock description	Mean (sd.v)
Land use/cover	*Annual Crops (proportion of total arable area)*	Maize		0.26 (0.27)
		Rice		0.07 (0.22)
		Sorghum+	Sorghum and Millet	0.06 (0.16)
		Cassava		0.23 (0.30)
		SweetPotato		0.03 (0.09)
		Cowpea		0.08 (0.14)
		Beans	Pigeon peas, Jugo and Kidney beans	0.07 (0.14)
		Groundnut		0.08 (0.16)
		Sesame		0.01 (0.08)
		Cotton		0.01 (0.08)
		Tobacco		0.01 (0.07)
		Hort1	Pumpkin, Watermelon and Okra	0.04 (0.09)
		Hort2	Tomato, Kale, Onion, Potato, Lettuce and Cabbage	0.02 (0.12)
		Hort3	Cucumber, Yam, Green beans, Garlic, Carrot, Pepper and Eggplant	0.01 (0.04)
		OtherAnC	Other annual crops (e.g. peas, sunflower, soy, sugarcane, wheat, ginger)	0.01 (0.07)
	Permanent Crops (PermC) (proportion of total fruit tree stems)	Mango		0.24 (0.40)
		Cashew		0.20 (0.33)
		Coconut		0.11 (0.32)
		Citrus	Orange, Lemon, Tangerine and Grapefruit	0.08 (0.23)
		OtherFruit	Papaya, *Maçanica*, *Mafurra*, Guava, Avocado, *Jambalão*, Peach, Litchi and Apple	0.20 (0.17)
	Proportion of equivalent arable area with permanent crops [(1)]	PermC		0.18 (0.29)
Livestock Variables	*Livestock (proportion in total standard livestock units)*	Bovine		0.10 (0.27)
		Goats		0.16 (0.31)
		Swine		0.08 (0.22)
		SmallLivestock	Chickens, Ducks, Bush chicken, Turkeys, Rabbits and Geese	0.42 (0.46)
		Sheep		0.01 (0.06)
	Livestock density (number of standard livestock units per hectare of arable area)	LivDens		1.16 (2.36)
Output Diversification	*Gross Product [(2)] (proportion of total output, i.e. Total Gross Product –TGP [(3)])*	GPAnBFC	Annual Basic Food Crops	0.45 (0.44)
		GPHortC	Horticultural Crops	0.01 (0.07)
		GPCashC	Cash Crops	0.03 (0.12)
		GPCashew	Cashew	0.02 (0.10)
		GPCoconut	Coconut	0.02 (0.12)
		GPLivestock	Livestock	0.44 (0.44)
	Economic Intensity (output (MZN) per hectare of arable area)	EconInt		38565 (52297)

Table B.1. Summary of the variables considered for the classification of farms by farming systems (n=27,805) (cont.)

Variables			Mean (sd.v)
Yield-raising input intensity *(proportion of arable area)*		Irrigation	0.02 (0.14)
		Pesticide	0.01 (0.10)
		Fertilizer	0.03 (0.13)
		Manure	0.02 (0.14)
Labour and labour-saving inputs	Labour productivity – output (MZN) per labour unit [(4)]	LabProd	11652 (13212)
	Labour intensity – labour units per hectare of arable area	Labour	3.38 (2.66)
	Bovine traction use: 1 – yes; 0 – otherwise	Traction	0.20 (0.40)
	Tractors use indicator: 1 – yes; 0 – otherwise	Tractor	0.02 (0.15)

[(1)] CAP 2009-2010 did not provide data on arable area with permanent crops for all farms. Therefore, the total arable area with permanent crops was computed based on the average area per fruit tree stem (Rehm and Espig 1991) and the number of fruit tree stems (extracted from CAP database).

[(2)] The Gross Product (GP) for crops was computed based on data extracted from CAP 2009-2010, i.e. the harvested amount and the median price for each crop (in the national currency, Metical – MZN). The median price was computed based on total amount sold for each crop and the value received for the sale. Harvested and sold amounts were given in different units of measure; therefore, they were converted into kilograms (kg), using the conversion parameters provided by the Ministry of Agriculture and Food Security and the National Statistical Institute. When conversion factors were not available, and when applicable, land productivity was used to estimate the farm production. Conversion factors for horticultural crops and fruits were not available, therefore it was assumed that the gross product was equal to the sales (MZN). For livestock, the GP was computed based on livestock outputs, i.e. slaughtered (either for consumption or sale) and live animals sold and offered. The average price was computed based on the purchase and sale price (of meat and live animals) – extracted from CAP.

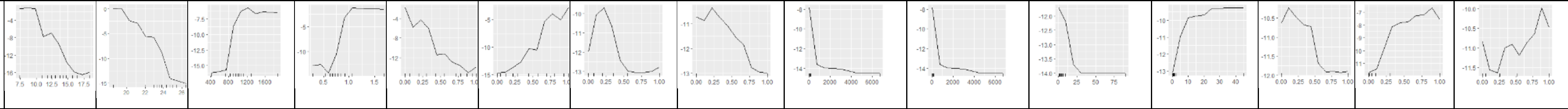
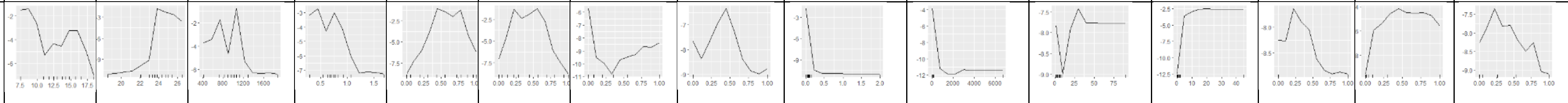
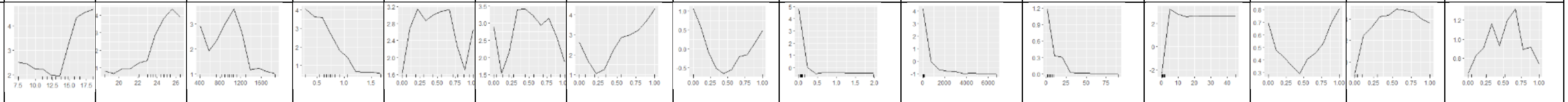
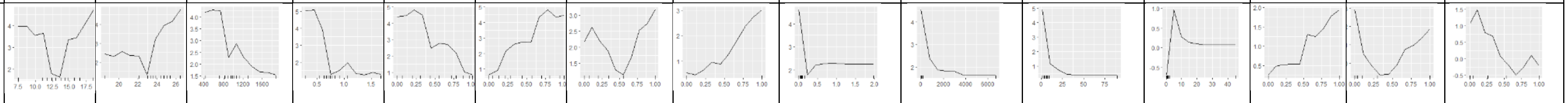
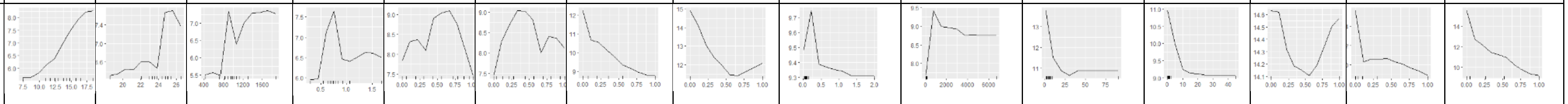
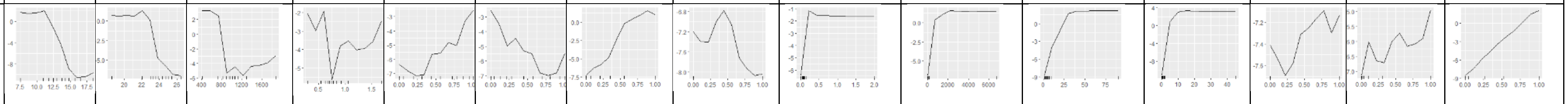
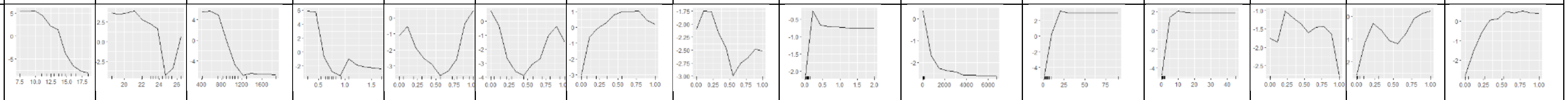
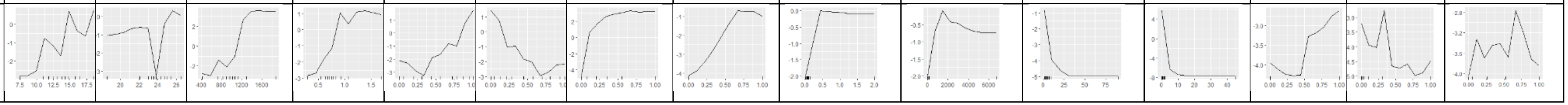
[(3)] TGP refers to the total output of the farm, including crops (annual and permanent) and livestock.

[(4)] Labour units correspond to the sum of all units of labour employed in agriculture and livestock activity, including: i) family labour (weighted in 100% for those who had agricultural as their main activity, and 25% as their secondary activity); ii) full-time workers (assumed to dedicate 100% of their time to agricultural activity); and iii) temporary workers (assumed to spend 10% of their time).

Table B.2. Computation of biophysical and socioeconomic drivers

Variable	Variable name	Unit	Formula	Variable code	Description	Unit	Source of data
Biophysical variables							
LOWAREA	Proportion of farm area in lower areas	%	(ALow/FArea)*100	ALow	Total area in lower areas (all parcels)	ha	CAP
				FArea	Total area (all parcels)	ha	
Socioeconomic variables							
POPDENS	Population density	Inhabitants /km^2	POP/APA	POP	Population by administrative post	inhabitants	INE
				APA	Administrative post area	km^2	
HOUSEHOLD	Household size	N					CAP
FARMSIZE	Farm size	ha	FArea	FArea	Farm area (all parcels)	ha	CAP
WOMEN	Proportion of farm area managed by women	%	(AWom/FArea)*100	AWom	Total farm area managed by women (all parcels)	ha	
				FArea	Farm area (all parcels)	ha	
MARKET	Market integration	%	(TSale/TGP)*100	TSale	Total farm sales: TSale = CropSale + LivSale; CropSale - total farm crop sales LivSale - total livestock sales	MZN	
				TGP	Total Gross Product: TGP = GPC + GPLiv GPC - Crop Gross Product GPLiv - Livestock Gross Product		
PAIDWORK	Proportion of paid work in total labor unit	%	(FTWork+TWork)/LU	FTWork	Total full-time workers used in farming (agriculture and livestock)	N	
				TWork	Total temporary workers used in farming	N	
				LU	Labor Unit: LU = FamWork+FTWork+Twork FamWork - family workers	N	

Table B.3. Partial Dependence Plots for each driver by farming system

Farming System	MINTEMP (ºC)	AVGTEMP (ºC)	RAINFALL (mm)	ARIDITY INDEX	SLOPE5 (%)	SLOPE10 (%)	HIGHFERT (%)	LOWAREA (%)	ROADDENS (km/km^2)	POPDENS (inhab/km^2)	HOUSEHOLD (N)	FARMSIZE (ha)	WOMEN (%)	MARKET (%)	PAIDWORK (%)
FS1_Tobacco and Maize															
FS2_Cotton															
FS3_ Sesame and Maize															
FS4_Annual Food Crops															
FS5_Annual Basic Food Crops															
FS6_MixedLiv & Maize															
FS7_Bovine, Maize & OtherAnFC															
FS8_Roots & Mixed PermC															

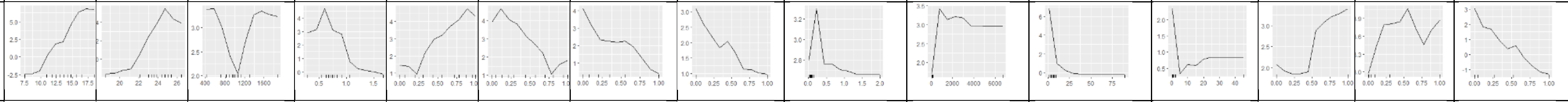
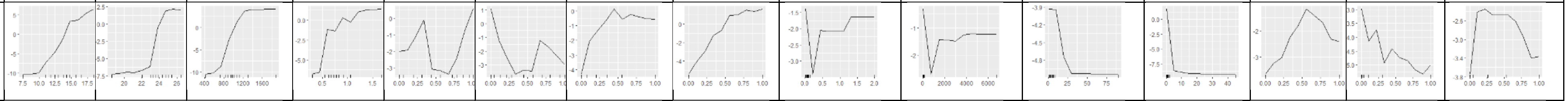
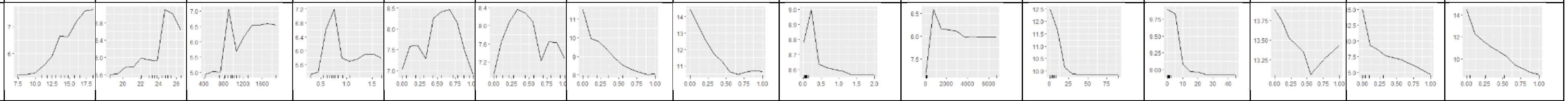
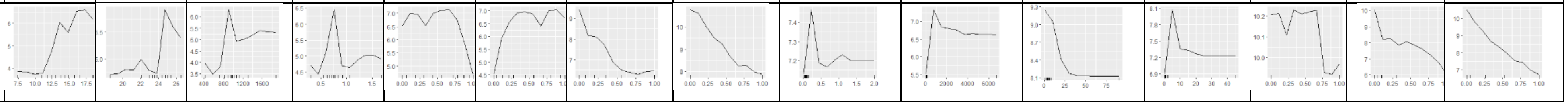
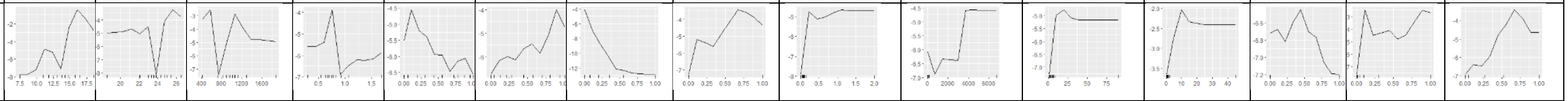
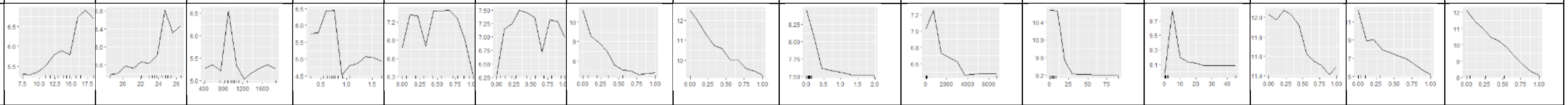
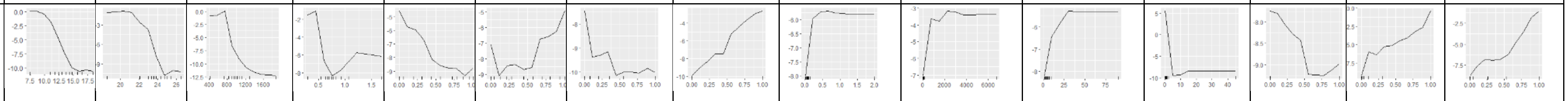
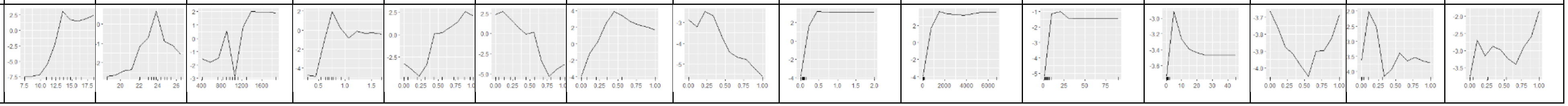
Farming System	MINTEMP (ºC)	AVGTEMP (ºC)	RAINFALL (mm)	ARIDITY INDEX	SLOPE5 (%)	SLOPE10 (%)	HIGHFERT (%)	LOWAREA (%)	ROADDENS (km/km^2)	POPDENS (inhab/km^2)	HOUSEHOLD (N)	FARMSIZE (ha)	WOMEN (%)	MARKET (%)	PAIDWORK (%)
FS9_Cashew & Mixed AnBFC															
FS10_Rice Mixed															
FS11_ Small Livestock and Mixed Crops															
FS12_ Swine and Mixed Crops															
FS13_ Sheep and Mixed Crops															
FS14_ Goats and Mixed Crops															
FS15_ MixedLiv, HortC and Mixed PermC															
FS16_ MixedLiv, Coconut and Cassava															

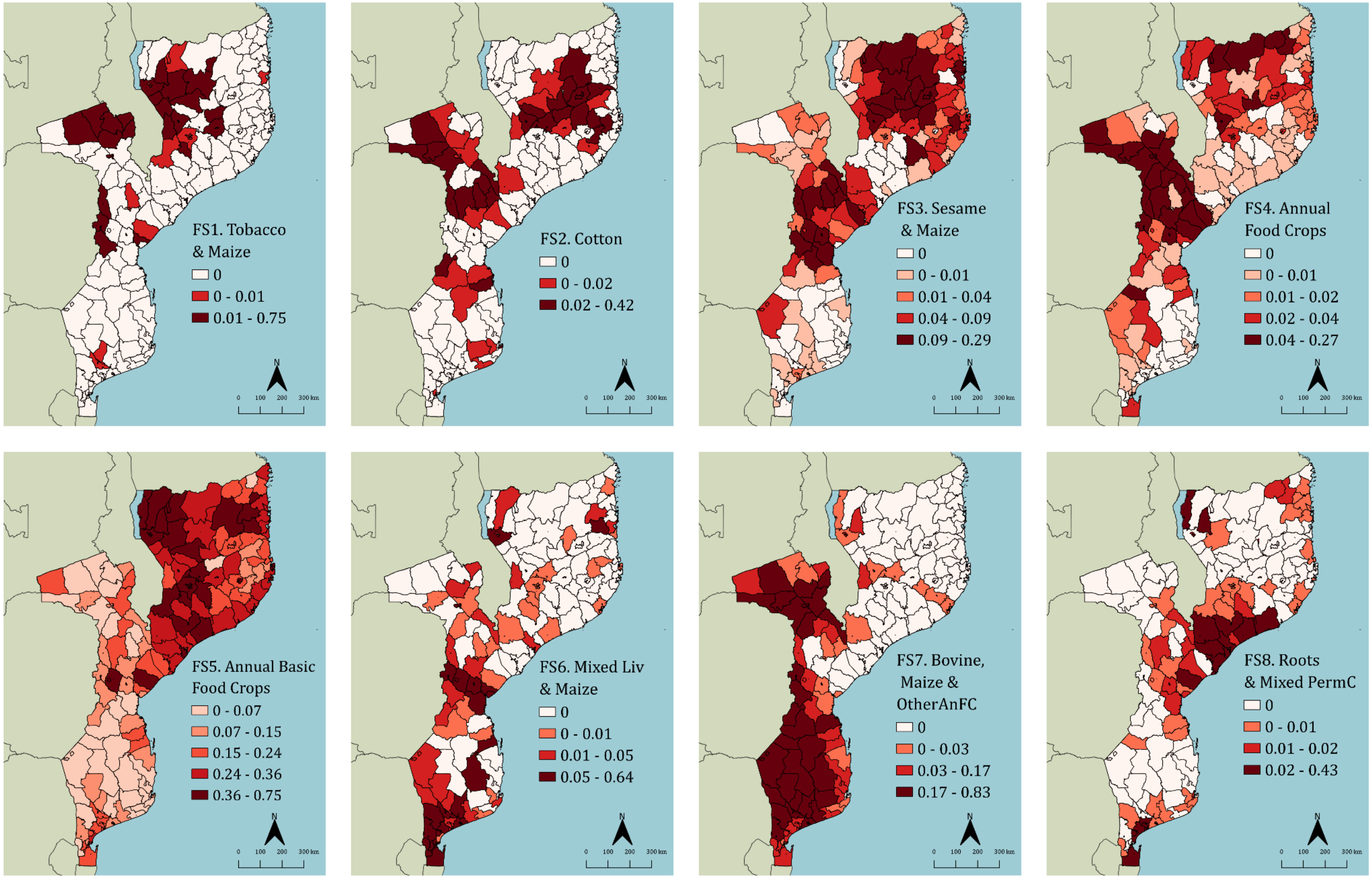
Table B.4. Identification of farming systems: Cluster analysis output

Farming system	House-hold	Maize	Rice	Sorghum+	Cassava	Sweet Potato	Cowpea	Beans	Groundnut	Sesame	Cotton	Tobacco	Hort1	Hort2	Hort3	Other AnC
FS 1	525	0.300	0.002	0.014	0.023	0.017	0.034	0.059	0.043	0.003	0.000	0.390	0.041	0.039	0.008	0.024
FS 2	408	0.139	0.007	0.062	0.048	0.005	0.039	0.025	0.030	0.039	0.571	0.001	0.022	0.003	0.005	0.005
FS 3	1158	0.309	0.018	0.081	0.094	0.017	0.055	0.056	0.035	0.268	0.004	0.002	0.039	0.009	0.008	0.007
FS 4	924	0.259	0.007	0.183	0.061	0.021	0.065	0.027	0.032	0.010	0.000	0.000	0.177	0.029	0.117	0.017
FS 5	6749	0.273	0.034	0.046	0.290	0.021	0.075	0.112	0.087	0.001	0.000	0.000	0.026	0.022	0.003	0.003
FS 6	578	0.442	0.058	0.009	0.106	0.033	0.100	0.031	0.075	0.008	0.000	0.001	0.069	0.025	0.007	0.016
FS 7	2105	0.456	0.007	0.089	0.034	0.019	0.103	0.039	0.082	0.008	0.001	0.001	0.118	0.015	0.019	0.007
FS 8	535	0.088	0.036	0.004	0.290	0.455	0.053	0.018	0.007	0.002	0.000	0.000	0.021	0.025	0.002	0.003
FS 9	1530	0.185	0.025	0.069	0.396	0.006	0.098	0.066	0.119	0.001	0.000	0.000	0.022	0.003	0.002	0.002
FS 10	1248	0.017	0.932	0.006	0.021	0.004	0.003	0.002	0.002	0.000	0.000	0.000	0.002	0.004	0.001	0.006
FS 11	3968	0.299	0.023	0.066	0.269	0.018	0.094	0.083	0.080	0.003	0.000	0.000	0.036	0.008	0.006	0.003
FS 12	2287	0.225	0.013	0.058	0.253	0.024	0.088	0.111	0.084	0.007	0.001	0.001	0.028	0.014	0.007	0.080
FS 13	267	0.145	0.025	0.069	0.185	0.013	0.054	0.064	0.099	0.011	0.003	0.002	0.020	0.014	0.006	0.288
FS 14	3126	0.294	0.010	0.145	0.186	0.022	0.081	0.071	0.104	0.003	0.001	0.001	0.049	0.014	0.011	0.004
FS 15	426	0.115	0.038	0.000	0.013	0.016	0.025	0.049	0.008	0.000	0.001	0.000	0.035	0.658	0.032	0.009
FS 16	1971	0.091	0.062	0.004	0.493	0.010	0.195	0.026	0.100	0.001	0.000	0.000	0.009	0.004	0.001	0.001

Farming system	Perm Crops	Mango	Cashew	Coconut	Citrus	Other Fruits	Livestock density	Bovine	Goats	Swine	Small Livestock	Sheep
FS 1	0.016	0.582	0.017	0.003	0.035	0.176	0.598	0.092	0.223	0.082	0.411	0.004
FS 2	0.032	0.205	0.153	0.030	0.075	0.251	0.884	0.139	0.193	0.081	0.418	0.003
FS 3	0.065	0.308	0.181	0.033	0.062	0.188	0.553	0.018	0.213	0.032	0.515	0.000
FS 4	0.040	0.139	0.059	0.018	0.018	0.417	0.204	0.009	0.017	0.015	0.470	0.000
FS 5	0.077	0.280	0.075	0.083	0.098	0.188	0.140	0.008	0.014	0.004	0.411	0.000
FS 6	0.090	0.220	0.113	0.051	0.174	0.324	2.400	0.270	0.159	0.053	0.348	0.005
FS 7	0.081	0.189	0.170	0.032	0.073	0.273	6.124	0.834	0.098	0.022	0.021	0.008
FS 8	0.227	0.266	0.112	0.162	0.085	0.212	0.784	0.025	0.095	0.023	0.533	0.001
FS 9	0.274	0.087	0.791	0.033	0.023	0.060	0.183	0.009	0.047	0.014	0.435	0.000
FS 10	0.170	0.242	0.134	0.242	0.049	0.154	0.757	0.038	0.123	0.024	0.436	0.001
FS 11	0.142	0.281	0.220	0.090	0.061	0.211	0.320	0.002	0.009	0.004	0.976	0.000
FS 12	0.179	0.262	0.228	0.101	0.093	0.181	0.872	0.004	0.084	0.537	0.282	0.000
FS 13	0.199	0.211	0.411	0.074	0.088	0.131	1.455	0.047	0.175	0.037	0.197	0.455
FS 14	0.122	0.228	0.279	0.038	0.071	0.209	1.279	0.008	0.763	0.033	0.164	0.001
FS 15	0.271	0.343	0.072	0.057	0.081	0.302	2.949	0.165	0.221	0.063	0.327	0.004
FS 16	0.880	0.059	0.193	0.516	0.111	0.096	2.538	0.255	0.224	0.212	0.199	0.001

Table B.4. Identification of farming systems: Cluster analysis output (cont.)

Farming system	GP AnBFC	GP HortC	GP CashC	GP Cashew	GP Coconut	GP Liv	Economic Intensity	Irrigation	Pesticide	Fertilizer	Manure	Labour Productivity	Labour Intensity	Traction	Tractor
FS 1	0.306	0.013	0.322	0.001	0.000	0.344	41,284	0.054	0.139	0.546	0.077	15,645	2.815	0.310	0.010
FS 2	0.345	0.000	0.237	0.007	0.001	0.398	33,230	0.007	0.227	0.047	0.035	11,618	2.909	0.169	0.012
FS 3	0.321	0.005	0.233	0.011	0.001	0.414	35,544	0.003	0.004	0.028	0.022	11,810	3.195	0.052	0.004
FS 4	0.676	0.028	0.012	0.004	0.001	0.199	15,055	0.041	0.005	0.051	0.029	4,812	3.081	0.110	0.004
FS 5	0.821	0.015	0.004	0.006	0.007	0.094	14,391	0.013	0.001	0.011	0.027	3,804	3.602	0.064	0.000
FS 6	0.279	0.019	0.007	0.007	0.012	0.621	54,913	0.059	0.003	0.031	0.024	15,940	3.544	0.429	0.958
FS 7	0.176	0.005	0.009	0.017	0.001	0.765	55,705	0.015	0.003	0.030	0.010	16,677	3.531	0.873	0.000
FS 8	0.539	0.002	0.009	0.009	0.015	0.399	54,339	0.023	0.002	0.010	0.011	12,394	4.630	0.095	0.006
FS 9	0.668	0.001	0.003	0.238	0.004	0.073	8,953	0.002	0.001	0.007	0.006	3,646	2.752	0.072	0.008
FS 10	0.498	0.001	0.003	0.009	0.009	0.367	42,408	0.002	0.000	0.000	0.003	9,580	4.145	0.047	0.002
FS 11	0.131	0.001	0.003	0.003	0.003	0.838	67,254	0.002	0.000	0.014	0.004	19,604	3.334	0.108	0.000
FS 12	0.449	0.004	0.019	0.016	0.012	0.480	39,716	0.006	0.002	0.021	0.013	12,876	3.268	0.176	0.002
FS 13	0.417	0.006	0.036	0.039	0.011	0.446	39,187	0.032	0.004	0.038	0.012	12,035	3.596	0.127	0.052
FS 14	0.356	0.002	0.005	0.012	0.001	0.601	51,319	0.008	0.002	0.022	0.009	15,669	3.293	0.111	0.000
FS 15	0.295	0.116	0.053	0.010	0.020	0.445	87,190	0.864	0.367	0.435	0.542	13,580	6.739	0.319	0.061
FS 16	0.124	0.001	0.002	0.031	0.248	0.578	37,771	0.003	0.000	0.003	0.003	17,016	2.127	0.605	0.001


FS1. Tobacco & Maize
0
0 - 0.01
0.01 - 0.75
FS2. Cotton
0
0 - 0.02
0.02 - 0.42
FS3. Sesame & Maize
0
0 - 0.01
0.01 - 0.04
0.04 - 0.09
0.09 - 0.29
FS4. Annual Food Crops
0
0 - 0.01
0.01 - 0.02
0.02 - 0.04
0.04 - 0.27
FS5. Annual Basic Food Crops
0 - 0.07
0.07 - 0.15
0.15 - 0.24
0.24 - 0.36
0.36 - 0.75
FS6. Mixed Liv & Maize
0
0 - 0.01
0.01 - 0.05
0.05 - 0.64
FS7. Bovine, Maize & OtherAnFC
0
0 - 0.03
0.03 - 0.17
0.17 - 0.83
FS8. Roots & Mixed PermC
0
0 - 0.01
0.01 - 0.02
0.02 - 0.43

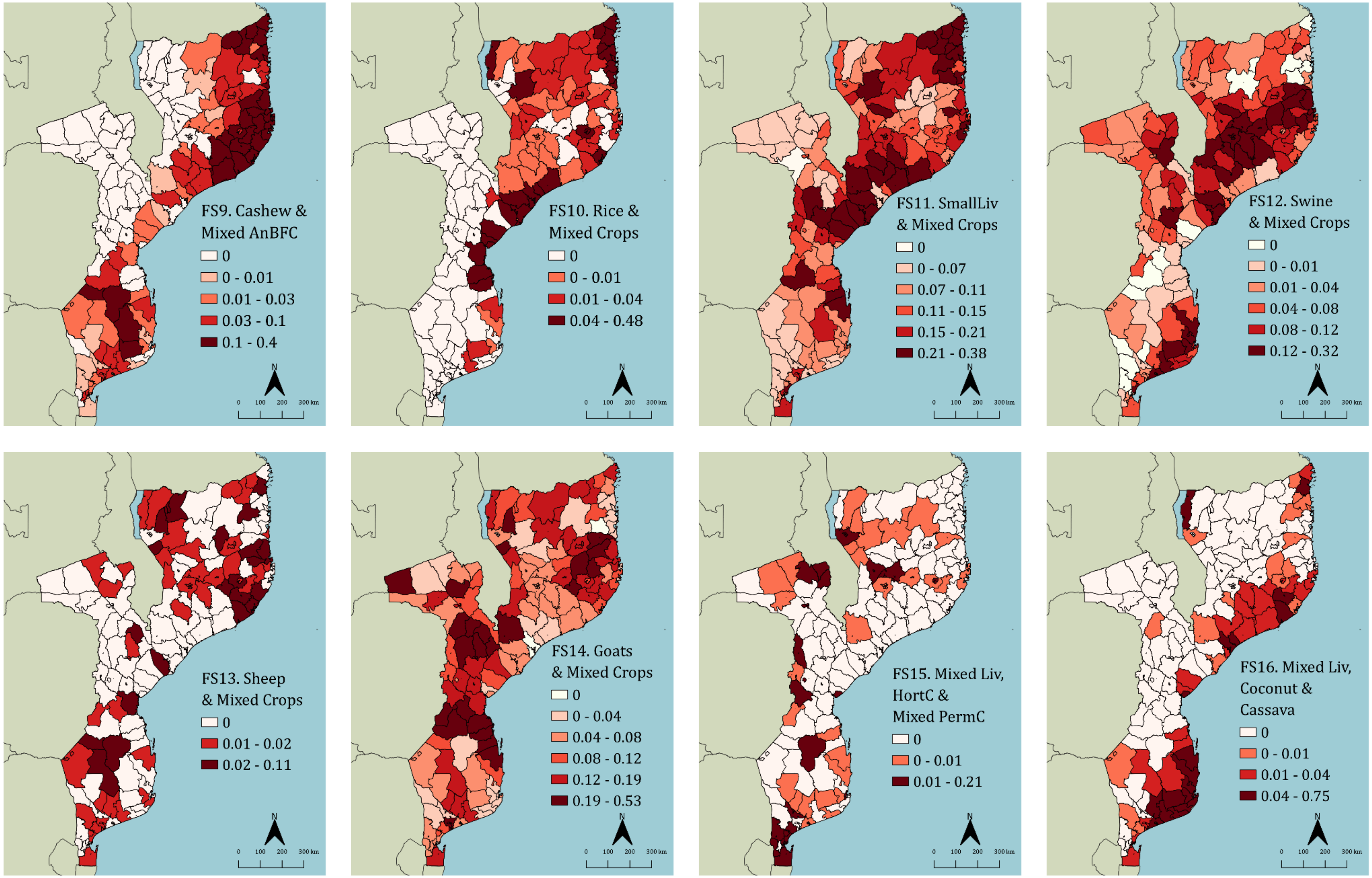


Figure B.4. Spatial distribution of farming systems in Mozambique (% of Total Agricultural Area)

CHAPTER 4

FARMING SYSTEM CHANGE UNDER DIFFERENT CLIMATE SCENARIOS AND ITS IMPACT ON FOOD SECURITY: AN ANALYTICAL FRAMEWORK TO INFORM ADAPTATION POLICY

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Farming system change under different climate scenarios and its impact on food security: an analytical framework to inform adaptation policy

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ABSTRACT

Developing countries are considered extremely vulnerable to climate change, due to the high dependence of their livelihoods on natural resources. Rural areas in these countries concentrate most of the poor and food insecure people in the world, being farmers in these regions the most vulnerable and the ones that will be the most affected by climate change. Nevertheless, the impacts of climate change will be spatially highly heterogeneous. In this sense, this paper aims at assessing the impact of climate change on farming system choice and food security, based on predictions of farming system change under different climate scenarios, using a space for time modelling strategy, that is based on a farming system typology previously identified. The results indicate major changes in farming system choice and its spatial distribution due to climate change, which will impact considerably the livelihoods and food security status of smallholder farmers. The most food secure farming systems are expected to disappear in the context of climate change. This analysis allowed to map areas that will have higher stress for change due to farming system transitions, that will be at risk of deteriorating their food security status. The proposed framework can be used to inform adaptation policies for food security under climate change, by identifying priority areas that will most likely need government interventions.

Keywords: farming system change, food security, climate scenarios, adaptation policy, developing countries.

1. INTRODUCTION

Climate change has been gaining increasing relevance in national and international debates in the last decades, due to its effects on poverty, food security, biodiversity, among others. Developing countries are considered the most vulnerable to climate change, being exposed to a series of climate related challenges that affect the agricultural sector and therefore food security and poverty (Ford et al. 2015). The developing regions concentrate about 98% of the undernourished people in the world, with Africa being the region with the highest prevalence of hunger (19% of the population – more than twice the world average of 8.9%) (FAO et al. 2020). Most of these undernourished, food insecure and poor people lives in rural areas, with agriculture as their main source of income and subsistence (FAO et al. 2020), and they will be the ones disproportionately impacted by climate change, exacerbating the potential effects on food security and poverty. Small-scale farmers living in rainfed areas and/or female-headed households, pastoralists, farm labourers and the landless are likely to be the most dramatically impacted by climate change (Lewis, Monem, and Impiglia 2018). Nevertheless, the impacts of climate change will be spatially and temporally highly heterogeneous, posing challenges to policymakers. It is, therefore, of utmost importance to deepen the knowledge about these impacts to allow early planning of adaptation strategies.

Climate is an important driver influencing farming system choice (Abbas, Ribeiro, and Santos n.d. b) and affecting farmers' livelihoods. Therefore, to preserve food security and provide alternative income generating options, farmers tend to respond to changes in temperature and rainfall by adjusting their farming practices, that can ultimate lead to switching from vulnerable farming systems to others less susceptible to a changing climate (Etwire 2020; Jones and Thornton 2009). These farming system transitions, that move the farmer to particularly different farming system may imply large changes in required knowledge and significant investments, putting the farmer under stress for changing farming systems. A higher stress for change can have substantial negative impacts on food security if farmers do not have the essential resources to embrace and deal with the inevitable change.

Therefore, an analysis of the impacts of climate change at the farm level, as well as the implications for the livelihoods of those farming-dependent households, will provide useful insights on priority areas, that will be under high stress for change in the future, relevant for adaptation policies aimed at promoting food security in a context of climate change.

Projections of the impacts of climate change on the agricultural sector has been based on crop modelling (e.g. Brito and Holman 2012; Knox et al. 2012; Kontgis et al. 2019) sometimes combined with socio or bio-economic models (e.g. Habtemariam, Abate Kassa, and Gandorfer 2017; Souissi et al. 2018), multinomial logit models (e.g. Etwire 2020), among others. A farming system approach has been recognized to provide an understanding of the rationality behind farmers productive decisions, contributing to improve knowledge on priority areas for policy implementation (Abbas, Ribeiro, and Santos n.d. a, n.d. b). The use of this approach, based on a space for time modelling strategy, allows to evaluate the farming system as whole and infer the changes that may occur at the farm system level as a result of climate change. In simple words, a space for time analysis seeks to understand when and where (and sometimes why) certain events occur; this can be done using a number of models (e.g. survival analysis, panel regression, latent trajectory/multilevel, among others) (An et al. 2015).

Following a farming system approach, based on previous studies where a typology of farming systems was made (Abbas, Ribeiro, and Santos n.d. a) and the drivers of its spatial distribution were studied (Abbas, Ribeiro, and Santos n.d. b), this paper used a space for time modelling strategy to assess the impact of climate change on farming system choice i.e., to predict the choice of farming systems in the context of climate change, through the use of machine learning techniques (random forests), aiming to: i) assess the impact of alternative climate scenarios on farming system choice by mapping predicted farming system change under each scenario; ii) map the variation in food security levels based on predictions of farming system change under different climate scenarios; and, iii) assess the potential and limitations of the used modelling strategy to better inform about adaptation policy options for food security.

2. MATERIALS AND METHODS

2.1. The study area

Mozambique is in the Southern Eastern coast of Africa and has a coastline of about 2 500 km that spans over eight of its eleven provinces, making the country vulnerable to the effects of ocean currents and air-sea interactions. Given its geographical location, the country is extremely vulnerable to climate change related disasters, ranking third among the African countries most exposed to weather-related hazards (World Bank 2010). Globally, it is considered the 45th most vulnerable and the 24th least ready country to address climate change effects (ND-GAIN index, available at www.gain.nd.edu/).

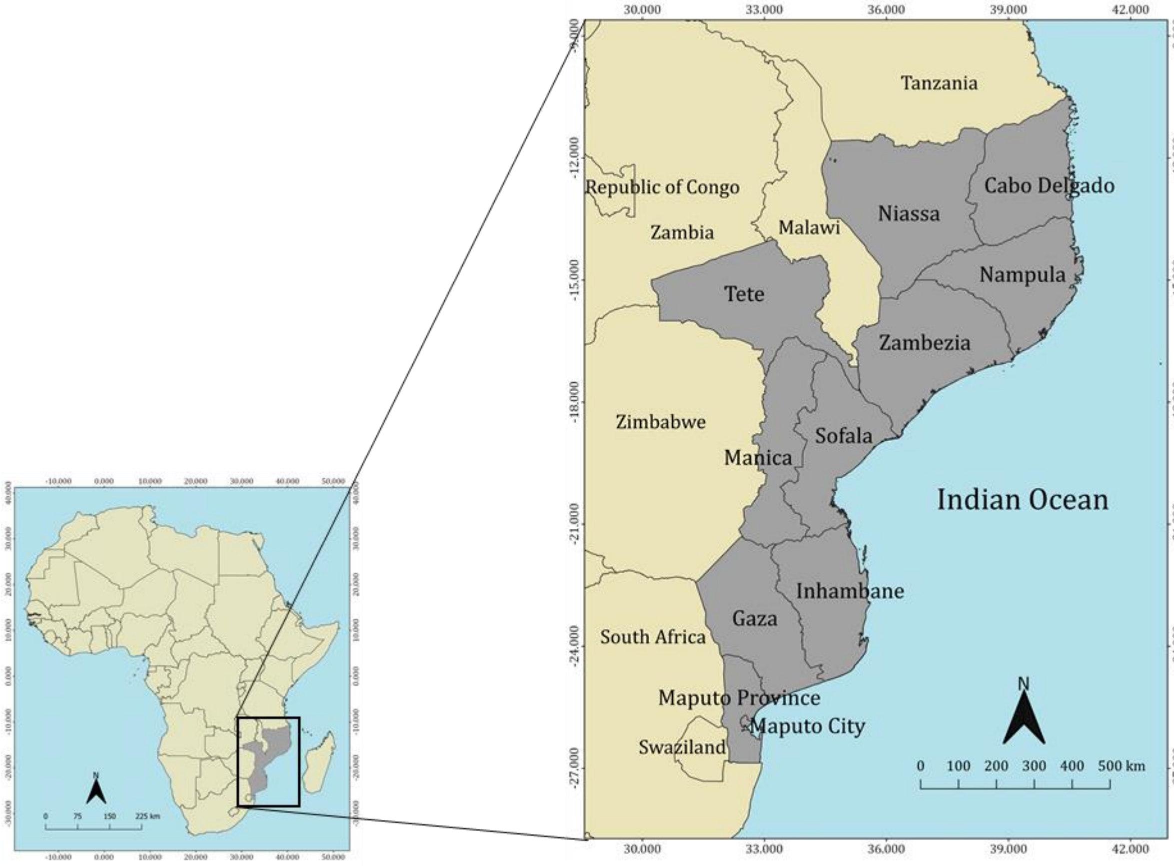


Figure 4.1. The study area: Mozambique

The country's vulnerability to climate change is linked to its inter-tropical location downstream of shared rivers basins, as well as the socioeconomic conditions of the population. Climate change will affect significantly people living in rural areas (ca. 70% – among which 50% are poor), due to their high dependence on natural resources essential to agriculture (e.g. land and water), and their weak ability to cope with extreme climatic events, such as floods and droughts (Marques et al. 2009).

The last decade have been characterized by many climatic shocks, i.e. tropical cyclones, intense rains and floods in the Central and Northern regions, and lack of rain and droughts in some parts of Central and southern regions of the country (Lötter 2017; SETSAN 2015). The past climatic events have caused delays in sowing, poor crop development, shortage of food and water for human consumption and livestock watering, therefore affecting food production and food security among the already most vulnerable population (SETSAN 2015).

Food insecurity is a major issue in the country, with about 24% of households being chronically food insecure (SETSAN 2014). It occurs largely in the central and northern regions, where most of the farmers and food production is concentrated (Abbas 2017a), and will be exacerbated by climate change. Households involved in production and commercialization of agricultural production and livestock are considered the most vulnerable to food insecurity (SETSAN 2014).

Public policies and strategies implemented have failed in addressing food security, especially as regards climate change, highlighting the need to align the response to climate change as a political priority in all sectors at the field-level, to promote development while ensuring food security and supporting climate resilience to small farmers (Joala et al. 2020).

A farming system approach have been recognized to play an important role in improving farmers' resilience, food security and alleviating poverty (Dixon, Gulliver, and Gibbon 2001; Stephens, Jones, and Parsons 2018), Public policies should support and allow small-scale farmers to innovate within a system that recognizes the diversity and the complexity of the challenges faced (FAO 2014).

A typology of farming system was built for Mozambique, based on farmers' individual productive decisions regarding agricultural land use/cover, livestock density and composition, use of yield-raising (e.g. fertilizer) and labour-saving (e.g. mechanical or animal traction) inputs, identifying 16 broad farming systems (Table 4.1).

Table 4.1. Farming Systems in Mozambique[(1)]

Farming system	Predominant location/climate	Main characteristics
FS1 – Tobacco and Maize	Central region (Tete)/ Humid	Market-oriented, intensive use of yield-raising inputs. Highly food secure.
FS2 – Cotton	Northern and central regions/ Humid	Market-oriented, pesticide-input user. Food secure.
FS3 – Sesame and Maize	Northern and central regions/Humid	Market-oriented. Food secure.
FS4 – Annual Food Crops (horticultural crops, maize and sorghum)	Across the country, emphasis to the Central region (Tete)/ Humid and semi-arid	Labour intensive. Highly food insecure.
FS5 – Annual Basic Food Crops (cassava, maize and beans)	Across the country, emphasis to the northern region/ Humid	Labour intensive. Mild food insecure.
FS6 – Mixed livestock and Maize	Southern region (Maputo province)/ Dry sub-humid	Intensive use of labour-saving inputs (animal traction and tractors). Food secure.
FS7 – Bovine, Maize and Other food crops	Inland southern and Central (upper Zambezi Valley) regions/ Semi-arid	Partially market oriented, high use of animal traction. Mild food insecure.
FS8 – Roots (cassava and sweet potato) and Mixed Permanent Crops	Central region/ Humid	Labour intensive. Food insecure.
FS9 – Cashew and Mixed annual basic food crops	Along the coast mostly in the Northern region/ Humid	Partially market oriented. Highly food insecure.
FS10 – Rice and Mixed Crops	Northern region and along the coast in the central region/ Humid	Highly labour intensive. Food insecure.
FS11 – Small livestock and Mixed Crops	Across the country with emphasis to the central and Northern region/ Humid	Mild food insecure.
FS12 – Swine and Mixed Crops	Northern and Central region, and along the coast in the southern region/ Humid	Mild food insecure.
FS13 – Sheep and Mixed Crops	Northern region/ Humid	Partially market oriented. Mild food insecure.
FS14 – Goats and Mixed Crops	Central and Northern regions/ Humid	Mild foo insecure.
FS15 – Mixed Livestock, Horticultural and Mixed permanent crops	Southern region/ Humid and dry subhumid	Market-oriented, irrigated with intensive use of yield-raising inputs and animal traction. Food secure.
FS16 – Mixed Livestock, Coconut and Cassava	Along the coast, with emphasis to the southern region/ Humid	High use of animal traction. Mild food insecure.

[(1)] See the spatial distribution of farming systems in Figure C1 in Appendix C.

Source: based on Abbas et al. (n.d. a).

2.2. Generating climate scenarios

Climate data used to generate climate scenarios included annual mean temperature (AVGTEMP), minimum temperature of the coldest month (MINTEMP) and annual precipitation (RAINFALL), which were collected from the WorldClim online database, version 2.1 (Fick and Hijmans 2017). An aridity index was also used, based on the average annual precipitation and the long-term climatic water demand, i.e. the potential evapotranspiration (PET), which was computed using the Thornthwaite method (Pascual-ferrer and Candela 2015), based on monthly mean temperatures calculated by averaging monthly mean minimum and maximum temperatures, also collected from the WorldClim.

The climate baseline scenario was set based on historical climate data for 1970-2000 provided by WorldClim v2.1 (with spatial resolution of 2.5 minutes, i.e. ~4.5 km). Climate data for three climate scenarios for 2081-2100 were also derived from the same source. The period 2081-2100 considering that in the short-term farmers tend to adapt to changes in climate by changing crop varieties and only later crop types (Ouédraogo et al. 2017).

Climate change data was assessed for three Shared Socio-economic Pathways (SSPs): SSP1-2.6, SSP3-7.0 and SSP5-8.5 for the end of the century (2081-2100). The SSPs are the new set of emission scenarios driven by different socioeconomic assumptions developed by the energy modelling community, in light of the Intergovernmental Panel on Climate Change (IPCC) sixth assessment report (AR6) (Hausfather 2018, 2019). The SSPs are based on narratives describing broad socioeconomic trends that could shape future society: i) SSP1 – the "sustainability narrative" referring to a world of sustainability-focused growth and equality – hereafter referred to as the optimistic scenario; ii) SSP3 – the regional rivalry narrative refers to a fragmented world of "resurgent nationalism" – referred in this paper as the intermediate scenario; and iii) SSP5 – the fossil-fuelled development narrative referring to a world of rapid and unconstrained growth in economic output and energy use – the most severe scenario. The global warming forecast for each of these scenarios are 3 to 3.5ºC, 3.9 to 4.6ºC and 4.7 to 5.1ºC by 2100, respectively (Hausfather 2018).

Climate scenarios were generated using climate data projections from Coupled Model Intercomparison Project Phase 6 (CMIP6) multi-model ensemble of 8 Global Climate Models (GCMs) available at WorldClim (https://www.worldclim.org/) (Table 4.2). Climate data for the different climate scenarios was mapped at the post administrative level (fourth administrative division), using QGIS 3.14.

Table 4.2. General Climate Models used to produce climate data

Originating Group	Country	ID	Reference
Beijing Climate Center	China	BCC-CSM2-MR	Wu et al. (2019)
Centre National de Recherches Météorologiques and Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique	France	CNRM-CM6-1	Voldoire et al. (2019)
		CNRM-ESM2-1	Séférian et al. (2016)
Canadian Centre for Climate Modelling and Analysis	Canada	CanESM5	Swart et al. (2019)
Institut Pierre-Simon Laplace	France	IPSL-CM6A-LR	Boucher et al. (2020)
Research Institute for Global Change	Japan	MIROC-ES2L	Hajima et al. (2020)
Research Center for Environmental Modeling and Application	Japan	MIROC6	Tatebe et al. (2019)
Meteorological Research Institute	Japan	MRI-ESM2-0	Yukimoto et al. (2019)

2.3. Predicting farming system choice under different climate scenarios

A random forest modelling approach was used to predict farming system choice under each climate scenario. The random forest model used for prediction was previously estimated in a recent study by Abbas et al. (n.d. b) to identify the drivers of farming system choice in the study area, based on a farming systems typology previously identified and mapped by (Abbas, Ribeiro, and Santos n.d. a). Climate variables, along with other acknowledged biophysical and socioeconomic drivers of farming system choice were tested as potential independent variables in model building (Table 4.3) (Abbas, Ribeiro, and Santos n.d. b).

Table 4.3. Observed biophysical and socioeconomic drivers used to predict farming system choice in the current scenario (1)

Variables	**Description**	**mean (min-max) s.d.**
Biophysical variables		
MINTEMP	Average minimum temperature in the coldest month 1970-2000 (℃)	13.7 (7.5-18.5) 2.1
AVGTEMP	Average annual temperature 1970-2000 (℃)	23.8 (18.5-26.5) 1.4
RAINFALL	Average annual rainfall 1970-2000 (mm)	994 (413-1877) 224
ARIDITYINDEX	Aridity Index	0.78 (0.29-1.68) 0.22
SLOPE5	Proportion of administrative post area with smooth slopes (<5%)	0.54 (0-1) 0.32
SLOPE10	Proportion of administrative post area with steep slopes (>10%)	0.46 (0-1) 0.32
HIGHFERT	Proportion of administrative post area with high fertility	0.17 (0-1) 0.26
LOWAREA	Proportion of the farm area in lower, valley bottom locations	0.33 (0-1) 0.46
Socioeconomic variables		
POPDENS	Population density (inhabitants/km^2)	122 (0.1-6735) 442
ROADDENS	Road density (km/km^2)	0.1 (0-2) 0.1
HOUSEHOLD	Household size	5 (1-90) 3
FARMSIZE	Farm size (ha)	1.2 (0.0001-45) 1.4
WOMEN	Proportion of farm area managed by women	0.36 (0-1) 0.48
MARKET	Market integration	0.09 (0-1) 0.19
PAIDWORK	Proportion of hired labour in total labour units (2)	0.13 (0-1) 0.24

(3) Biophysical and socioeconomic drivers were computed at the administrative post level (fourth administrative level division) – see Abbas et al. (n.d. b) for details. The sample used to estimate the model included 26,421 farms.

(4) Labour units correspond to the sum of all units of labour employed in agriculture and livestock activity, including family labour, full-time and temporary workers (see Abbas et al., n.d. b, Table C1).

Climate revealed to be an important driver of farming system choice (Abbas, Ribeiro, and Santos n.d. b) which enabled to use the estimated model to predict farming system choice under different climate scenarios. Therefore, predictions were performed using the predict function within the “randomForest” package on R software, version 4.0.2 (Breiman 2001), for the three climate scenarios – SSP1-2.6 (optimistic), SSP3-7.0 (intermediate) and SSP5-8.5 (most severe) – based on the observed values of biophysical and socioeconomic drivers for each farm (Table 4.3), except for climate drivers, in which the set of climate data representing each scenario was used (Table 4.4). All climate data current and future were mapped using QGIS 3.14.

Table 4.4. Climate data for the three climate scenarios for 2081-2100 – Median of 8 GCMs

Variable	Mean (min-max) s.d.		
	SSP1-2.6	**SSP3-7.0**	**SSP5-8.5**
MINTEMP	15.3 (8.9-20.4) 2.3	17.5 (11.3-22.2) 2.2	18.6 (12.4-23.1) 2.2
AVGTEMP	25.4 (20.2-28.3) 1.4	27.8 (22.8-30.8) 1.3	28.4 (23.5-31.8) 1.4
RAINFALL	977 (399-1865) 231	937 (379-1778) 223	928 (388-1714) 209
ARIDITYINDEX	0.6 (0.2-1.3) 0.2	0.4 (0.1-1.0) 0.1	0.4 (0.1-0.8)0.1

For each climate scenario, a transition matrix was computed, expressing the percentage of the current area under a particular farming system that transitioned to other farming systems as well as the percentage that persisted in the same system (persistence in the matrix diagonal). The transition matrix was computed based on the identification of the particular farms that were predicted to shift from one farming system to another, under each scenario (SSP1-2.6, SSP3-7.0 or SSP5-8.5), and the area currently occupied by each of these farms.

2.4. Farming system change indicators

To analyse the impact of climate change on farming system choice, two indicators were considered: 1) the stress for farming system change; and 2) the food security variation.

The stress for farming system change measures the level of difficulty associated with switching from one farming system to another. This indicator is the weighted average Euclidean distance between the original and final farming system in each transition, considering the area of that particular transition. The Euclidean distance shows the distance between the centroids of the original farming system under the current climate (e.g., FS16) and the farming system under climate change (e.g., FS5) – see Figure 4.2. Higher values identify FS that are more different from each other and, for that reason, where the transition between them is more difficult. The Euclidean distance was computed on the selected principal components from the Principal Component Analysis (PCA) that preceded the cluster analysis in the classification of farms by farming systems (see Abbas, Ribeiro, and Santos n.d. a). For instance, analysing Figure 4.2, consider that in the context of climate change a proportion of FS16 is expected to transition to FS5, with Factor 1 (F1) being animal traction and Factor 2 (F2) labour productivity. In this case, we can assume that the distance between FS16 to FS5 is the intensification of labour (as the use of animal traction and labour productivity reduces), i.e., farmers that were used to practice FS16 are expected to adopt a more labour-intensive system (FS5).

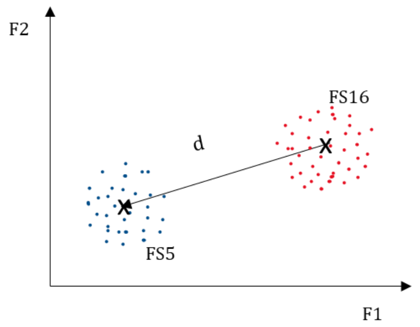


Figure 4.2. Euclidean distance between centroids of two farming systems (e.g., FS16 and FS5), represented as (d). Where, x are the centroids of each FS; and, assume, for instance, that Factor 1 (F1) is animal traction and Factor (F2) is labour productivity.

This indicator has certainly weaknesses. However, considering the limited available data, it represents a good proxy for assessing the level of difficulty or stress that farmers will be subject to, from shifting from one farming system to another because of climate change, such as knowledge gap and investments (e.g. financial, human and others). For example, a farmer that used to produce exclusively rainfed food crops, and then moves to a farming system with bovine and irrigated crops, will need the technical knowledge to manage the new farming system; moreover, acquisition of animals and irrigation infrastructures if not facilitated or supported by the government will require significant financial investment. This can provide policy makers with knowledge to inform better adaptation policies, by identifying the main challenges in FS transitions.

The other indicator is the food security variation, computed as the difference between the percentage of farmers reporting food shortages in the transitioned (final) farming system and the original system. This indicator is interpreted as the variation in the probability of a farmer being food insecure (i.e. incurring a food shortage in a year) due to farming system change (i.e. the transition from one farming system to another) caused by climate change. Food security data was estimated by farming systems by Abbas et al. (n.d. a), as the proportion of farmers in a particular farming system reporting food shortages in a year.

Both indicators were mapped, using QGIS 3.14, at the administrative post level (fourth administrative division) as it is the spatial unit of analysis of the previous study (i.e. Abbas, Ribeiro, and Santos n.d. b) that enabled current predictions and analysis.

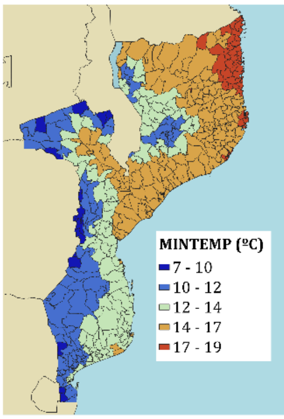
3. RESULTS

3.1. Climate scenarios

Expected changes in climate are presented for the three climate scenarios for the period 2081-2100, compared to the baseline scenario (observed climate) (Table 4.5 and Figure 4.3). Past trends show that observed temperature, both minimum of the coldest month and average, is higher along the coast and lower in high and inland regions. The average minimum temperature tends to increase along the coast from south (10-14ºC) to the North (14-19ºC) – and to be lower in inland regions (10-12ºC) and inland high-altitude (7.5-10ºC) (Table 4.5-a). On the other hand, the average temperature tends to be higher in central and northern regions along the coast and along the Zambezi River (24.5-26.5ºC) and lower in high-inland areas (18.5-23ºC) (Table 4.5-b).

Future projections indicate that it is expected an increase in temperature, both minimum and average, by the end of the century, between 1-2ºC in the optimistic scenario (SSP1-2.6) and 4-5.4ºC in the most severe scenario (SSP5-8.5). This increase will be lower along the coast and higher in inland regions.

Table 4.5. Observed (1970-2000) and expected changes (2081-2100) for three climate scenarios of (a) minimum temperature of the coldest month (ºC), (b) annual mean temperature (ºC), and (c) annual precipitation (mm) – based on the median of 8 GCMs

<table>
<tr><th rowspan="2"></th><th rowspan="2">Baseline Scenario</th><th colspan="3">Expected changes in climate (1)</th></tr>
<tr><th>Optimistic scenario SSP1-2.6</th><th>Intermediate scenario SSP3-7.0</th><th>Most severe scenario SSP5-8.5</th></tr>
<tr><td>a. Minimum temp of coldest</td>
<td>
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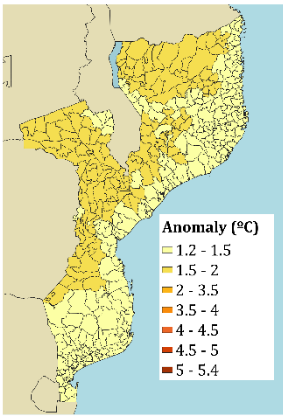
<td>
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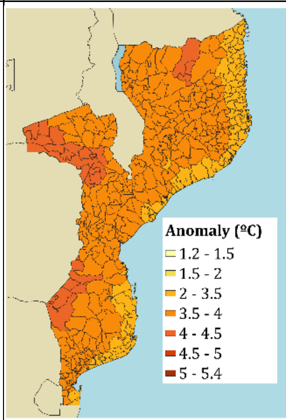
<td>
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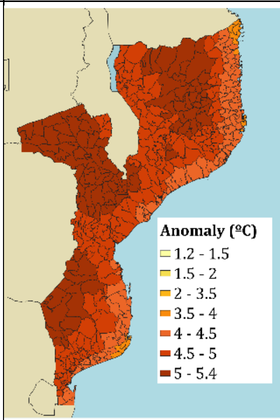
<td>
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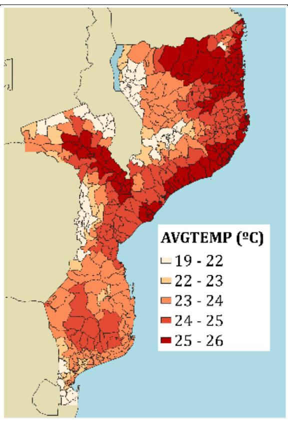
<td>
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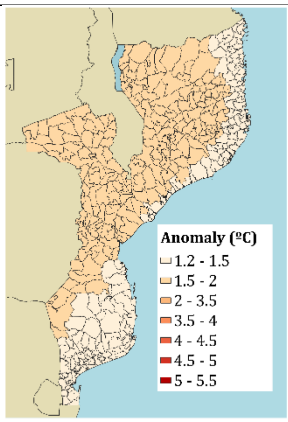
<td>
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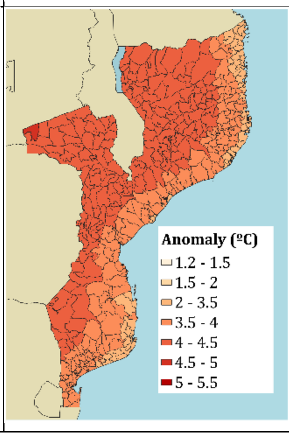
<td>
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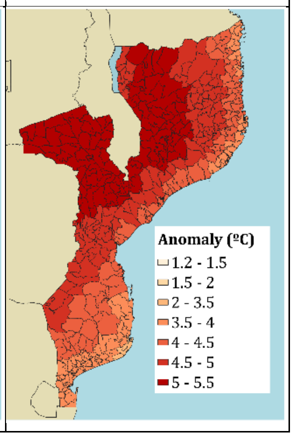
<td>
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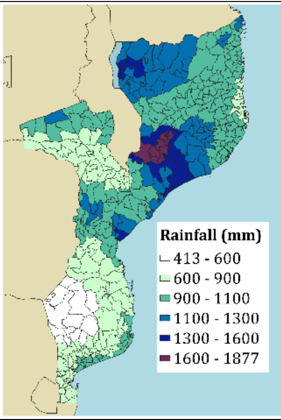
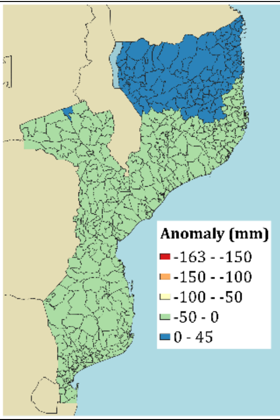
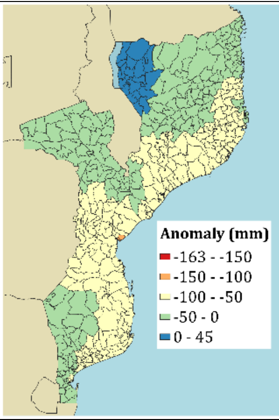
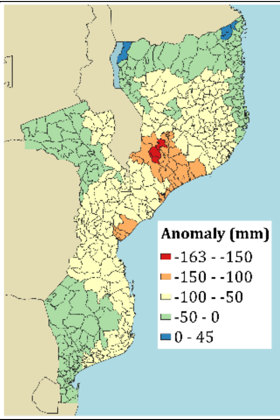
	Baseline Scenario	Expected changes in climate [1]		
		Optimistic scenario SSP1-2.6	Intermediate scenario SSP3-7.0	Most severe scenario SSP5-8.5
c. Annual precipitation (mm)				

[1] Future changes were expressed as anomalies, representing the difference from the baseline scenario compared to the future climate scenario. For example, a positive anomaly in temperature indicates that the expected temperature is warmer than the baseline, while a negative anomaly indicates that the expected temperature is cooler than the baseline.

Regarding rainfall, the observed trend shows that rainfall values are lower in inland southern areas (annual average less than 600mm), followed by the rest of the southern region and along the upper Zambezi valley (between 600 and 900mm), and higher in central and northern regions, with particular emphasis to the high-altitude inland areas (1300 – 1900mm) (Table 4.5-c).

Rainfall projections for the optimistic scenario (SSP1-2.6) show no substantial change at the national level, however it is expected a small increase on average annual rainfall (less than 50mm) in the northern region, while the rest of the country is expected to experience a decrease in the same proportion. However, the situation is expected to be exacerbated in the most severe scenario (SSP5-8.5), with decreases in overall rainfall, on average between 50 and 100mm, along the coast and in central and northern regions. The area that is currently with high levels of rainfall (between 1300 and 1900mm) is the same that will experience stronger reduction in rainfall (up to 165mm). On the other hand, regions with observed low levels of rainfall (less than 600mm) will see no substantial reduction in rainfall in all three scenarios (less than 50mm).

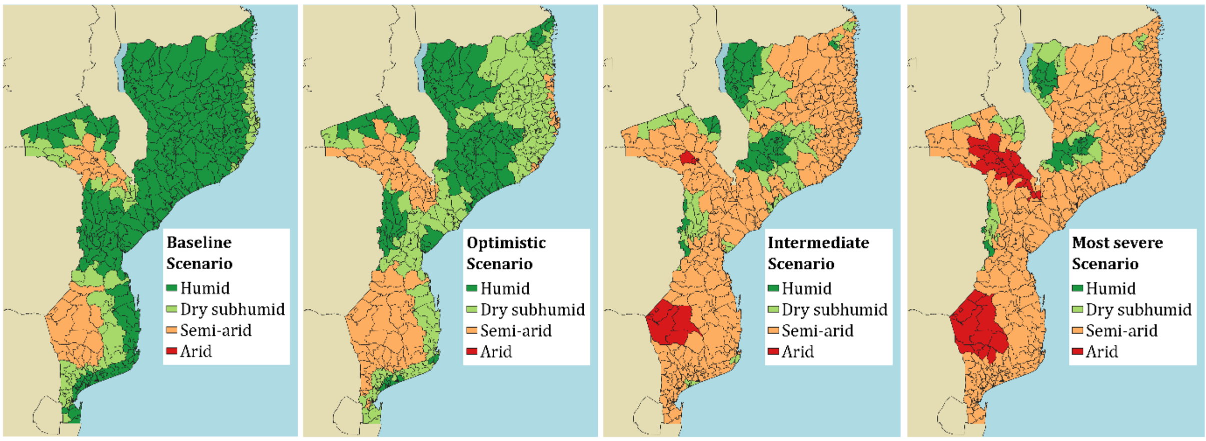


Figure 4.3. Observed (1970-2000) and expected future (2081-2100) climate type based on the aridity index for three scenarios, based on the median of 8 GCMs

Mozambique is currently characterized by a humid climate mostly in central and northern regions, and a semi-arid climate occurring in the south-west and upper Zambezi Valley in the central region (Figure 4.3 – baseline scenario). Considering climate change, by 2100 it is expected an expansion of the semi-arid areas in the south and along the Zambezi Valley and, dry subhumid areas along the coast under the optimistic scenario (SSP1-2.6). In an intermediate scenario (SPP3-7.0), the semi-arid areas will expand and there is a tendency for the appearance of small arid regions. On the other hand, in the most severe scenario (SSP5-8.5) areas that are currently humid/dry subhumid will become semi-arid, covering almost the entire country, and current semi-arid regions will become drier (arid).

3.2. Farming system change under climate scenarios

Our results show that most farmers will transition to other farming systems in response to the forecasted climate change (Table 4.6). Even in the most optimistic scenario (SSP1-2.6) the choice of farming systems is expected to change, even though some farmers will maintain a significant share in the predicted current farming system, e.g. FS5 dedicated mostly to staple food crops (retain 85% of the area), FS7 dedicated to bovine (79%), FS1 – tobacco (68%), FS11 – small livestock (e.g. poultry), FS14 - goats and FS10 – rice and mixed crops (53% each). The most significant changes under this scenario are expected to occur under FS16 (Coconut) which loses 49% of the area to FS5, FS11 (24%) and FS14 (13%); FS13 (Sheep) shifts to FS5 (39%), FS11 (20%) and FS7 (18%); FS2 (Cotton) transition to FS7 (30%) and FS5 (29%); and FS8 (roots) losing area mostly to FS5 (51%). On the other hand, FS3 (Sesame) – 36% of the area persist in the same system and the remaining is distributed by FS5 (27%), FS12 (Swine) and FS11 (12% in each), and FS7 (11%); FS4 (dedicated to food crops) is expected to retain 49% of the area, while 29% transition to FS5.

Table 4.6. Farming system change under climate scenarios (1)

Farming system	OPTIMISTIC SCENARIO (SSP1-2.6)															
	FS1	FS2	FS3	FS4	FS5	FS6	FS7	FS8	FS9	FS10	FS11	FS12	FS13	FS14	FS15	FS16
FS1 - Tobacco & Maize	0.68		0.04	0.00	0.18		0.02		0.00	0.00	0.06			0.02	0.00	0.00
FS2 - Cotton	0.01	0.07	0.10	0.01	0.29		0.30		0.01	0.00	0.08	0.01		0.12		
FS3 - Sesame & Maize	0.01		0.36	0.01	0.27		0.11		0.00	0.00	0.12	0.00		0.12		
FS4 - AnFC (Horticultural Crops, Maize & Sorghum+)			0.01	0.49	0.29		0.08		0.00	0.00	0.05	0.00		0.08		
FS5 - AnBFC (Cassava, Maize & Beans)	0.00		0.01	0.01	0.85		0.04		0.00	0.00	0.04	0.00		0.04		
FS6 - Mixed Livestock & Maize			0.03	0.01	0.13	0.17	0.48			0.00	0.04	0.02		0.12	0.00	
FS7 - Bovine, Maize and Other AnFC	0.00	0.00	0.02	0.01	0.08	0.00	0.79	0.00	0.00	0.00	0.03	0.00		0.07	0.00	
FS8 - Roots (Cassava & Sweet Potato) & Mixed PermC			0.03	0.00	0.51	0.00	0.04	0.09	0.00	0.03	0.20			0.09	0.00	
FS9 - Cashew & Mixed AnBFC			0.02	0.03	0.40		0.11		0.26	0.01	0.09	0.00		0.09		0.00
FS10 - Rice Mixed (PermC and Livestock)			0.01	0.00	0.34		0.03			0.53	0.05			0.04		
FS11 - Small Livestock & Mixed Crops	0.00		0.00	0.03	0.27	0.00	0.07		0.01	0.00	0.53	0.00		0.08	0.00	0.00
FS12 - Swine & Mixed Crops	0.00		0.02	0.01	0.41		0.06		0.00	0.00	0.19	0.15		0.14	0.00	0.00
FS13 - Sheep & Mixed Crops	0.01		0.04	0.00	0.39		0.18		0.00	0.00	0.20		0.07	0.11		0.00
FS14 - Goats & Mixed Crops	0.00		0.01	0.03	0.23		0.10		0.00	0.00	0.10	0.00		0.53		0.00
FS15 - Mixed Livestock, Horticultural & Mixed PermC	0.00		0.02	0.00	0.19		0.32			0.02	0.04	0.00		0.14	0.26	
FS16 - Mixed Livestock, Coconut & Cassava			0.04	0.01	0.49		0.05		0.01	0.00	0.24	0.01		0.13		0.02

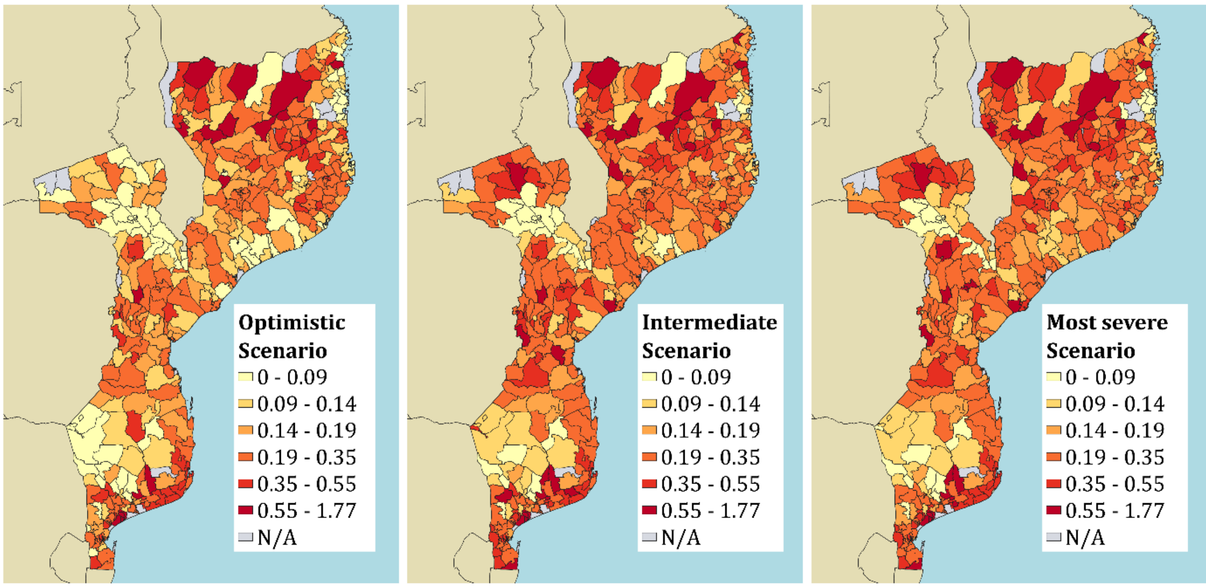
Farming system	INTERMEDIATE SCENARIO (SSP3-7.0)															
	FS1	FS2	FS3	FS4	FS5	FS6	FS7	FS8	FS9	FS10	FS11	FS12	FS13	FS14	FS15	FS16
FS1 - Tobacco & Maize	0.08		0.11	0.01	0.43		0.16		0.01	0.00	0.06			0.14		
FS2 - Cotton		0.03	0.03	0.02	0.30		0.46			0.01	0.06			0.09		
FS3 - Sesame & Maize			0.16	0.02	0.34		0.26		0.00	0.00	0.07			0.15		0.00
FS4 - AnFC (Horticultural Crops, Maize & Sorghum+)			0.00	0.48	0.29		0.12		0.00	0.00	0.03	0.00		0.07		
FS5 - AnBFC (Cassava, Maize & Beans)			0.00	0.04	0.73		0.09	0.00	0.00	0.00	0.07	0.00		0.06		
FS6 - Mixed Livestock & Maize	0.00		0.02	0.06	0.18	0.02	0.55		0.00	0.00	0.05			0.11		
FS7 - Bovine, Maize and Other AnFC	0.01		0.02	0.02	0.11		0.68		0.00		0.06			0.10		
FS8 - Roots (Cassava & Sweet Potato) & Mixed PermC			0.00	0.03	0.57		0.09	0.05	0.00	0.02	0.17			0.07	0.00	
FS9 - Cashew & Mixed AnBFC			0.00	0.08	0.43		0.27		0.06	0.00	0.06			0.09		
FS10 - Rice Mixed (PermC and Livestock)			0.01	0.01	0.47		0.11			0.32	0.06			0.02		
FS11 - Small Livestock & Mixed Crops			0.00	0.06	0.34		0.11		0.00	0.00	0.35	0.00		0.13	0.00	
FS12 - Swine & Mixed Crops			0.01	0.03	0.43		0.16		0.01	0.00	0.16	0.03		0.16	0.00	0.00
FS13 - Sheep & Mixed Crops			0.03	0.01	0.33		0.31		0.01	0.00	0.19		0.04	0.08		
FS14 - Goats & Mixed Crops			0.00	0.05	0.26		0.22		0.00	0.00	0.11	0.00		0.34		
FS15 - Mixed Livestock, Horticultural & Mixed PermC			0.08	0.02	0.25		0.47		0.01	0.02	0.08			0.05	0.02	
FS16 - Mixed Livestock, Coconut & Cassava			0.00	0.03	0.58		0.11			0.00	0.12			0.16		0.01

Farming system	MOST SEVERE SCENARIO (SSP5-8.5)															
	FS1	FS2	FS3	FS4	FS5	FS6	FS7	FS8	FS9	FS10	FS11	FS12	FS13	FS14	FS15	FS16
FS1 - Tobacco & Maize	0.00		0.01	0.02	0.21		0.66		0.00	0.00	0.02			0.07		
FS2 - Cotton		0.00	0.03	0.01	0.25		0.55			0.01	0.05			0.10		
FS3 - Sesame & Maize			0.15	0.02	0.29		0.33			0.00	0.07			0.14		
FS4 - AnFC (Horticultural Crops, Maize & Sorghum+)			0.02	0.45	0.27		0.16		0.00	0.00	0.02	0.00		0.07		
FS5 - AnBFC (Cassava, Maize & Beans)			0.00	0.04	0.72		0.11	0.00	0.01	0.00	0.06	0.00		0.06		
FS6 - Mixed Livestock & Maize			0.02	0.06	0.20	0.02	0.57		0.01	0.00	0.03			0.09		
FS7 - Bovine, Maize and Other AnFC			0.00	0.02	0.09		0.75				0.05			0.09		
FS8 - Roots (Cassava & Sweet Potato) & Mixed PermC			0.00	0.04	0.53		0.14	0.04		0.02	0.13			0.10		
FS9 - Cashew & Mixed AnBFC			0.00	0.07	0.41		0.33		0.04	0.00	0.04			0.11		
FS10 - Rice Mixed (PermC and Livestock)			0.01	0.01	0.47		0.11			0.32	0.05			0.03		
FS11 - Small Livestock & Mixed Crops			0.00	0.06	0.35		0.13		0.00	0.00	0.32	0.00		0.14	0.00	
FS12 - Swine & Mixed Crops			0.01	0.03	0.42		0.19		0.00	0.00	0.14	0.03		0.17	0.00	
FS13 - Sheep & Mixed Crops			0.03	0.00	0.32		0.38		0.01	0.00	0.14		0.04	0.07		
FS14 - Goats & Mixed Crops			0.01	0.06	0.27		0.26			0.00	0.09	0.00		0.32		
FS15 - Mixed Livestock, Horticultural & Mixed PermC			0.07	0.02	0.24		0.49		0.00	0.02	0.07			0.06	0.02	
FS16 - Mixed Livestock, Coconut & Cassava			0.00	0.02	0.59		0.13			0.00	0.11			0.13		0.01

(1) The values presented in the table above refer to the percentage of the area under a particular farming system that transitioned to other farming system(s) as well as the percentage that persisted in the same system (persistence expressed in the matrix diagonal). Blank spaces means that there was no transition from the particular farming system to another, i.e. the percentage of the area of a farming system transitioning to another system is zero.

Under the two most critical scenarios – intermediate (SSP3-7.0) and most severe (SSP5-8.5) – most farming systems are expected to disappear, transitioning to other systems, with particular emphasis to the staple food crops system (FS5) and the bovine system (FS7) which absorb most of the systems existing in the predicted current scenario. Under the most severe scenario (SSP5-8.5), FS3 (sesame) is the only cash crop system expected to retain some farm area (15%). Although FS4 (food crops) loses a significant proportion of its area to FS5 and FS7, it is expected to continue to be adopted by some farmers, retaining about 45% of the predicted current area. FS11 (small livestock) and FS14 (goats) also retain a significant proportion of their area, and tend to expand by integrating some farmers from other systems (e.g. FS3, FS8, FS12, FS16 and others).

As farmers adapt to changes in climate by switching from one system to another, it is important to analyse the stress for change, i.e. the stress or difficulties that farmers are expected to incur for moving from one farming system to another, to reduce the effects of climate change on their livelihoods. The higher the stress, the more different the original farming system (baseline scenario) is from the other system expected to occur under climate change (Figure3).



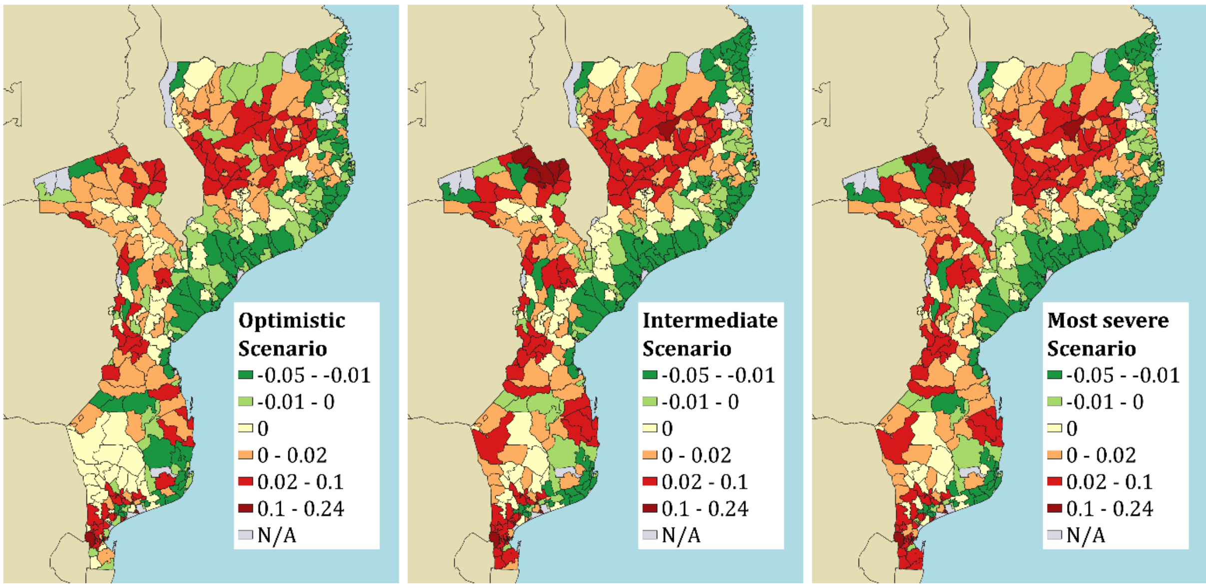
Note: The stress indicator was computed based on the Euclidean distances between farming systems.

Figure 4.4. Stress for farming system change

The results show that in all three scenarios the coastal areas – with emphasis to the south – and the inland northern region, will suffer the highest stress for change i.e., the distance/difference between the current farming system and the predicted farming system under a climate change scenario is significant, therefore farmers in these regions will have more struggle adapting to climate change. Moreover, as the climate conditions become more severe (e.g., SSP5-8.5), the stress for changing from one farming system to another increases, covering larger areas of the country.

The inland southern region and the upper Zambezi Valley has showed the lowest stress for change, meaning that farms in these areas are likely to easily adapt to climate change even in the most severe scenario (SSP5-8.5 i.e., extremely high temperature and lower rainfall levels). As temperature rises and overall rainfall decreases the central region become more stressful to farming system change.

The expected change in farming system choice caused by changes in climate (i.e., increased temperatures and decreased rainfall), will impact food security in the country. The food security variation indicator (Figure 4.5) shows the variation in the probability of a farmer becoming food insecure (i.e. experience food shortages) due to shifting farming systems.



Note: Negative values (green areas) mean that the probability of farmers becoming more food insecure decreases (in percentage) as a result of farming system change derived from a changing climate; and positive values (red areas) mean that the probability of farmers becoming food insecure increases.

Figure 4.5. Food security variation (in percentage)

The results indicate that the coastal areas are more likely to benefit, in terms of food security, in a context of climate change, as the probability of farmers suffering food shortages decreases by 1 to 5%. Nevertheless, most areas of the country are expected to become more food insecure, as the probability of having food shortages increases up to 10% in the optimistic scenario (SSP1-2.6), reaching almost 25% in the other two scenarios.

The inland regions are expected to record higher levels of food insecurity, as most farmers in these regions become more likely to suffer from food shortages, due to farming system change caused by climate change. Food insecurity levels are expected to rise considerably (up to 25%) in all regions, with emphasis to the Maputo province (the capital) in the South, Manica and Tete provinces in the Central region, and Niassa in the North.

4. DISCUSSION

4.1. Predicting farming system change under climate scenarios using a space for time modelling strategy

The space for time modelling strategy adopted in this study allows to directly predict farming systems transitions under different climate scenarios – using machine learning techniques i.e., random forests – instead of just focusing e.g., on plant physiology and phenology, nutrient cycles and emerging pests (e.g. Buyantuyev et al. 2012; Frauendorf et al. 2020). As many studies referred, the effects of climate change will be manifested through changes in soil characteristics, water availability, crop productivity, farm management systems, pest and disease life cycles, and water resources (Lötter 2017). Although most of these impacts are not directly accounted in our approach, these will be translated into changes in farming practices, leading to changes in farming system choice which will directly affect farmers' livelihoods and food security status – which is the focus of our approach. The approach and method of analysis adopted enable to analyse the farming systems dynamics and its competition for land as climate changes.

Moreover, this approach includes annual (food and cash crops) and permanent crops, and livestock – which are important elements for food security – unlike most studies analysing single crops or cropping/livestock systems (Brito and Holman 2012; P. Thornton et al. 2010; P K Thornton et al. 2009). Nevertheless, based on our framework it is also possible to analyse the effects of climate change on a specific crop by analysing the farming system.

Additionally, the farming system approach adopted, based on Abbas et al. (n.d. a), expresses the actual productive decisions made by farmers. Many studies agree that including the farmer into the process of policymaking is key for better policy outcomes (Simmonds 1985; Woodward et al. 2008). Woodward et al. (2008) considers that whole farm simulation models that use decision rules to specify alternative farm management strategies are the best available form of virtual world models of farming systems.

Farming system change was assessed for the 2081-2100 period. However, it is important to note that farming practices may change, evolve, and develop over shorter periods of time due to changes in the socioeconomic context, for instance (such as, technological progress, market development, among others); Moreover, policy makers may respond and be more willing to adopt measures for shorter period predictions, therefore, a mid-term period projection may be of importance for future research. In this case, a longer period was selected, as the main objective was to isolate the effect of climate on farming system change, while keeping all other drivers constant. This is also a limitation of the framework presented, considering that the socioeconomic and the other biophysical drivers included in the model will also change overtime. Nevertheless, this assumption was made to simplify the model and analyse only the effects of climate on farming system choice, to understand how farming systems may change due only to climate change. Despite this shortcoming, this model still allows to integrate and analyse the impact of all factors (socioeconomic and biophysical), which can be done in future research.

Another disadvantage of the model is that is does not allow to analyse or control other crops/livestock and or new farming systems that might appear in the future. Instead, the model is built based on existing conditions e.g., crops and livestock. An advantage is that the model allows to discuss what may appear in the future based on what already exists, assuming that it is possible for crops and livestock that already exist to also exist in the future, i.e. farming systems that already exist in some parts of the country may occur in other regions, all factors permitting.

4.2. Climate change and its impacts on farming system choice

Our results showed that both temperature and rainfall patterns are expected to change considerably by the end of the century, with the study area becoming hotter and drier – which is consistent with other studies in Africa (Lewis, Monem, and Impiglia 2018 - Near East and North Africa; e.g. Lötter 2017 - Southern Africa).

The findings have showed that projected changes in climate (i.e. temperature, rainfall, and aridity) will have a significative impact on farming systems choice in the study area – consistent with previous results from (Abbas, Ribeiro, and Santos n.d. b) that found that climate, especially rainfall and minimum temperature in the coldest month are the most important drivers affecting farming system choice . Even in a more optimistic climate scenario – i.e., with increases in temperature limited at 2ºC and no substantial changes in rainfall – most farming systems will tend to disappear. Smallholder farming systems across Sub-Saharan Africa have been recognised as highly vulnerable to climate change, with land use patterns and crop choices shifting as a result of climate change (Mbow et al. 2019). Rainfed farming systems and systems where crops are grown near to their maximum temperature tolerance, are particularly exposed to the impacts of climate change and the challenge of reducing the negative effects could be overwhelming, impacting the livelihoods of subsistence farmers (Lewis, Monem, and Impiglia 2018; Marques et al. 2009; Mbow et al. 2019)

Based on our results, we found that the cash crops systems – tobacco (FS1), cotton (FS2) and sesame (FS3) – are expected to be highly impacted by climate change, with emphasis to FS2 and FS1, which are expected to completely disappear under the most severe climate scenario. Cash crops systems are currently located in areas that are expected to experience high levels of stress for change due to climate change (see Figure 4.4 and Figure C1). Although climate influences the choice of these farming systems, market integration is an important driver to consider (Abbas, Ribeiro, and Santos n.d. b). Farmers in these systems are currently integrated in a value chain that facilitates their integration in the market – e.g., through the provision of inputs and access to output markets (Lukanu et al. 2004; Maggio and Sitko 2018). However, in the face of climate change farmers in these systems are expected to intensify the existing maize production and diversify into other food crops (e.g. FS5) and livestock (e.g. bovine – FS7), moving away from cash crops. This will imply a shift in the knowledge and resources used, as these farmers will move to more labour intensive and rudimentary systems (i.e., with low use of yield-raising inputs or at least in which the mechanisms through which they had access to inputs is no longer available). Moreover, acquisition of bovine will imply a whole new knowledge and investment dynamic to farmers. On the other hand, sesame is considered to be more tolerant to water stress, diseases and pests, and so it is likely that farmers may continue growing it, if a developed value chain exists (Lukanu et al. 2004).

In the inland southern and upper Zambezi valley regions, the existing aridity is expected to intensify by the end of the century. These areas show the lowest stress for change, suggesting that there are fewer options for transitions to other systems or that the transitions will occur to particularly similar systems. The results confirm that the predominant system in these regions (i.e. FS7 – specialized in bovine, and food crops) will persist, intensifying in the already existing areas and will tend to expand to other regions, i.e. central and northern regions, integrating farmers from other systems as the country becomes more arid. However, it is important to note that the concentration of bovine has always been higher in the south of the country, in part due to the prevalence of the tsetse fly (trypanosomiasis disease) in the central and northern regions – which are currently humid areas (Cunguara et al. 2013). Therefore, if this disease persists under climate change – which may not be the case as the regions will become drier – this system, as it is, may not expand to these areas. The impacts of climate change differ among livestock systems and regions; some consider that specialized livestock and mixed systems tolerate better increases in temperature compared to food crop systems (Etwire 2020), while others found that globally, livestock systems are expected to be adversely affected by rising temperatures (Mbow et al. 2019).

The horticultural system (FS15) which is mostly irrigated, is negatively impacted by rising temperatures (Abbas, Ribeiro, and Santos n.d. b). This system is mostly predominant in the southern region (Maputo province), which will experience no substantial changes in precipitation, but temperature is expected to increase (up to 1.5ºC in the optimistic scenario and 4 to 5ºC in the most severe), which justifies that farmers in this system will transition to other systems (e.g. FS14 – goats, FS5 and FS7 – all include food crops, e.g. cassava, maize, sorghum and in less proportion horticultural crops). Systems integrating heat and drought tolerant crops (e.g. sorghum) are expected to persist as the country becomes drier.

The coastal areas are expected to become drier, although it is the area that will see the lowest increase in temperature (compared with inland areas), it will negatively affect the coconut mixed system (FS16) which is sensitive to increases in temperature (Abbas, Ribeiro, and Santos n.d. b). Climate change negatively impacts tree-crops such as coconut and cashew, which are usually produced in areas with higher rainfall and humidity (e.g. coastal areas) (Etwire 2020). These areas concentrate most of the population (see Figure C2 in Appendix C) and have shown higher stress for farming system change, which might be due to the fact that farmers in this system will have to stop growing coconut and cashew crops and focus on other food crops (e.g. sorghum) for their subsistence.

Our results show that specialized livestock farming systems (e.g. FS7 - bovine, FS11 – small livestock and FS14 - goats) are expected to be less affected by climate change and will expand, as other farmers from other farming systems will integrate them. In many of the semiarid systems in sub-Saharan Africa, livestock production enables farmers to diversify incomes, helping to reduce income variability, and providing an alternative for cropping where crop production becomes marginal (Jones and Thornton 2009; Mbow et al. 2019). These systems (FS7, FS11 and FS14), although deriving most of their product from livestock (i.e. bovine, small livestock and goats, respectively), also grow food crops (e.g. maize, cassava, sorghum and millet, and legumes). Unlike some studies (e.g. Etwire 2020), we found that FS5, which is mostly specialized in food crops will also persist and expand under climate change. Overall, these systems are the most resilient to climate change as they already grow some drought-tolerant crops (e.g. sorghum and cassava) which is a positive adaptation strategy to climate change, and also because they include livestock, such as small livestock which other studies have considered to be less exposed to the impacts of climate change compared to other animals (e.g. Lewis, Monem, and Impiglia 2018). Moreover, Marques et al. (2009) found that land suitability in Mozambique for cassava, maize, sorghum, and groundnuts is likely to remain unchanged, by mid-century. For cassava and sorghum, a decrease is expected in land suitability in the northern region (Marques et al. 2009). Nevertheless, it is expected that even slight warming will decrease yields of some of the most important staple crops in tropical regions (e.g. maize, wheat and rice), while cassava is expected to benefit from climate change (Porter et al. 2014).

In general, the higher stress for change will occur in the Northern and Central regions, and along the coast in the Southern region. In the North the emphasis lays on farming systems transitioning mostly from FS11 and FS14 to FS5, meaning that these systems which derives most of their product from livestock production, i.e. small livestock and goats, respectively, will dedicate more to food production (e.g. maize and cassava), implying a reorganization in terms of livelihoods. In the central region, the stress for change will also intensify as climate changes, with emphasis to FS14 that will transition to other different systems (e.g. FS7), therefore will continue to obtain most of their product from livestock, however bovine rather than goats – this implies a huge investment both in terms of capital and knowledge. In the southern region the focus should be on FS16 which will transition from a diversified livestock (i.e. bovine, goats, swine and small livestock) and coconut production to either bovine or staple food and small livestock production, i.e. FS7 and FS5, respectively.

The stress for farming system change is expected to be higher in areas that are currently humid, and that will be considerably affected by climate change, as these become more arid. On the other hand, the already semi-arid areas (that will become arid as climate changes) will not show high levels of stress from changing from one system to another. This is also true, because the bovine system (FS7) predominates in these (arid) areas, which under the forecasted climate changes will not disappear, but rather expand – meaning that farmers in these systems will continue to choose the system not forcing significant changes at the farm-level.

4.3. Implications of climate-induced farming system change on food security

The implications of climate change for food security is significant, as the most food secure systems e.g., FS1 – tobacco, FS15 – irrigated horticultural crops, FS2 – cotton and, FS6 – mixed crop-livestock (Abbas, Ribeiro, and Santos n.d. a), are expected to completely disappear by the end of the century. These systems are the most market oriented, with high use of yield-raising inputs and the most food secure (Abbas, Ribeiro, and Santos n.d. a), indicating that under climate change farmers in these systems are likely to become prone to food insecurity, as they are moving to more labour-intensive systems with low use of yield-raising inputs.

On the other hand, it is expected an expansion of systems dedicated to crop-livestock production, some being more crop oriented (e.g. FS5) than others (i.e. FS7, FS11 and FS14). Mixed crop-livestock systems are considered to provide resilience as incomes are diversified and also because livestock can be sold as assets (Lewis, Monem, and Impiglia 2018). These farming systems grow food crops, largely for their own consumption since they are mostly not integrated in the market (Abbas, Ribeiro, and Santos n.d. a). These farming systems also concentrate most of the population (representing 67% of the sampled households), concentrating also most of the rural poverty, i.e. low-income households with small farms, and extremely low use of yield-raising and labour-saving inputs and highly dependent on agricultural incomes (Abbas, Ribeiro, and Santos n.d. a). Although these systems may be considered diverse, due to some crop diversity (e.g. maize, cassava, sorghum, legumes and horticultural crops in lower proportions) and the existence of livestock (mostly poultry; besides FS7 which has bovine), these systems are still considered relatively poor. Nevertheless, the existence of bovine (FS7) and goats (FS14), can contribute positively for the adoption of yield-raising and labour-saving inputs, e.g. animal traction and organic fertilizers, which may result in an increase in crop yields. Moreover, sorghum and cassava are generally considered drought-resistant crops, which makes it ideal for food security in a changing climate, given their role as subsistence crops for already poor small-scale farmers (Lewis, Monem, and Impiglia 2018).

The results indicate that the coastal areas are more likely to benefit in terms of food security in the context of climate change. The predominant systems in the coastal areas are the tree-based systems (e.g. coconut – FS16 and cashew – FS9). Although these crops have cultural and even some economic value, they do not add much to improve food security among smallholders (e.g. Mozambique) as it has lost its economic importance over the years – which is not the case in countries such as Ghana (Etwire 2020). This means that, by substituting these permanent crops for food crops that can be consumed and sold by the household (e.g. FS5) or that have better integration in the market (e.g. FS7) would likely benefit the farmers. Nevertheless, permanent crops are less risk to grow in coastal areas compared to food crops, due to the vulnerability of the area to a number of climate-related hazards. Therefore, even though it is expected an improvement in food security due to farming system change, the expected new system may also be negatively impacted over time, as these areas might become unsuitable for crop and livestock production due to the factors referred previously.

On the other hand, the inland regions from south to north, are expected to experience an increase in food insecurity among farmers. This is motivated by the fact that farmers are transitioning from farming systems that are currently food secure (e.g. FS1, FS15 and FS6 – which produce, among other crops, cash crops and horticultural crops, being integrated in the market and using yield-raising and labour-saving inputs) to relatively food insecure systems (e.g. FS7, FS5, FS11, FS14 and FS4 – which are labour intensive, not integrated in the market with low use of inputs). Access to input and output markets, i.e. market integration and the use of yield-raising and labour-saving inputs, seems to play an important role in improving food security (Abbas, Ribeiro, and Santos n.d. a), as also confirmed by other studies (e.g. Dixon, Gulliver, and Gibbon 2001; Massawe 2017). Therefore, it is important for governments to consider adopting a market integration policy for food crop systems (which are expected to expand under climate change), so that the farming systems that will replace these already market-oriented systems (cash crops and horticultural) in the future, do not reduce the integration of the farmer in the market, and therefore farmers' income, which has proved to be a very important factor to guarantee food security among small producers, especially under climate change.

4.4. A framework to inform adaptation policy options for food security

Small farmers in developing countries are already facing several challenges related to the sustainability of their livelihoods which, depending on the location and other factors, may be significantly amplified by climate change. Climate change will act as a risk-multiplier to already poor and food insecure farmers (Lewis, Monem, and Impiglia 2018). Therefore, there is a significant role for public policies in reducing the negative impacts of climate change on small farmers' livelihoods and improving their food security levels. Small farmers are the centrepiece of farming systems and food production in developing countries, therefore action must focus on supporting them by creating the necessary mechanisms to make them more resilient to climate change and ensure that food security needs are met (Lewis, Monem, and Impiglia 2018). On this note, the proposed framework is a useful tool essential to ensure better policy formulation and resource allocation, producing better outcomes.

The proposed framework has enabled the identification of priority areas that will most likely need government intervention so that the livelihoods and food security goals of the farmers are met and secured under climate change. With this knowledge, governments will be able to determine where their actions will be better suited and, help enforce the capacities of small-scale farmers to ensure their productivity and food security levels in a changing climate.

Given that resources – either financial, human, or physical – are scarce, governments, especially in developing countries, need to identify priority areas for action. This framework is a cost-effective way for governments in developing countries, to carry out policy evaluations with low resources, while acknowledging the existing diversity of farming systems and including the key actors, i.e., farmers, that will benefit with the policy implementation.

5. CONCLUSION

Climate change, manifested through increases in temperature, decrease in rainfall, resulting in an increase in aridity, will have a significant effect on the agricultural sector, through changes in farming practices among farmers. The results have indicated major changes in farming system choice and its spatial distribution in the context of climate change, which will impact considerably on the livelihood and food security status of small-scale farmers. While some regions may see some gains in terms of food security, others may experience the opposite. Moreover, the stress for changing from one farming system to another due to the impacts of climate change, will be significant in most parts of the country, especially in the current humid areas that are expected to become drier by 2100 due to increases in temperature and decreases in overall rainfall. The increased stress for change will be manifested in two ways – e.g., through knowledge and investment gap – as changes in farming practices may require different knowledge on farming management and increasing investment.

Overall, the proposed framework, based on a farming system approach, allows to understand the rationality behind farmer’s decisions, i.e. how farmers would respond in the context of climate change, which provides the basis for understanding how government policies can help reduce the negative effects of climate change on smallholder farmers. The output of this analysis, i.e. the proposed framework, is relevant in supporting policy design for food security under climate change, as it enabled the identification of priority areas that will most likely need government support so that poor food insecure farmers in developing countries can guarantee their livelihoods and meet their food security goals. Given the lack of resources in poor developing countries, efficient allocation of resources in priority areas that will translate into positive outcomes for rural small-scale vulnerable farmers is of utmost importance.

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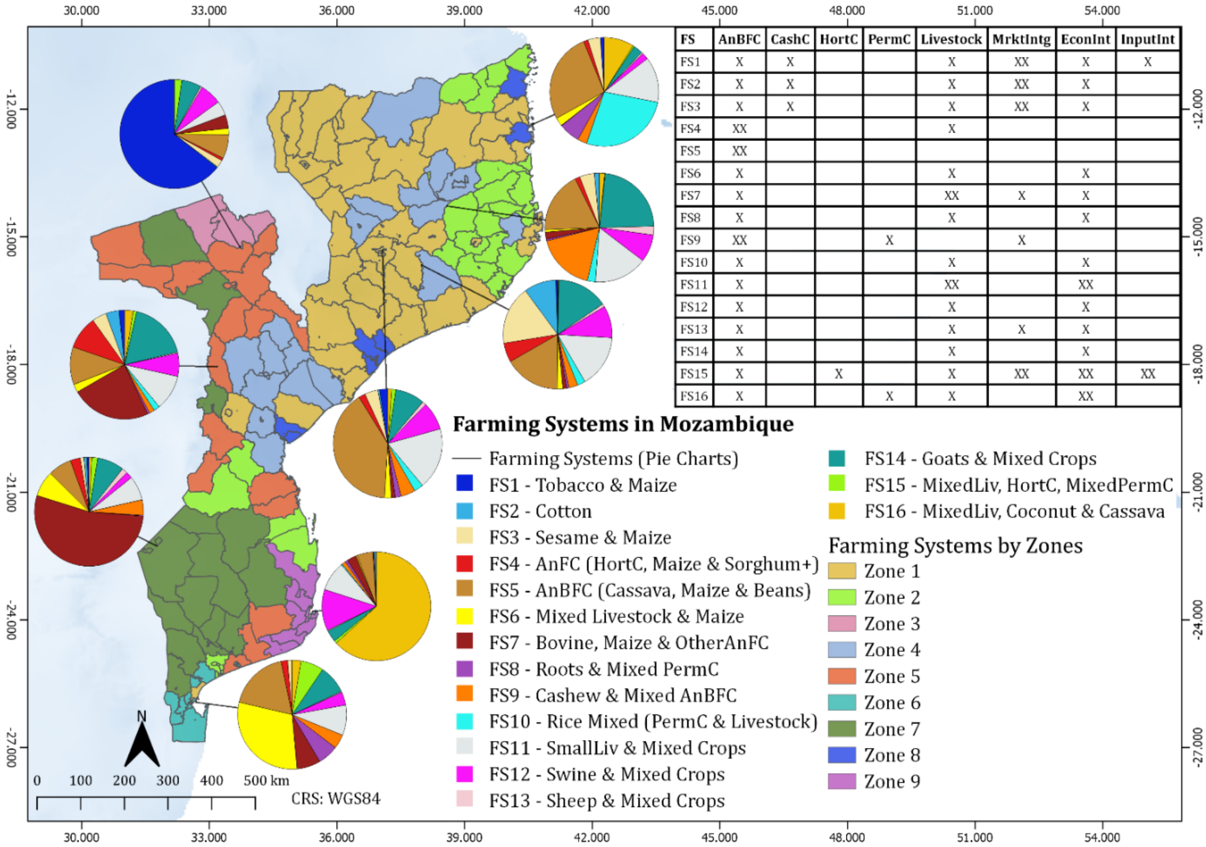
APPENDIX C



FS	AnBFC	CashC	HortC	PermC	Livestock	MrktIntg	EconInt	InputInt
FS1	X	X			X	XX	X	X
FS2	X	X			X	XX	X	
FS3	X	X			X	XX	X	
FS4	XX				X			
FS5	XX							
FS6	X				X		X	
FS7	X				XX	X	X	
FS8	X				X		X	
FS9	XX			X		X		
FS10	X				X		X	
FS11	X				XX		XX	
FS12	X				X		X	
FS13	X				X	X	X	
FS14	X				X		X	
FS15	X		X		X	XX	XX	XX
FS16	X			X	X		XX	

Note: The summary table reflects the main activities practiced in each farming system, as well as the level of market integration (MrktIntg or MARKET) – proportion of output sold, economic intensity (EconInt) – output per hectare of arable area and intensity in the use of yield-raising inputs (InputInt); X represents mildly weight and XX – high weight of the variable in the farming system, the absence of X means that the weight of the variable is very low or absent.
Source: Abbas et al. (n.d. a).

Figure C1. Spatial distribution of farming systems in Mozambique and summary table of farming systems

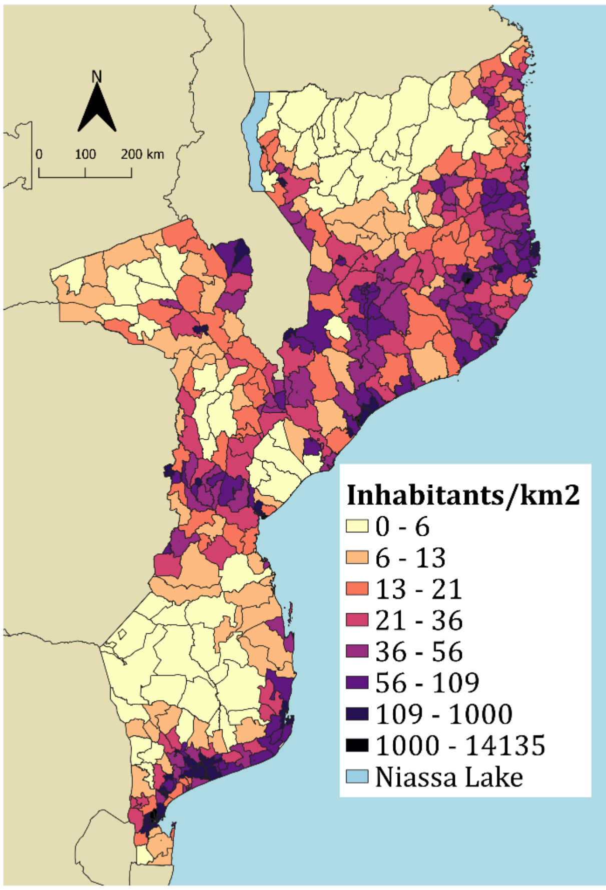
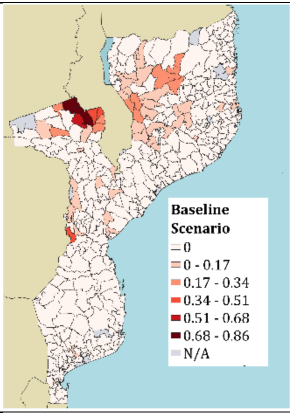
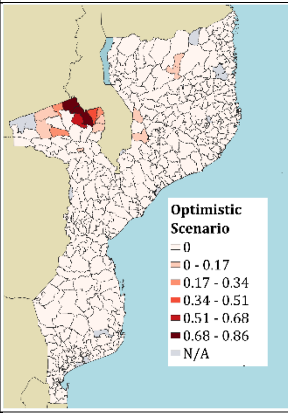
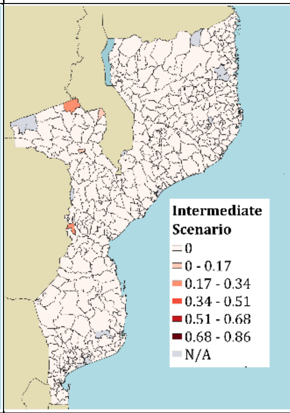
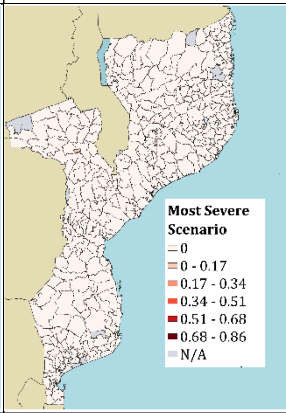
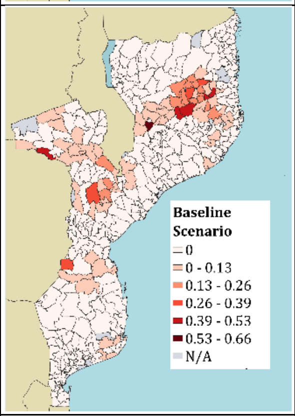
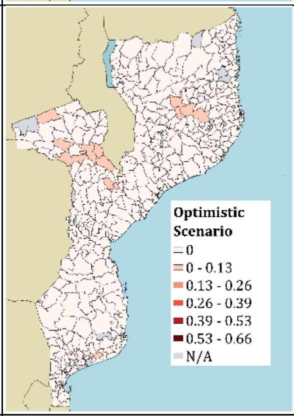
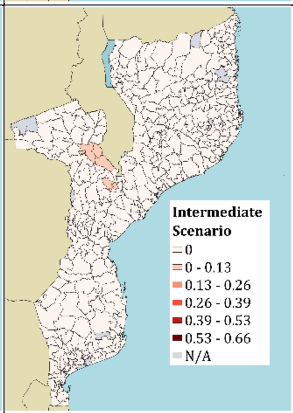
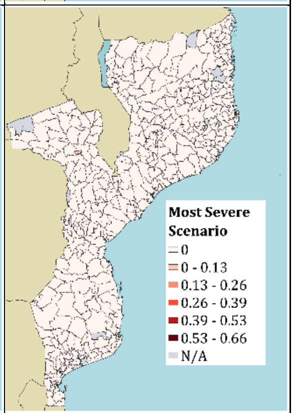
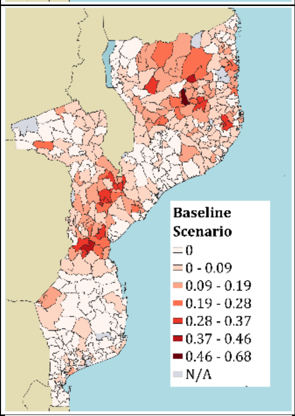
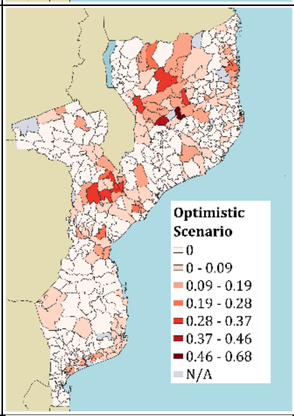
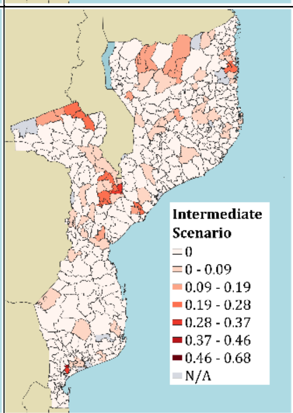
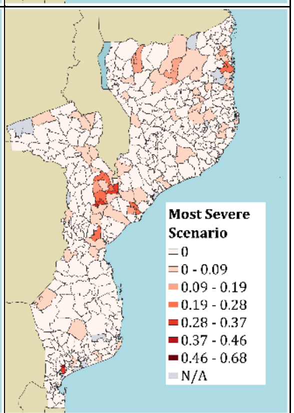
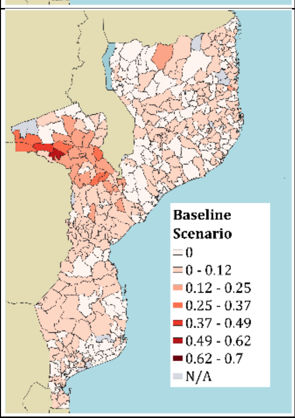
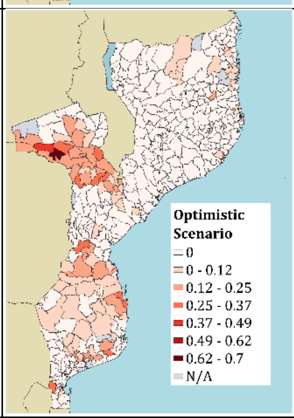
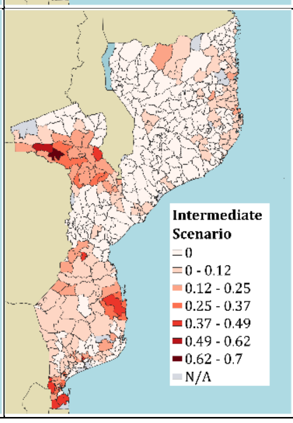
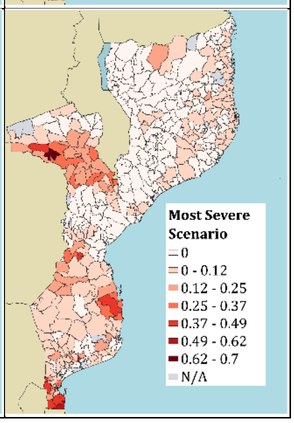
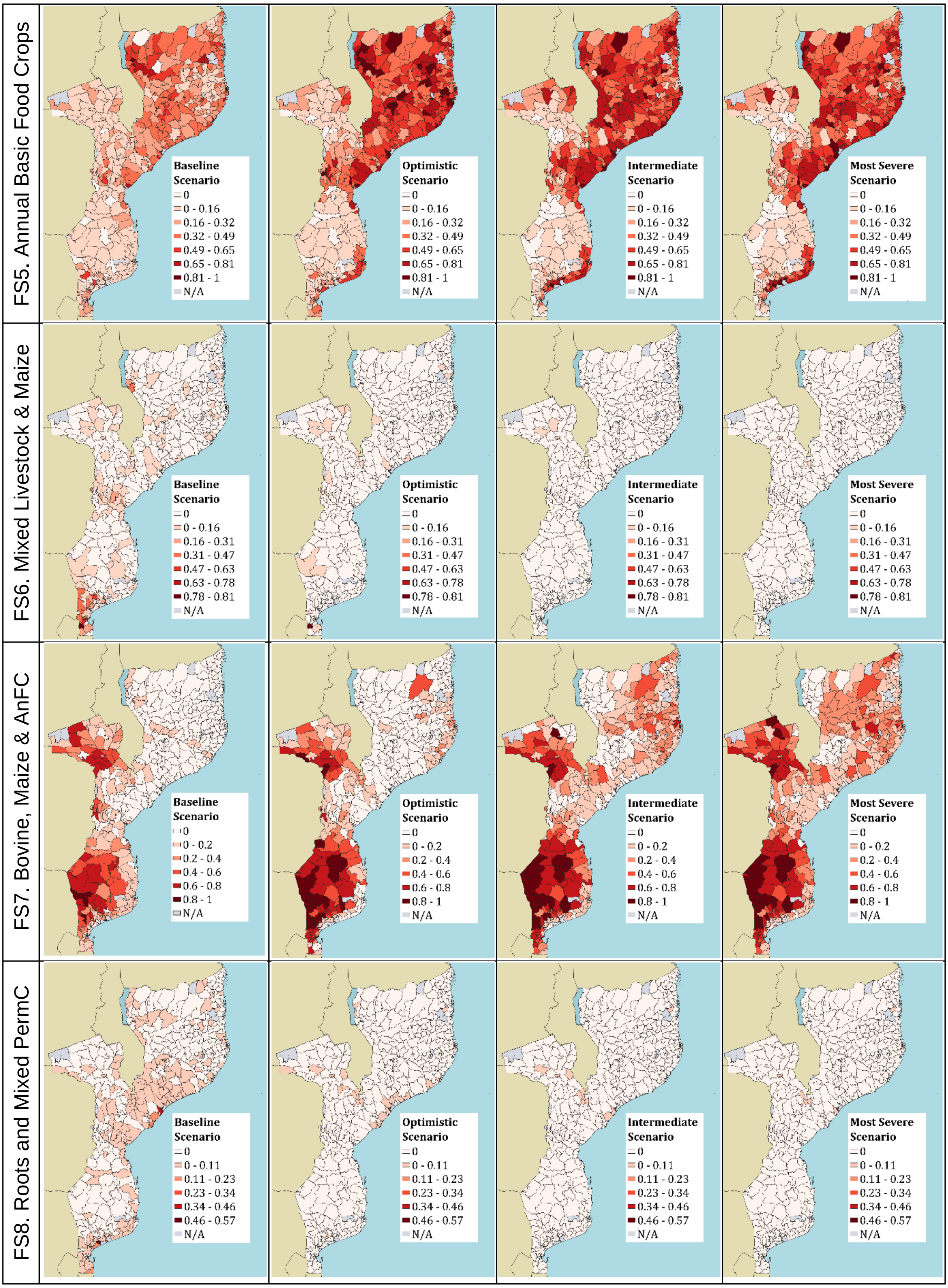
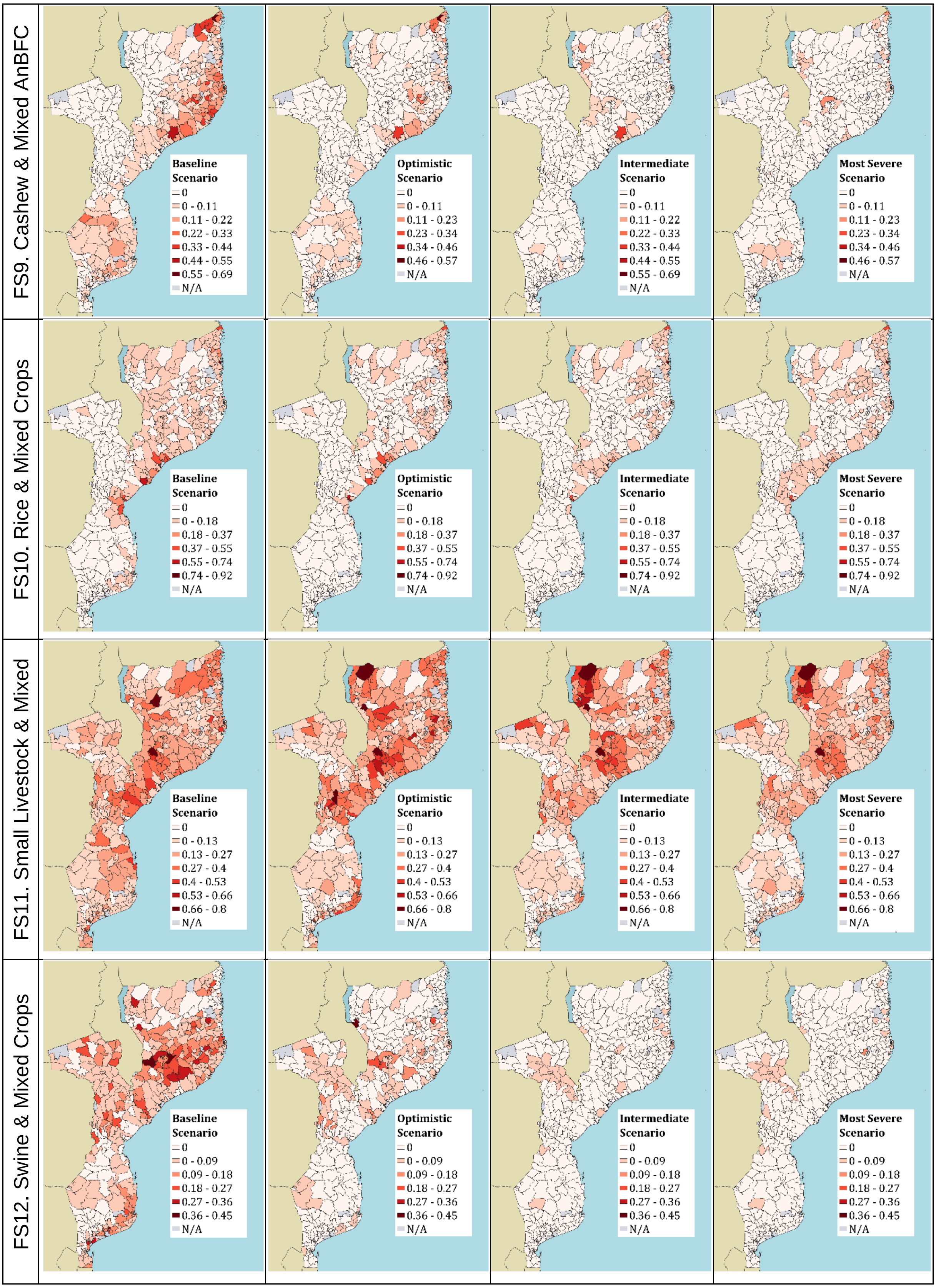


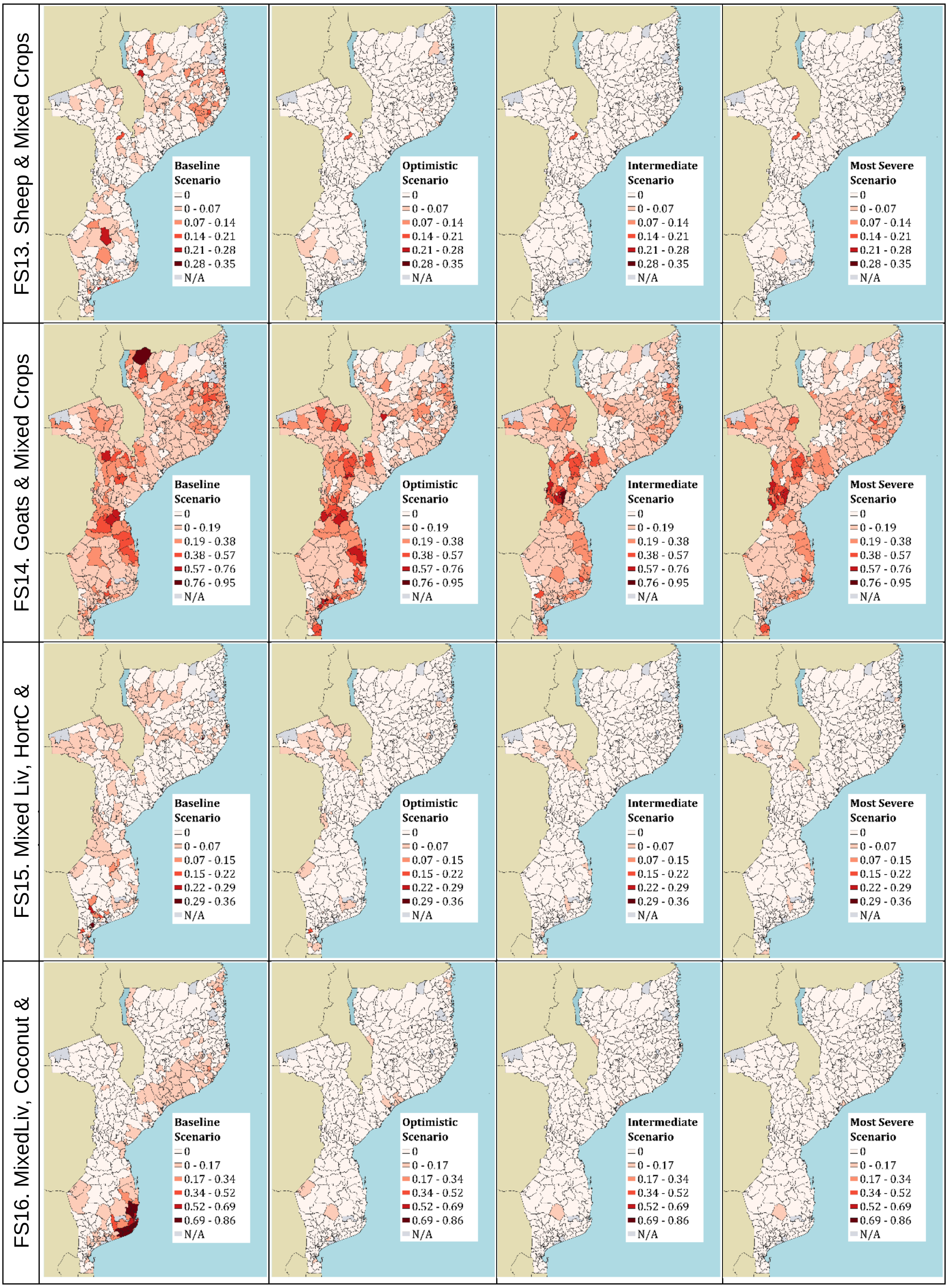
Figure C2. Population density (inhabitants/km²)

Table C1. Current and expected spatial distribution of farming systems under climate change

	Observed or current scenario	Expected changes in future		
		Optimistic Scenario SSP1-2.6	Intermediate Scenario SSP3-7.0	Most Severe Scenario SSP5-8.5
FS1. Tobacco and Maize				
FS2. Cotton				
FS3. Sesame & Maize				
FS4. Annual Food Crops				


FS5. Annual Basic Food Crops
Baseline Scenario
Optimistic Scenario
Intermediate Scenario
Most Severe Scenario
0
0 - 0.16
0.16 - 0.32
0.32 - 0.49
0.49 - 0.65
0.65 - 0.81
0.81 - 1
N/A
FS6. Mixed Livestock & Maize
Baseline Scenario
Optimistic Scenario
Intermediate Scenario
Most Severe Scenario
0
0 - 0.16
0.16 - 0.31
0.31 - 0.47
0.47 - 0.63
0.63 - 0.78
0.78 - 0.81
N/A
FS7. Bovine, Maize & AnFC
Baseline Scenario
Optimistic Scenario
Intermediate Scenario
Most Severe Scenario
0
0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1
N/A
FS8. Roots and Mixed PermC
Baseline Scenario
Optimistic Scenario
Intermediate Scenario
Most Severe Scenario
0
0 - 0.11
0.11 - 0.23
0.23 - 0.34
0.34 - 0.46
0.46 - 0.57
N/A


FS9. Cashew & Mixed AnBFC
Baseline Scenario
0
0 - 0.11
0.11 - 0.22
0.22 - 0.33
0.33 - 0.44
0.44 - 0.55
0.55 - 0.69
N/A
Optimistic Scenario
0
0 - 0.11
0.11 - 0.23
0.23 - 0.34
0.34 - 0.46
0.46 - 0.57
N/A
Intermediate Scenario
0
0 - 0.11
0.11 - 0.22
0.22 - 0.33
0.33 - 0.44
0.44 - 0.55
0.55 - 0.69
N/A
Most Severe Scenario
0
0 - 0.11
0.11 - 0.23
0.23 - 0.34
0.34 - 0.46
0.46 - 0.57
N/A
FS10. Rice & Mixed Crops
Baseline Scenario
0
0 - 0.18
0.18 - 0.37
0.37 - 0.55
0.55 - 0.74
0.74 - 0.92
N/A
Optimistic Scenario
0
0 - 0.18
0.18 - 0.37
0.37 - 0.55
0.55 - 0.74
0.74 - 0.92
N/A
Intermediate Scenario
0
0 - 0.18
0.18 - 0.37
0.37 - 0.55
0.55 - 0.74
0.74 - 0.92
N/A
Most Severe Scenario
0
0 - 0.18
0.18 - 0.37
0.37 - 0.55
0.55 - 0.74
0.74 - 0.92
N/A
FS11. Small Livestock & Mixed
Baseline Scenario
0
0 - 0.13
0.13 - 0.27
0.27 - 0.4
0.4 - 0.53
0.53 - 0.66
0.66 - 0.8
N/A
Optimistic Scenario
0
0 - 0.13
0.13 - 0.27
0.27 - 0.4
0.4 - 0.53
0.53 - 0.66
0.66 - 0.8
N/A
Intermediate Scenario
0
0 - 0.13
0.13 - 0.27
0.27 - 0.4
0.4 - 0.53
0.53 - 0.66
0.66 - 0.8
N/A
Most Severe Scenario
0
0 - 0.13
0.13 - 0.27
0.27 - 0.4
0.4 - 0.53
0.53 - 0.66
0.66 - 0.8
N/A
FS12. Swine & Mixed Crops
Baseline Scenario
0
0 - 0.09
0.09 - 0.18
0.18 - 0.27
0.27 - 0.36
0.36 - 0.45
N/A
Optimistic Scenario
0
0 - 0.09
0.09 - 0.18
0.18 - 0.27
0.27 - 0.36
0.36 - 0.45
N/A
Intermediate Scenario
0
0 - 0.09
0.09 - 0.18
0.18 - 0.27
0.27 - 0.36
0.36 - 0.45
N/A
Most Severe Scenario
0
0 - 0.09
0.09 - 0.18
0.18 - 0.27
0.27 - 0.36
0.36 - 0.45
N/A


FS13. Sheep & Mixed Crops
Baseline Scenario
Optimistic Scenario
Intermediate Scenario
Most Severe Scenario
0
0 - 0.07
0.07 - 0.14
0.14 - 0.21
0.21 - 0.28
0.28 - 0.35
N/A
FS14. Goats & Mixed Crops
Baseline Scenario
Optimistic Scenario
Intermediate Scenario
Most Severe Scenario
0
0 - 0.19
0.19 - 0.38
0.38 - 0.57
0.57 - 0.76
0.76 - 0.95
N/A
FS15. Mixed Liv, HortC &
Baseline Scenario
Optimistic Scenario
Intermediate Scenario
Most Severe Scenario
0
0 - 0.07
0.07 - 0.15
0.15 - 0.22
0.22 - 0.29
0.29 - 0.36
N/A
FS16. MixedLiv, Coconut &
Baseline Scenario
Optimistic Scenario
Intermediate Scenario
Most Severe Scenario
0
0 - 0.17
0.17 - 0.34
0.34 - 0.52
0.52 - 0.69
0.69 - 0.86
N/A

CHAPTER 5

GENERAL CONCLUSIONS AND FUTURE RESEARCH

1. GENERAL CONCLUSIONS

1.1. A farming system approach to support policies for food security under climate change in developing countries

This research aimed at developing and evaluating a farming system approach to predict and map the impacts of climate change on food security in developing countries, using the case of Mozambique. The ultimate objective of the approach proposed it to contribute to better adaptation policies, through the identification of priority areas for food security under climate change that are likely to need government intervention. To fulfil the overall objective of the thesis, four specific objectives were set and addressed in the three intermediate chapters of the thesis (Chapter 2 to 4).

The two first specific objectives of the thesis aimed to identify and map farming systems at the country level, and to assess the diverse farming systems regarding food security. Chapter 2 addressed these two objectives by first, developing a census-based countrywide approach to identify farming systems by classifying farms based on farmers productive decisions. This chapter brings a different approach for the classification of farms by farming systems in developing countries. Farming systems were classified based only on farming system descriptors i.e., factors that are endogenous to the farmer (e.g., type of crops and livestock and use of yield-raising and labour-saving inputs). The proposed classification thus, reflects the actual choices made by farmers in the study area. That is, in a set of different available options, this classification considers and brings together the choices made by farmers, given a specific biophysical and socioeconomic context. This approach differs from others that have been implemented in other studies (e.g. Erling Andersen et al. 2007; Dixon, Gulliver, and Gibbon 2001) as biophysical (e.g. climate) and socioeconomic variables (e.g. farm size) – considered as farming systems drivers (Silva et al. 2020) – are not considered for the classification of farms by farming systems. The inclusion of these drivers inhibits further analysis on farming system dynamics as these drivers change across time and space. Therefore, the approach adopted allowed further analysis on the factors influencing farming system choice, described in Chapter 3, which provides an important basis to further identify and analyse farming system dynamics and how farmers' productive choices may change under climate change – addressed in Chapter 4.

Chapter 2 also brought a relatively new and cost-effective approach for the classification of farming systems, based exclusively on statistical secondary agricultural data, in this case data from the agricultural census (a readily available source of information) – which includes data for the whole country on the many productive decisions made by farmers on multiple dimensions. Most studies on farming system typology in developing countries have been based on household surveys, which is an expensive source of information, therefore limiting the scale of is application – focusing in most cases in specific areas or regions in a country (e.g. C. Köbrich, Rehman, and Khan 2003 - Chile's Coastal Mountains and the rice-wheat zone of the irrigated Punjab of Pakistan; Kuivanen et al. 2016 - Northern Ghana; Massawe 2017 - two districts in Tanzania; Steeg et al. 2010 - Kenya Highlands).

Following the proposed farming system approach, 16 farming systems were identified and mapped in the study area (i.e., Mozambique). The identification of these farming systems was the first step for addressing the overall objective of the thesis. Based on this classification, food security was derived at the farming system level, based on data collected form the agricultural census.

A farming system approach to support policy formulation has been recognized as an effective and useful approach to achieve and evaluate relevant societal goals (e.g., food security) as it accounts for the heterogeneity of farmers, allowing to target more effective policies that would respond to the specific needs of the population (e.g., farmers) (Dixon, Gulliver, and Gibbon 2001; Ribeiro et al. 2014; Santos et al. 2020). By analysing and exploring the distribution of farming systems along the gradients of two covariates i.e., rainfall and market integration, we found that farming systems with better access to markets are more likely to be food secure. That is, the results indicate that food secure systems are mostly market-oriented with high use of yield-raising inputs and high use of labour-saving inputs. On the other hand, the most traditional subsistence farming systems i.e., dedicated mostly to food production for consumption, labour-intensive with low use of yield-raising inputs, and with absence of livestock besides poultry are the most food insecure. So, in this chapter it was possible to link food security with the diverse farming systems existing in Mozambique, as well as explore the factors most likely contributing to improve farmers' food security among farming systems.

Chapter 3 addressed the third specific objective of this thesis i.e., modelling the choice of farming systems based on climatic and other drivers at the farm and country level. In this chapter a farming system framework was developed, based on the farming system typology developed in Chapter 2 derived solely from farming system descriptors, therefore allowing to model the biophysical (e.g., climate) and socioeconomic drivers of farming system choice, and its potential for estimating the effects of policy and climate scenarios at the region/country level, contributing to food security. This chapter is relevant because it allows to understand and increase the knowledge on the factors affecting farmers' choices in developing countries, which *per se* can contribute to enhance policies tackling the challenges posed to poor small farmers in rural areas in developing countries (e.g. food security, poverty). It also enables to further predict farmers' choices under climate change, allowing to identify priority areas for food security (and other related issues) that will be under higher stress due to changes in climate in the future (Chapter 4).

The results indicate that both biophysical and socioeconomic drivers play an important role in explaining farming system choice. Nevertheless, the role of biophysical drivers is evidenced, as among the ten most important drivers determining farming system choice among farmers, six are biophysical, with emphasis to climate (i.e., rainfall, temperature, and aridity). Climate was found to be an important driver influencing the choice of most farming systems identified, which is consistent with findings from other studies (e.g. Etwire 2020; Greig 2009; Ouédraogo et al. 2017). Emphasis is given to rainfall, as agricultural activity, especially in African developing countries, is mostly rainfed. In Chapter 2, rainfall was also found to have a strong relationship with the distribution of faming systems in the study area. Nevertheless, in chapter 3 the role of socioeconomic drivers was also evidenced, as these also play an important role influencing farmers' decisions, with four socioeconomic drivers (describing farm and household characteristics and the level of market integration) being among the top-ten drivers of farming system choice – also confirmed in other studies (e.g. Bhatta et al. 2016; Maggio and Sitko 2018; Stylianou, Sdrali, and Apostolopoulos 2020). Therefore, socioeconomic drivers revealed to be important variables that can be managed in policymaking to reduce the effects of climate change on farmers' livelihoods in developing countries, in the present.

The fact that climate drivers are important determinants of farming system choice, as found in Chapter 3, enabled to further assess the impacts of climate change on farming system choice and food security in Chapter 4, as climate was expected to change over time affecting farmers' decisions on farming practices. This analysis addressed the last specific objective of the thesis. In Chapter 4 a space for time modelling approach was used to predict the choice of farming systems under different climate scenarios i.e., optimistic, intermediate and the most severe scenario. The framework proposed in Chapter 4 was based on the farming system typology developed in Chapter 2 and on the assessment of the climate drivers influencing the choice of these systems (Chapter3).

In Chapter 4 it was concluded that climate is expected to change considerably by the end of the century, with an expansion in semi-arid areas and the appearance of arid areas. These changes will considerably affect farmers' productive decisions, with significant impact on farming systems choice, moving farmers from farming systems that are currently vulnerable to the impacts of climate change to other systems less vulnerable. Most farming systems are expected to be replaced by others under climate change, with the expansion of the most food insecure systems (as seen in Chapter 2) – labour intensive, dedicated mostly to food production for consumption and with some livestock, mostly poultry – in detriment of the most food secure systems, which are market oriented and with high use of yield-raising and labour-saving inputs. The results indicate that diverse mixed crop-livestock systems are expected to better tolerate the changing climate and subsist persisting. The resilience of farming systems to climate change depends on the combination of activities that initially exist on the farm, offering more or less adaptation possibilities. In this case, the higher resilience found in mixed crop-livestock systems to climate change is consistent with the fact that they already grow some drought-tolerant crops (e.g., sorghum), a positive adaptation to climate change, and (small) livestock rearing, which is claimed to be less exposed to the impacts of climate change (Lewis, Monem, and Impiglia 2018) and can be sold in times of food shortages.

Nevertheless, farming system transitions, caused by climate change, forcing farmers to move to a particularly different farming system (compared to the original system) may imply large changes in terms of required knowledge and investment needed to manage the new system, putting farmers under high stress for changing farming systems. Higher stress for change can imply substantial negative impacts on food security. Therefore, the need to identify the areas that will be under high levels of stress due to farming system change in the context of a changing climate – which is also done in this chapter. The current humid areas, including coastal areas, have showed the higher stress for change, which is understandable as these will become drier in the future, and may become unsuitable for the crops that are currently grown in these areas, implying the adoption of new crops (that were not cultivated before, at least not in those areas) and livestock – which will require knowledge and additional investment (either capital or human). The results of the analysis, presented in Chapter 4, are relevant to support policy for food security as it enabled the identification of priority areas that will most likely need government support so that poor food insecure farmers' in developing countries can guarantee their livelihoods and meet their food security goals. Given the lack of resources in poor developing countries, efficient allocation of resources in priority areas that will translate into positive outcomes for rural small-scale vulnerable farmers is of utmost importance.

Overall, this research provides relevant knowledge to inform policymakers aiming at adaptation to climate change now (Chapter 2 and 3) and in the future (Chapter4), contributing to improve policies for food security among rural farmers in developing countries. The findings of this research support the idea that designing effective policy requires the understanding of the diversity of farming systems, as well as the factors affecting its choice, and how farmers respond and adapt to external shocks such as climate change, based on the resources available to them. The farming system framework developed in this study provides the right tool for such an understanding.

Moreover, this research presents the first detailed countrywide farming system typology for Mozambique. One of the greatest advantages of the proposed framework is its use of statistical secondary data e.g., agricultural census data (a cost-effective available and detailed source of information), worldwide climate online data publicly available, and other biophysical and socioeconomic data (also available in online, national, or international, platforms or publicly accessible when requested to the competent institutions in the country of analysis), allowing this framework to pe replicated in other parts of the world, especially developing countries, which lack detailed, consistent and continued data on agricultural activity and practices.

1.2. Policy options for food security in Mozambique

In Mozambique, most policies and programs for the agricultural sector have focused on the development of agriculture with increasing integration of farmers in markets and value chains, however mostly oriented to the external market, i.e., export-oriented (Abbas et al., 2021). As referred in Chapter 2, farmers producing cash crops receive more incentives (such as access to inputs, to credit, guaranteed market, etc.) than farmers producing food crops, which do not have access to the same incentives.

According to the results, in order to improve food security in Mozambique in the context of climate change, especially among the most vulnerable social groups, agricultural policies must focus on farming systems that simultaneously ensure food production and access to income to acquire essential goods and services and are also resilient to climate change. The results of this thesis suggest that mixed crop farming systems such as FS7, FS5, FS11, and FS14 provide the conditions to achieve this goal, as these are considered resilient to climate change. These systems are located in areas with high pressure on existing resources. The lack and/or irregularity of rainfall is an important factor influencing production and, consequently, food security in these farming systems.

In the case of farming systems with a high livestock density, measures to dynamize and promote the development of these systems may include, among others: 1) promotion of livestock production (taking into account the predominant type of animals) for sale, consumption and animal traction; 2) promotion of the use of organic inputs such as manure; among others. For farming systems essentially dedicated to the production of basic food crops, measures may include: 1) promotion of food crops with high nutritional value and resistant to a dry climate, considering local experience and knowledge; 2) support for the development of food storage and conservation infrastructure (taking into account the existing crops in the systems: cereals, roots and tubers, legumes, vegetables, fruits); 3) promote and disseminate food processing techniques suited to each system; among others.

It is important to promote the development of value chains for basic food crops, which will increase the income for farmers and, on the other hand, increase the availability of food. Access to markets (inputs and output) is an important aspect for selling surplus production, to provide monetary income that can be used to purchase food and other essential goods during lean periods. In addition, it is also important to invest in infrastructure to support agricultural production, such as roads, food conservation and storage facilities, among others. It is also important to encourage and promote the organization of farmers, through farmers' associations, so that they have autonomy, dominion, and power in the various stages of the value chain. However, such measures must take into account the heterogeneity of farming systems. If appropriate policies are adopted and implemented, even in the event of an external (e.g., climatic) shock, farmers would be better prepared to cope with food insecurity.

For example, in FS4 (food crops) and FS7 (bovine, maize and other staple food crops) just over 50% of farmers reported the lack and/or irregularity of rain and/or drought as the main cause of food shortage. These systems are predominant in semi-arid regions, with low rainfall levels, and often include water-demanding horticultural crops which, although dependent on rainfall availability, may add to diet diversification and provide income, from selling production surpluses, and thus contribute to food security. Therefore, measures aimed at these systems can also focus, among other aspects, on: 1) creation of water reservoirs and irrigation mechanisms; 2) promotion of crop diversity, including drought resistant crops; 3) promotion of access to rural and urban markets, among others.

In general, strategies to promote diversification, considering the farming systems that will persist and expand in the future, aligned with policies to regulate and improving access to markets are strategies that can contribute to improving farmers' incomes and, therefore, contributing to food security. Rural extension is also an important aspect that should be dully considered, due to the knowledge gap separating farmers practicing one farming system and farmers practicing another farming system. Measures to support and promote drought-resistant crops can contribute to the inclusion of these crops in current and future farming systems, contributing to crop diversity. Promoting and encouraging farmers' associations can also play a key role in disseminating new farming systems, as they could share information and techniques. The promotion of reservoirs and small water dams, as well as the introduction of water-efficient irrigation systems, can significantly contribute to increased water availability and better water resource management.

2. LIMITATIONS OF THE STUDY AND FUTURE RESEARCH

Although this research provides a cost-effective approach and significantly contributes to increase the general knowledge on the farming system approach to improve food security in developing countries, there are some limitations of the study that should be addressed.

One of the limitations is that food security by farming systems is assessed based on data available on the agricultural census. This is both a limitation and an advantage; an advantage because it provides data on food security for the same sample of farmers used to build the farming system typology. On the other hand, it is a limitation mostly because of the nature of the data, representing the proportion of farmers that reported food shortages on the year of the survey. The data is, therefore, vulnerable to any shocks that might have occurred in the year of analysis. However, in this research the patterns of food insecurity observed are consistent with what was expected considering the literature and experts' knowledge. Another limitation is the fact that the multidimensional role of forests as a component of farming systems and on food security was not explored. The integration of forests in the study was not possible in this study because the agricultural census did not provide data regarding the use of forest resources by farmers. The role of forests in food security and as part of the farming system should be considering in future research. Future research can also focus in developing a stronger indicator of food security, e.g. based on calories and proteins potentially provided by each farming system.

Farming system change was assessed for the 2081-2100 period. However, it is important to note that farming practices may change, evolve, and develop over shorter periods of time due to changes in the socioeconomic context, for instance (such as, technological progress, market development, among others). Moreover, the risk associated with increased volatility (variability) of the climate, may be more determinant of farmers' choices (in the short term) than the change in the average climate predicted for the long-term scenarios used in the thesis. However, this would require data on scenarios of changing climate volatility, which are not available. Nevertheless, considering that policy makers may respond and be more willing to adopt measures for shorter period predictions, a mid-term period projections may be of importance for future research.

Another limitation of this framework is that socioeconomic (e.g., market access, road, and population density) and other biophysical variables (e.g., soils, water availability) – except climate – are held constant over time, although these will certainly change in the future. This assumption was made to simplify the model and analyse exclusively the effects of climate change on farming system choice and food security. Nevertheless, the framework does not prevent the model to assume that both biophysical (others, also including climate) and socioeconomic drivers will change over time, allowing to assess the impact of all drivers on farming system choice. Assessing the impacts of socioeconomic drivers on farming system choice and food security can provide useful and relevant insights on how farmers would react to policy intervention, for example – which is recommended for future research.

One of the contributions of this research was the identification of areas in which farmers will struggle to adapt to climate change, with high stress for change from moving from one farming system to another, particularly when the latter is too different from the former. Since changing farming systems will be inevitable, due to the biophysical conditions in the future, farmers will need support through policies, strategies, and technology and knowledge exchange. Local knowledge is local-specific, therefore is very sensitive to changes in the basic (biophysical and socioeconomic) conditions. Nevertheless, farming systems that are expected to exist in the future already exist in other areas of the country, or even in other neighbouring countries. Therefore, it is important to collect information on farming-specific local knowledge being applied in the current farming systems. This would allow to draw some suggestions on how to mobilize existing local knowledge from different areas where the future farming system already exists to reduce the vulnerability of current farming systems and to facilitate their transition. This is therefore left as a recommendation for future research.

Despite the limitations mentioned above, overall, it was possible to achieve the objectives set for this study. The research developed is a major contribution to the policy analysis debate for food security under climate change in developing countries, as it develops a cost-effective farming system framework to support governments in policy evaluation for food security among small farmers in developing countries, in the context of climate change, while acknowledging the existing diversity of farming systems and including the key actors that will benefit with the policy implementation.

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