BIOMASS FOR BIODIESEL PRODUCTION ON FAMILY FARMS IN BRAZIL: PROMISE OR FAILURE?

Integrated assessment of biodiesel crops, farms, policies and producer organisations

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Thesis

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Abstract

The rapid and dynamic development of biofuels over the last decade triggered two main scientific debates associated with environmental (i.e. GHG emissions, net energy production and resource conservation) and socioeconomic (i.e. opportunities for farmers to escape poverty) subjects. This thesis focuses on this second debate. In Brazil, a biodiesel policy was implemented as a way of reducing poverty among family farms. The objective of this thesis is to perform an integrated assessment of biodiesel crops, farm types, biodiesel policies and producer organisations that reveals opportunities and limitations of family farmers' engagement in the biodiesel supply chain. In the state of Minas Gerais two research sites (Montes Claros and Chapada Gaúcha) that have high concentration of family farms, active biodiesel initiatives and suitable agroecological conditions to grow biodiesel crops were selected. Chapada Gaúcha is located in the Northwest region of the state and is characterized by a tropical semi-humid climate, with 4-5 dry months, and flat landscape. In this municipality soybean and *Brachiaria* spp. are the most cultivated crops. Montes Claros is located in the North region of the state where semi-arid conditions can be found, with 6-8 dry months, together with plain to hilly landscape. In Montes Claros, most important crops are maize and beans. A farm survey (n = 555) followed by cluster and principal component analysis were employed to explore the diversity of family farms (farm types) in the research area and its implication for a better targeting of the biodiesel policy. The farm typology revealed that the majority of family farms (non-soybean producers; farm types 2, 3 and 4) face great challenges to participate in the biodiesel market. A stronger policy impact could be achieved by the promotion of biodiesel crops that have alternative markets and fit more easily into the current farming system. The sustainability of different crop production activities were explored through a set of environmental and socioeconomic indicators. A technical coefficient generator (TechnoGIN) was used to assess current (maize, beans, soybean and grass seed) and alternative (castor bean and sunflower) crop activities managed with different production techniques. These technical coefficients were quantified using a farm survey (n = 80), expert knowledge, field experiments, crop growth models and literature. Our results indicated that biodiesel crop activities were only economic competitive with a limited number of current crop activities in Montes Claros (i.e. maize) and Chapada Gaúcha (i.e. soybean); and under relatively intensive

use of inputs (fertiliser, machinery and biocides). Additional knowledge on sunflower management strategies was gained from the calibration and validation of the crop growth model OILCROP-SUN. Our simulations indicated that the opportunities for farmers to grow sunflower vary significantly across northern Minas Gerais. Higher sunflower yield levels were simulated in the northwestern area, when compared with the northeastern region. Double cropping opportunities are also associated with the northwestern region where the sowing window is relatively large. Moreover, for all simulated sowing dates, locations and growth conditions the hybrid cultivar (H358) had higher yield levels than the conventional cultivar (E122). An *ex-ante* integrated assessment was used to explore environmental and socioeconomic impacts of five different biodiesel policy scenarios towards the identified farm types. The applied modelling framework was a combination of a technical coefficient generator (TechnoGIN) and a bio-economic farm model (FSSIM). Simulations for soybean farmers in Chapada Gaúcha (farm types 1 and 5) presented a positive response, in terms of oil production and gross margins, to all explored policy scenarios. However, the cultivation of sunflower, particularly in double cropping systems, resulted in unsafe values of biocide residues. In Montes Claros (farm types 2 and 4) the impact of the explored biodiesel policy scenarios was limited, when compared to farms in Chapada Gaúcha. Input provision polices (fertiliser, land preparation machinery) had relatively large positive impacts on the explored indicators. The role of producer organisations (POs) in linking family farms to the biodiesel market was explored through a multiple case study design applied among producer organisations (n = 14) in the states of Minas Gerais and Sergipe. The explored case studies showed that there is limited scope for POs to fill the gap between family farmers and the biodiesel market. Low value added to biodiesel crops coupled with competition with current farm activities are the main hindering factors. Finally, it is concluded that more farming systems research that combines the characteristics of the production environment with objectives of the actors involved is essential to provide farmers, scientists and policymakers with new insights on the effects of biomass production for fuel across Brazil and other countries. Yet, the overall environmental impact of the explored crops and management options has to be analysed before comprehensive policy recommendations can be made.
Keywords: farming systems, modelling, biofuel, policy, rural development

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CHAPTER 1

General Introduction

1.1 Biofuels and the search for sustainability

While the world's reserves of fossil fuel are finite, the demand for energy grows at a rate of ≈ 2% (Scragg, 2009). With 81% of the world's energy being supplied by fossil fuels, i.e. oil, coal and gas (IEA, 2012), the search for alternative and sustainable sources of energy has become a determinant factor to ensure socioeconomic development of societies across the globe (IEA, 2008). Moreover, instability of fossil fuel supply coupled with increasing environmental concerns associated with climate change (IPCC, 2007) have driven (inter)national policies towards renewable sources of energy, particularly those made from plant material (Coyle, 2007; EC, 2008; Ewing and Msangi, 2009).

Biomass from energy crops, forestry residues and organic wastes can be used to produce biofuels. Biofuels can be classified in three types: solid (e.g. fuel wood, charcoal, and wood pellets), gaseous (e.g. biogas) and liquid (e.g. ethanol and biodiesel). Altogether, these different types of biofuels account for ca. 10% of the world's energy supply (IEA, 2012). Worldwide biofuels have become one of the most dynamic and rapidly growing sectors of the global energy economy (Tomes et al., 2010; UN, 2007). The production of liquid biofuels from agricultural feedstocks is acknowledged as one of the most significant agricultural developments in recent years (Elbehri *et al.*, 2013). Between 2000 and 2011 the global ethanol production has increased five-fold, to reach 87 million cubic meters while biodiesel production increased more than twenty-fold reaching 23 million cubic meters (EIA, 2013).

Despite the recent surge, liquid biofuels are not undisputed. Their rapid and dynamic development triggered two main scientific and societal debates from the environmental and socioeconomic arena. In the first debate, particular attention has been given to the contribution of biofuels to reduce greenhouse gas (GHG) emissions and the production of net energy[1] when, respectively, (in)direct land use changes and fossil fuel consuming production factors such as fertilisers and mechanisation are taken into account. Although there are a number of studies that highlight the overall carbon saving effect of most biofuels (Armstrong et al., 2002; de Vries et al., 2010; Farrell et al., 2006; Gnansounou et al., 2009; Iriarte and Villalobos, 2013; Lee and Ofori-Boateng, 2013; Nogueira, 2011), scientists also argue that such positive effect can be reversed if biomass

[1] Net energy is the result of the energy contained in the (bio)fuel and its co-products minus the fossil energy used in the production process. Net energy values are obtained through life cycle analysis (Ou et al., 2009).

for biofuels leads to the conversion of rainforests, peatlands, savannas, or grasslands into biofuel cropping areas (Fargione et al., 2008; Lapola et al., 2010; Scharlemann and Laurance, 2008). These studies are underpinned by the assumption that biofuel crops require very large areas of land and will, directly or indirectly, exacerbate the pressure on natural resources (Righelato and Spracklen, 2007). Although the relationship between biofuel crop production and land use change is not yet clear (Kim et al., 2012; Nassar et al., 2008; Sparovek et al., 2009), further expansion of agricultural-based biofuels (without technological breakthroughs) driven by environmentally concerned policy agendas are likely to backfire on GHG emissions (Fargione et al., 2008; Lapola et al., 2010; Righelato and Spracklen, 2007). Some studies have also indicated that biofuels can consume more energy than they produce. This is the case of sorghum and maize-derived ethanol in Europe, United States and China (Ou et al., 2009; Pimentel and Patzek, 2005; Ulgiati, 2001). Main driving factors are excessive use of production inputs (i.e. fertilisers) and high energy consumption during the fuel production stages. The overall environmental impact of biofuels, however, extends beyond GHG and energy efficiency. Resource conservation is also an important environmental component which includes biodiversity conservation, hydrological functioning, soil protection and air pollution (Cook et al., 1991; Hill et al., 2006; Kaltschmitt et al., 1997; Schnoor et al., 2008). In this regard, the impact of liquid biofuels is generally negative. Most concerning effects are related to the feedstock production (agricultural) process (eutrophication, acidification, water depletion, ecotoxicity) instead of the biofuel consumption (burning) effect (Emmenegger et al., 2012).

The second subject of debate focuses on the claim that biomass production for biofuel by family farms can be a way out of poverty being thus eligible as an instrument of rural development policies, particularly in developing regions. Although concerns have been raised around food *vs.* fuel and implications on food security (Ewing and Msangi, 2009; FAO, 2008; Cassman and Liska, 2007), little knowledge is yet available on the impacts of biomass production for biofuels at the farm level and how farmers may respond to this new market opportunity. This thesis focuses on this second debate and aims at contributing to better inform scientists, farmers and policymakers in developing sustainable pathways for integrated food and energy production systems.

1.2 Biofuels in Brazil

The Brazilian history on biofuels started in the 1930s when the first legislation that allowed the blending of sugarcane-based ethanol (40%) into gasoline was approved. However, the production of ethanol would not take-off until the 1970s when oil prices soared to record levels and a national policy (ProÁlcool) was launched based on a series of subsidies and market intervention (Nass et al., 2007). The enthusiasm generated around ProÁlcool, however, was short lived. Later in the 1980s a combination of economic and political instability, coupled with the fall of crude oil prices and the withdrawal of subsidies to ethanol producers halted the program progress. At this time competitive ethanol mills were becoming associated with large private businesses, geographically concentrated in the state of São Paulo (Rosillo-Calle and Cortez, 1998). From the mid 1990s up to present days the ethanol industry in Brazil has reinvigorated. The main causes were the stabilisation of the economy, a new rise in oil prices, R&D investments and the development of the flex-fuel industry for light vehicles that produce car engines capable of running on ethanol, gasoline or the combination of both (Nass et al., 2007).

Over the last decade the production of biofuels in Brazil has been strengthened with the introduction of the Brazilian program for biodiesel technological development in 2002, followed by the creation of the National Program for Biodiesel Production and Use (PNPB, in Portuguese) in 2004 (Brasil, 2005). In contrast to the large scale production system of sugarcane for ethanol, which is often associated with the displacement of family farmers (e.g. Novo et al., 2012), the biodiesel policy was designed to combine renewable energy production with rural development, particularly in semi-arid regions. In terms of volume of production, however, biodiesel is still in its infancy compared with ethanol (Figure 1.1), which is by far the most important liquid biofuel in Brazil.

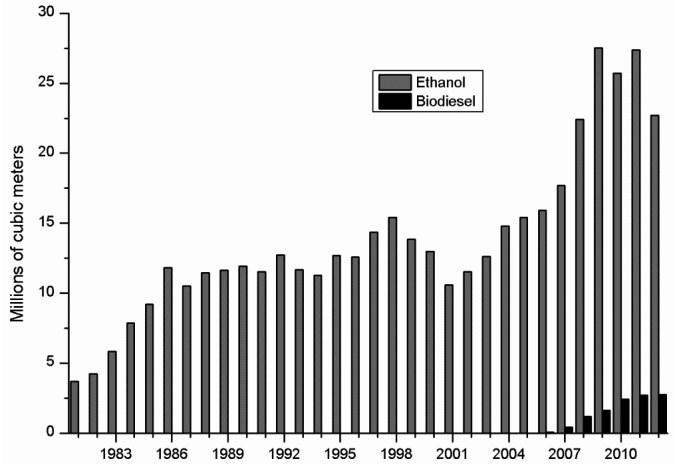

Figure1.1 Brazilian production of ethanol and biodiesel from 1981 to 2012. Source: ANP (2013); Unicadata (2013).

The biodiesel policy is framed by a set of regulations which aim to develop biodiesel production in a sustainable way throughout the country, with the inclusion of family farmers and communities in rural areas (Brasil, 2005). In Brazil farms are divided into two groups – family farms (targeted by this thesis) and non-family farms. Federal legislation (Brasil, 2006) defines family farms on the basis of four main criteria: (i) a maximum farm size, the predominance of (ii) family labour and (iii) income from farming activities; and (iv) the local management (by farmers) of farm activities (for more information see Appendix 1). Currently, in Brazil, the blend of biodiesel into fossil diesel is at 5%. Besides the mandatory blending legislation, the Brazilian government offers tax reductions and selling preferences at biodiesel auctions for biodiesel producers that purchase a minimum amount of their feedstock from family farms, the so-called "social fuel stamp" policy (MDA, 2011). The minimum amount varies according to agroecological conditions and family farms' distribution across the country (Figure 1.2).

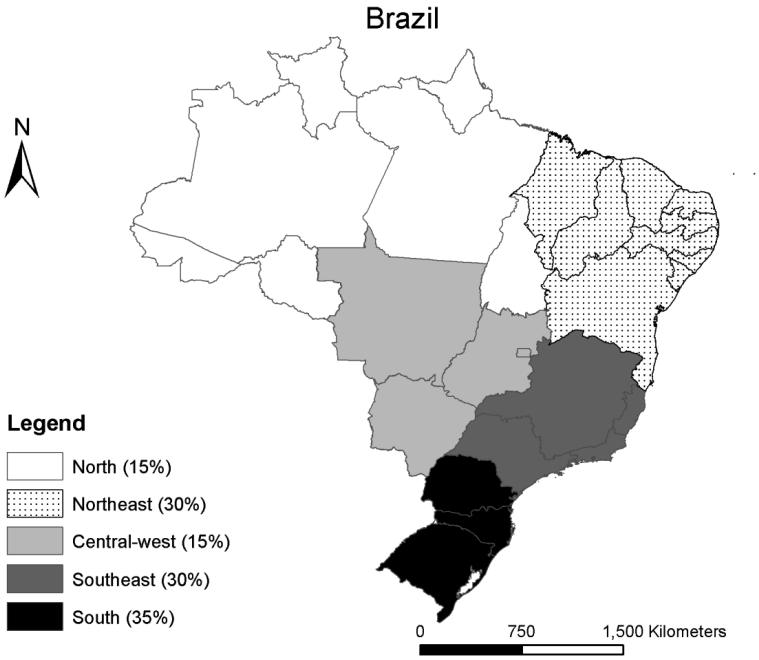

Figure 1.2 Brazilian regions and required feedstock acquisitions from family farms (in bracts), according to the social fuel stamp policy. Source: MDA (2012).

Although the number of family farmers engaged in biodiesel crop production increased over the last five years, reaching over 100,000 families in 2010, diversity in biodiesel crops is rather low as 95% of the feedstock purchased is soybean. Soybean farmers are concentrated in the South and Central-West Brazilian regions, which together account for 91% of the feedstock supplied. The semi-arid Northeast region, on the other hand, has the highest concentration of family farms in the country (50%) and is responsible for only 5% of the total biodiesel feedstock acquisitions (MDA, 2011). Furthermore, this region is characterized by poor farmers, with the lowest agricultural GDP per capita in Brazil (IBGE, 2006).

1.3 Current academic debate and the scope of this thesis

Over the last decade the academic debate on biofuels in Brazil has been ignited, partially fuelled by the launch of the biodiesel policy in 2004. Before this period, little research was initiated on this topic (Figure 1.3). The growing interest in renewable

sources of energy worldwide follows a similar pattern, with the number of published documents soaring in the beginning of the 2000s. The surge of biofuel research in the beginning of the decade is marked by increasing concerns regarding societal energy needs and the associated environmental effects of current energy sources (i.e. fossil), such as climate change. This trend can be recognised by prevailing subject domains of biofuel-related publications in the same period, including environmental science, chemical engineering and energy (Figure 1.4).

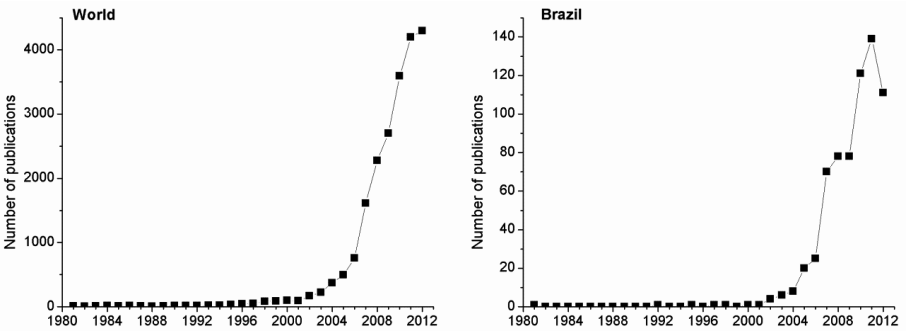

Figure 1.3 Number of biofuel-related publications worldwide (left) and in Brazil (right) from 1981 to 2012. Source: www.scopus.com

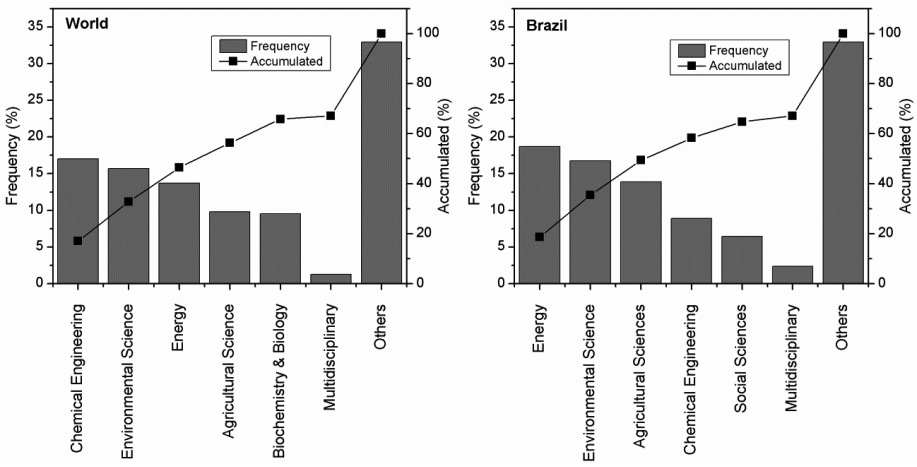

Figure 1.4 Frequency of biofuel related publications by subject domain worldwide (left) and in Brazil (right) from 1981 to 2012. Source: www.scopus.com

Although not the most frequent, around 10% of the publications on biofuels are associated with agricultural research (Figure 1.4). These publications generally aim to assess and explore sustainable options and implications of biomass production for fuel. Main challenges relate to the environmental and socioeconomic impacts that emerge at different levels (e.g. farm, region, world). The engagement of farmers in the production of biomass for biofuel could lead to the expansion of monocultures and the unbalanced use of inputs. This process could also create incentives for land expansion, which can jeopardize forest areas and other natural environments, coupled with losses of biodiversity and enhanced emissions of GHGs from land use change (Dixon et al., 2010; Doornbosch and Steenblink, 2007). Moreover, the food crisis of 2007-2008 and the ensuing peak of commodity prices (Figure 1.5) pushed forward the debate on food versus fuel and the likely consequences of biofuel production for food security (Elbehri et al., 2013).

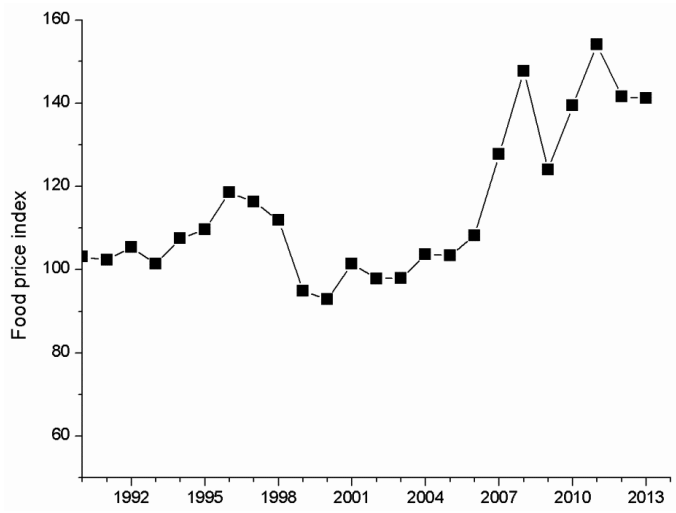

Figure 1.5 Food price index[2] from 1990 to 2013. Source: FAO (2013).

Yet another major concern for scientists is the interaction between producing biomass for fuel and elements of current farming systems. While there seem to be

[2] Consists of the average of 5 commodity group (meat, dairy, cereals, oil and fats, sugar) price indices weighted with the average export shares of each of the groups for 2002-2004 as the base period (=100). Source: www.fao.org

opportunities for farmers to increase their income and access new market opportunities, biofuel feedstock production can also lead to competition with current farm activities, hence affecting farm household food and feed self-sufficiency (Dixon et al., 2010; Pingali et al., 2008).

The complex relationship between farms and biofuels involves a number of different aspects such as production systems, energy efficiency, input management and income generation. Building comprehensive knowledge on such a topic requires the combination of diverse scientific disciplines allowing a better understanding of complex phenomena (Rotmans and Asselt, 1996). However, the number of multidisciplinary studies is still limited (Figure 1.4). In this thesis, therefore, we accepted the challenge of an integrated multidisciplinary approach, which combines findings from field to market access by farmers. It focuses on biodiesel opportunities and limitations for family farmers in Brazil, although I believe farmers, scientists and policymakers in different regions of the world can benefit from the presented methodological approach and the results and conclusions from this research.

1.4 Research problem, general objective and questions

Despite the interest of the government to improve family farmers' participation in biodiesel markets, farmers' uptake of biodiesel crops in poor semi-arid regions of the country is still limited (5% market share; MDA, 2011). While socioeconomic and biophysical farm characteristics are generally acknowledged as being essential in the design of rural policies, little has been done to understand family farms' diversity and its impact on policy targeting. Furthermore, the engagement of farmers in biodiesel crop production will also rely on sustainable biodiesel crop options, able to increase oil production while complying with socioeconomic and environmental criteria. From a policy and farming perspective, knowledge could be gained from the *ex-ante* assessment of different policies aimed at improving biodiesel feedstock production at family farms. Yet, when transacting with biodiesel producers, farms' small scale and dispersion over large areas increase transaction costs (Poulton et al., 2010; Wiggins et al., 2010). Producer organisations (POs) can be an effective way of dealing with high transaction costs. By acting collectively, farmers can benefit from economies of scale, increased bargaining power and reduced information costs (Dorward, 2001; Ton et al., 2007). In

the task of linking farmers to markets, POs can be supported by 'outsiders', such as government bodies, donors and NGOs, who provide essential services for market engagement (e.g. technical assistance, market information, credit; Markelova et al., 2009). However, uncertainty still exists on what functions POs are expected to fulfill and the type and level of support from outsiders that might be needed when farm and organisation specific characteristics are taken into account. Therefore, the general objective of this thesis is to perform an integrated assessment of biodiesel crops, farm types, biodiesel policies and producer organisations that could generate useful knowledge on opportunities and limitations of family farmers' engagement in the biodiesel supply chain. The following questions are addressed:

1. How can the socioeconomic and biophysical diversity of family farms be used to better target the biodiesel policy?
2. How do current and alternative (biodiesel) production activities perform in terms of socioeconomic and on-farm pollution (nitrogen losses and pesticide use) indicators?
    2.1 To what extent can knowledge on crop management be gained from a sunflower crop model applied under Brazilian conditions?
3. What are the socioeconomic and on-farm pollution impacts of biodiesel policy scenarios on different farm types?
4. What are the opportunities and limitations for producer organisations to facilitate farmers' engagement in the emerging biodiesel market in Brazil?

1.5 Study sites

In Brazil, Minas Gerais is the largest state in the Southeast with an area of 586,520 km^2 (Figure 1.6). In this area different climatic conditions can be found, from semi-arid to humid, and a wide variety of agroecological zones and a broad array of family farm types occur. The North of the state is a transition from semi-humid towards semi-arid and one of the poorest regions of the state (Fontes *et al.*, 2009). The Northwest region, which is on the frontier of the Brazilian Central-West, is one of the most important crop producing regions, accounting for ca. 38% of the state's soybean production (SEAMG, 2012).

Within each of these two regions one municipality was selected for this study, i.e., Montes Claros in the North and Chapada Gaúcha in the Northwest of the state (Figure 1.6). The criteria used to select these two municipalities were a high concentration of family farms, active biodiesel initiatives and suitable agroecological conditions for biodiesel crops (MAPA, 2012).

Chapada Gaúcha is located at 15º17'S and 45º37'W, 725 km from the state capital Belo Horizonte. The tropical semi-humid climate, with 4-5 dry months, is characterized by average air temperatures above 18º C and average annual rainfall of 1286 mm (2000 – 2009). Montes Claros is located more centrally at 16°44'S and 43°51'W, 425 km from the capital. In this municipality tropical semi-arid condition can be found, with at least 6 dry months; the average temperature is above 18º C and annual rainfall amounts 1050 mm (2000 – 2009). Savannah (cerrado) is the predominant vegetation in both municipalities. Table 1 presents socioeconomic and agroecological characteristics of the selected municipalities.

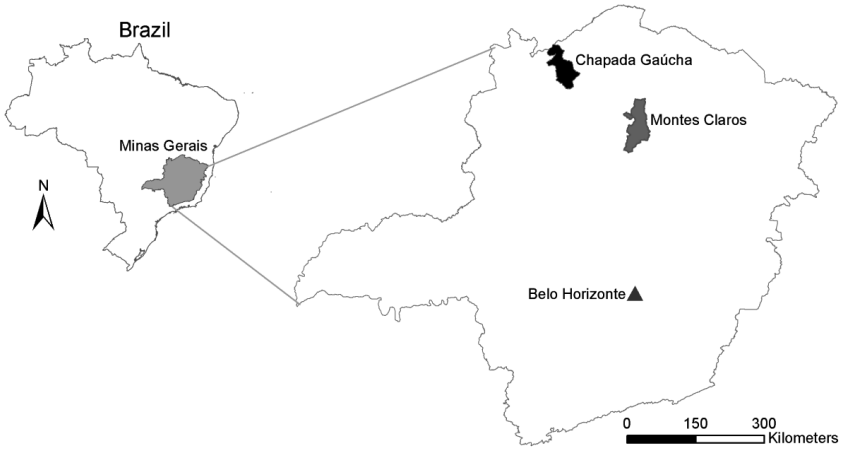

Figure 1.6 The state of Minas Gerais in the Southeast region of Brazil (left); and the research municipalities in the North and Northwest regions of the state (right).

Table 1.1 Main characteristics of the selected municipalities in the North and Northwest of Minas Gerais.

Characteristics	Montes Claros	Chapada Gaúcha
Socioeconomic		
Population density (persons km^2)[a]	101	4
Average farm sizes (ha)[a]	55	113
Distance to the biodiesel industry	*in situ*	300 km
Main crops	Maize, Beans, Cassava	Soybean, Grass seed, Maize, Beans, Cassava
Agroecological		
Landscape	Hilly, Plains	Plains
Soil type (FAO)	Ferralsols, Arenosols, Luvisols	Ferralsols, Cambisols, Arenosols, Luvisols
Average yearly precipitation from 2000 to 2009 (mm)[b]	1050	1286
Vegetation	Cerrado (savannah)	Cerrado (savannah)
Biodiesel zoned crops	Castor bean, Soybean, Cotton, Sunflower	Castor bean, Soybean, Cotton, Sunflower

[a] IBGE (2009); [b] INMET (2010).

1.6 Thesis outline

This thesis consists of seven chapters: this introduction (Chapter 1), five research chapters (Chapters 2 to 6), and a general discussion (Chapter 7).

Chapter 2 explores the diversity of family farms in the research area and its implication for a better targeting of the biodiesel policy. A database of socioeconomic (collective action, access to inputs, market orientation, labour, land tenure) and biophysical (area, crops, livestock, equipment) farm characteristics was built and used to develop a farm typology. The obtained farm types are used as recommendation groups to explore policy adaptations to improve farmers' engagement in biodiesel crop production.

In Chapter 3 a technical coefficient generator (TechnoGIN) is used to explore the sustainability of different crop production activities through a set of environmental (nitrogen losses, biocide residue) and socioeconomic (gross margin, labor demands, yield levels) indicators in northern Minas Gerais. Current (maize, beans, soybean and grass seed) and alternative (castor bean and sunflower) crop activities managed under different production techniques, that included current management, best farmers' technical means, improved management and irrigation are assessed. Findings of this chapter shed light on the most suitable crops and management options for farmers and the associated impact on the selected sustainability indicators.

In Chapter 4 we calibrated and validated the crop growth model OILCROP-SUN to simulate sunflower development and growth over an array of sowing dates in northern Minas Gerais. The generated simulations are used to explore temporal and spatial sunflower yield variability. Opportunities and limitations associated with different crop management, growth conditions and sunflower genotypes are discussed and used as inputs in Chapter 3.

Chapter 5 uses an *ex-ante* integrated assessment approach to estimate the socioeconomic and environmental impacts of five biodiesel policy scenarios towards different farm types in Montes Claros and Chapada Gaúcha. The applied modelling framework was a combination of a technical coefficient generator (TechnoGIN) and a bio-economic farm model (FSSIM). We explore the impact of market-driven (bonus price policy), input provision (fertiliser and land preparation policy), oil production (oil mill policy) and environmental (biocide residues and nitrogen losses) policy scenarios. In this chapter, we discuss and highlight the most effective policies in increasing farmers' gross margin (from on-farm activities) and biodiesel crop production on the identified farm types and their implications in terms of environmental impacts.

In Chapter 6, case studies are used to explore opportunities and limitations of producer organisations (POs) to facilitate family farmers' access to markets. A multiple case study design was applied with 14 POs in the states of Sergipe and Minas Gerais. Understanding the complex relationship between the functioning of a PO and the level and type of support from outsiders is often key to successfully connecting farmers to market opportunities. Useful insights could be gained by studying the characteristics of both the PO and the member-farms, as these determine, to a large extent, the transaction costs associated with farmers' access to markets (Pingali et al., 2005). Yet, under different conditions support from outsiders (i.e. government, NGOs, donors) through input and output services can reduce the gap between farmers and markets. Our findings are used to explore the scope for POs to fill the gap between family farms and the biodiesel market accounting for the effects of farm and product characteristics and the necessary support from outsiders.

Chapter 7 develops an overarching discussion across the research chapters of this thesis. Additionally, it explorers implications of the main findings for other regions

in Brazil and discusses the strengths and limitations of the selected methodological approach. Finally, considerations and recommendations are presented.

CHAPTER 2

Biodiesel policy for family farms in Brazil: one-size-fits-all?

This chapter has been published as:
João Guilherme Dal Belo Leite, Jos Bijman, Ken Giller, Maja Slingerland. Biodiesel policy for family farms in Brazil: one-size-fits-all? Environmental Science & Policy, 2013. 27, 195-205.

Abstract

Driven by the increasing environmental concern related to the use of fossil fuels and the growing worldwide demand for biofuels, the Brazilian government launched a national biodiesel policy promoting feedstock supply from family farms. Especially in semi-arid regions farmers have been encouraged to grow castor bean. However, there has been little farmer uptake and knowledge is lacking regarding the main constraints that hamper farmers' engagement in the biodiesel market. A farm typology, developed on the basis of original data gathered in two municipalities in the Southeast region of Brazil, revealed that the majority of farmers (Livestock, Mixed and Less endowed farm types) face great challenges to participate in biodiesel markets. A stronger policy impact could be achieved by the promotion of biodiesel crops that have alternative markets and fit more easily into the current farming system, such as sunflower, resulting in reduced trade-offs with current crop activities and allowing synergies between fuel and feed production (Livestock farmers). Better enforcement of resource providing contracts are critical to avoid default and to alleviate labour (Mixed farmers) and land constraints (Less endowed farmers), thereby improving farmers' ability to engage in biodiesel crop production. Furthermore, soybean farmers lack policy instruments based on price incentives which could enable their engagement in sunflower production.

Keywords: biofuel policies; farm systems; semi-arid

2.1 Introduction

Worldwide increasing environmental concern has drawn attention to bioenergy policies that could improve renewable fuel availability while complying with sustainability criteria (EC, 2008). In Brazil local governments believe that biodiesel has great potential as a renewable energy source with accompanying benefit of boosting rural economic development. In 2004 a national biodiesel program was created, framed by a set of regulations which aim to promote biodiesel production in a sustainable way through the inclusion of family farmers (Appendix 1) and communities in rural areas (MDA, 2011). Currently, federal legislation mandates a blend of 5% of biodiesel in diesel (Brasil, 2005). Furthermore, the Brazilian government offers tax reductions and sales preferences for biodiesel producers that purchase a minimum amount of their feedstock from family farms. The minimum amount of feedstock obtained from family farms varies from 15% in

the North and Midwest to 35% in the South, Southeast and Northeast regions (MDA, 2012).

Many questions have been raised concerning family farmers' ability to reap economic benefits from the biodiesel market. While semi-arid regions as the Northeast have the highest concentration of family farmers in the country (50%), they account for only 5% of the family farm feedstock acquisitions by biodiesel producers (MDA, 2011). In these regions castor bean has been at the forefront of government initiatives due to its suitability for semi-arid conditions. Furthermore, 95% of the feedstock is supplied by soybean family farmers from southern regions where the agricultural per capita GDP is up to seven times higher than in the Northeast (IBGE, 2006). The weak engagement of the non-soybean farmers could jeopardize further implementation of the biodiesel program. Although an increase of the mandatory blending of biodiesel from the current 5% to 10% in 2014 and to 20% in 2020 is foreseen (Ubrabio, 2010), the success of this policy greatly relies on the ability of family farmers to engage in biodiesel crop production thus ensuring a sustainable supply of feedstock.

Despite the government being keen to improve family farmers' participation in biodiesel markets, especially in semi-arid regions, knowledge is lacking regarding the main constraints that prevent these farmers from taking advantage of this opportunity. Transaction cost literature indicates that their small scale together with the lack of information and market connections, distorted or absent input markets and limited or no access to credit often make it difficult for family farmers to benefit from new market opportunities (Markelova et al., 2009; Wiggins et al., 2010). In addition, from the production perspective biodiesel crops might imply trade-offs between current and alternative crop activities which would pose further obstacles for farmers' engagement.

Smallholder farming systems are characterized by a strong rural diversity which is commonly driven by the interlocking of socioeconomic and biophysical factors (Ruben and Pender, 2004). Across geographical areas smallholders differ in resource endowment (land, labour, capital) and market opportunities, which are some of the factors that shape farmers' objectives and resource management strategies as well as production and consumption decisions, crop, livestock, and off-farm labour choices (Pender et al., 1999). Hence no household has the same resources or faces the same constraints; every farming system is different, facing distinctive decision-making problems which require specific if

not unique solutions (Köbrich et al., 2003). Recognising such variability within and among farm households and across localities is the first step to design effective rural economic development and environmental polices (Ruben and Pender, 2004; Tittonell et al., 2010). Higher policy impact could be obtained by better targeting policy instrument to specific groups of farmers. Improved targeting requires knowledge on the main causes of household heterogeneity, and on the ability to categorise diversity patterns that lead to distinct livelihood strategies and farming objectives (Pender et al., 1999).

To address such heterogeneity many policy studies use categorization methods or typologies to group farmers into recommendation domains which are composed of a group of roughly homogeneous farmers (Köbrich et al., 2003). Typologies are used *ex-ante* to design effective environmental and socioeconomic rural policies (Blazy et al., 2009; Briggeman et al., 2007), as well as *ex-post* to evaluate such policies (Andersen et al., 2007; Hazeu et al., 2011).

Although different claims have emerged, roughly eight years after the beginning of the biodiesel program in Brazil little is known about how this policy impacts different farming systems across geographical regions. Uncertainty exists regarding constraints faced by different farmers who try to access biodiesel markets and regarding options for better targeting less endowed farmers, thereby ensuring a more successful implementation of the biodiesel program.

The emerging research questions are: Which factors explain the weak response of family farmers to the biofuel policy?; and How the policy could be adjusted to increase its attractiveness to these farmers? To answer these questions, we developed a farm typology based on farm surveys and expert consultation in two municipalities of the State of Minas Gerais, in the Southeast region of Brazil. Transaction costs theory was used to identify variables to enrich the typology. We deployed a questionnaire with stakeholders to improve our understanding of the relationship between farmers and biodiesel producers. We conclude by assessing the suitability of the current policy for each of the identified farm types and proposing adaptations of policy that could improve the participation of family farms in the biodiesel market.

2.1.1 Theoretical approach

In selling their products, smallholder farmers and the agents with whom they transact, whether they are private or public, face high transaction costs (Wiggins et al., 2010). Transaction costs are the costs of contact, contract and control. In other words, transaction costs are the costs that transaction partners must incur to inform themselves about market conditions, the costs of negotiating an agreement, and the costs of monitoring and enforcing contract compliance. These costs can be reduced using particular contractual or ownership arrangements, such as contract farming (Stockbridge et al., 2003; Williamson, 2000) or producer organisations, which are a more formal expression of collective action. Acting collectively farmers can benefit from economies of scale, increased bargaining power, and reduced information and transportation costs (Bijman, 2007; Dorward, 2001). The more farmers participate in highly coordinated supply chains, the higher their potential transaction costs, as farmers in such chain make investments that are specific to the chain or the customer.

Pingali et al. (2005) classify the causes of farmers' transaction costs as household specific, location specific, and crop specific. Household specific factors that influence transaction costs are the knowledge of the farmer, the size of the farm, and the availability of family labour. These factors influence the extent to which farmers can bear risks and deal with uncertainty. Transaction costs can also vary across locations and regions and are often related to distance to the main market for the farmer's products. A large distance often entails few buyers, which increases the risk of exploitation. Also, high potential areas often have more reliable access to production inputs, better transport and communication infrastructure and hence relatively lower search and information costs (Wiggins et al., 2010). Transaction costs can also be related to crop characteristics. A perishable crop is more likely to entail high transaction costs, as farmers have few options for waiting for better prices and more trustworthy traders. Also a crop cultivated for a specific customer entails high transaction costs (high asset specificity).

The concept of transaction costs can be useful to explore constraints faced by farmers when trying to participate in new markets. Although transaction costs themselves cannot easily be measured as they are often potential costs related to particular risks, the extent of transaction costs that farmers face can still be measured by

using a number of proxies. First, collective action among farmers can reduce transaction costs related to information asymmetry, weak bargaining power and few contract enforcement options. Second, the possibilities of farmers to access input markets are also an indication of transaction costs. Better access implies lower transaction costs. Third, the extent of market orientation is a proxy for household and location specific transaction costs. A low market orientation often implies a high distance to the nearest market and/or a high focus on subsistence crops, thus a high risk aversion. These proxies are used as variables in the farm typology (see Table 2.2).

2.2 Material and methods

2.2.1 Study area

The State of Minas Gerais (MG) is characterized by a wide variety in agroecological zones and a broad array of small scale farms. Local government pursues an active bioenergy policy as it believes that biomass for biofuel can be the motor of rural economic development and a way of decreasing environmental impacts of fossil fuel use. The North of MG is a transition from Cerrado towards a semi-arid region with uneven rain distribution and poor soils. The main crops are maize, beans and cassava. With an annual per capita GDP of US$ 3,194[3] (FJP, 2008), the North is one of the poorest regions in the State. The Northwest region is on the frontier of the Brazilian Midwest and is one of the most important regions for the production of soybean, cotton, maize, beans and sorghum.

For this research, four criteria were used to select two municipalities in the North and Northwest of MG. First, given the distribution of small (<200 ha), medium (≥200 and <2,000 ha) and large scale farms (≥2,000 ha) (Girardi, 2008) within the region, micro-regions were selected with a relatively larger concentration of small-scale farms. Second, as biodiesel producers often face high transaction costs when dealing with small-scale farmers, collective action was used as an indication of a better environment for farmers' engagement in biodiesel markets. Third, the municipalities had experience with or agroecological potential to grow biodiesel crops (e.g. castor bean and soybean). Fourth, as the impact of a processing plant might be the focus of future studies, the chosen

[3] Monetary values in this paper were updated on the basis of the General Prices Index (IGP- DI) in September 2011 and converted to US$ using the exchange rate of the same period.

municipalities were close to or hosted a biodiesel production plant. Table 2.1 presents socioeconomic and agroecological characteristics of the selected municipalities.

Table 2.1 Main characteristics of the selected municipalities in the North and Northwest of Minas Gerais.

Characteristics	Montes Claros	Chapada Gaúcha
Socioeconomic		
Population density (persons km^2)[a]	101	4
Average farm sizes (ha)[a]	55	113
Distance to the biodiesel industry	*in situ*	300 km
Main crops	Maize, Beans and Cassava	Soybean, Grass seed, Maize, Beans, Cassava
Agroecological		
Landscape	Hilly, Plains	Plains
Soil type (FAO)	Ferralsols, Arenosols, Luvisols	Ferralsols, Cambisols, Arenosols, Luvisols
Average yearly precipitation from 2000 to 2009 (mm)[b]	1050	1286
Vegetation	Cerrado (savannah)	Cerrado (savannah)
Biodiesel zoned crops	Castor bean, Soybean, Cotton and Sunflower	Castor bean, Soybean, Cotton and Sunflower

[a] IBGE (2009);[b] INMET (2010).

2.2.2 Farm survey

Considering the size and distribution of farms in the study area, sampling farmers randomly was not possible. Instead a non-probabilistic approach was used in which only family farmers assisted by extension services were interviewed. There are two main reasons that justify such a strategy to approach farmers. First, the biodiesel company, located in Montes Claros, is also using extension services to engage family farmers in biodiesel feedstock production, hence unassisted farmer are less likely to connect with the biodiesel industry. Second, the extension services (Banco do Nordeste, Emater, and the Soybean Cooperative) together have a wide operational area, potentially reaching all farmers.

We identified extension services currently being used by family farmers (Emater, Banco do Nordeste and the Soybean Cooperative) and the biodiesel company (Emater and the Soybean Cooperative) in both municipalities. Most interviews were held during group meetings and visits of extension agents from the MG State Extension Services (Emater),

Banco do Nordeste[4], and the Soybean Cooperative. A second important source of data was Emater's database which has a rich description of farms assisted by their agents. A combined database was formed with 555 family farmers, comprising 360 from Montes Claros and 195 from Chapada Gaúcha. Considering the number of family farms in Montes Claros (2,566) and Chapada Gaúcha (650) (IBGE, 2006) and that not all the interviews might represent a single agricultural establishment as members of the same family could inadvertently be interviewed, an overlapping rate of 25% was considered. This would further imply a sampling rate of 10% of the family farmers in Montes Claros and 22% in Chapada Gaúcha (Appendix 1).

The selected farmers were interviewed between February and June 2010. This procedure followed a two-step approach. The first step was to explore agricultural databases in the Brazilian statistic centre (IBGE) and expert knowledge to support the selection of key variables to describe main farming systems that could be generally applied in both municipalities. The experts interviewed were agronomists and technicians from Emater and Banco do Nordeste at regional and municipal level in both municipalities, industry and supply chain managers from the biodiesel industry in Montes Claros, key researchers from the State agricultural research department (Epamig) in the North of Minas Gerais, technical and administrative staff from the soybean cooperative in Chapada Gaúcha and a smallholder family farm cooperative in Montes Claros, community leaders and presidents of farmers associations in both municipalities. The second step was to design and apply a questionnaire with a set of variables (Table 2.2) representing determinants of farm heterogeneity (both biophysical and socioeconomic) which have implications for farmers' ability to access biodiesel market.

The applied farm questionnaire (Appendix 1) is divided in a quantitative and qualitative section. The quantitative part mainly consists of biophysical farm data, i.e. farm size, crop area and herd sizes. Such variables are useful to identify differences in resource availability (i.e. land), production orientation (i.e. crop or animal production) and crop diversification (e.g. soybean, maize, fodder). The qualitative section of the questionnaire is formed by set of socioeconomic variables associated with farm endowment (i.e. equipment), land tenure (i.e. off farm area) and labour relations (i.e. off farm labour). This section also gathers three variables (i.e. collective action, access to

[4] Larger amounts of credit are negotiated under Banco do Brasil with further assistance of Emater while smaller amounts of credit are dealt in Banco do Nordeste, with the assistance of its own extension agents.

inputs and market orientation) which are used as proxies to evaluate transaction costs faced by farmers. Each of the selected qualitative variables was measured using different classes which can be related with low, fair and high farm performance (Table 2.2).

In addition farmers and experts were interviewed using a topic list to obtain their perception on the linkage between farmers and the biodiesel company as a new market opportunity, and on the suitability of particular biodiesel crops for different farmers and regions.

Table 2.2 The quantitative and qualitative variables used in the farm survey.

Variable	Unit	Description
Area	ha	Total cropped area including set aside areas
Annual crops	ha	Household area allocated to maize, cassava, beans, castor and soybean
Horticulture	ha	Household area allocated to horticulture (e.g. lettuce, tomato, banana, etc.)
Grazed crops	ha	Area allocated to natural, cultivated grazed and fodder crops
Beef/dairy	#	Total number of livestock with meat and dairy purpose
Pigs/poultry	#/class	Total number of pigs and poultry (1) 1-30; (2) 31-60; (3) > 60
Equipment	class	(1) Rudimentary equipment to cultivate and/or prepare the land being predominantly manual (2) Ownership/capacity to hire oxen for plough, small tractor, motor and/or horticulture irrigation equipment (3) Ownership/capacity to access tractors, combines, sprayers, soil preparation equipment and irrigation systems
Collective action	class	(1) Incipient forms of collective action (associations) where the main goal is to easily access technical and financial assistance (2) Farmers use the associations also to buy inputs or sell their production (3) Highly developed collective action with active role on market information, technical assistance, credit, biophysical inputs, storage and market
Access to inputs	class	(1) Limited access to inputs due to distance and cost (2) Fair access through association and commercialization of farm products, mainly horticulture and dairy (3) Unlimited access to private, public or collective forms of information with also unlimited access to inputs
Market orientation	class	(1) Self-consumption, farmers' main concern is the household food supply with occasional product sales (2) Market and self-consumption have equal importance (3) Market oriented
Off-farm labour	class	(1) Occasional labour-off farm (2) Labour off-farm is frequent (important share of the family revenue)
Off-farm area	class	(1) Renting land off the owned farm area is rare (2) Renting land off the owned farm area is often

2.2.3 Farm typology

The selected quantitative and qualitative farm variables were subjected to a principal component analysis (PCA) to identify non-correlated variables or indicators as proxies to the family farm categorization criteria. The threshold to select most relevant principal components (PCs) was drawn below those which together explained most of the database variance (>70%) and with meaningful loadings. Following such criteria five principal components were selected which together account for 80% of the data variability (Appendix 1).

Family farms were then grouped in homogeneous classes using a non-hierarchical cluster analysis (CA) based on the extracted principal component scores as new variables. Subsequently, the resulting clusters were refined by reallocating observations falling within fuzzy boundaries over the defined groups and limiting the number of groups to five (Appendix 1). After statistical analysis, expert consultation was used to evaluate the emerging farm types and their occurrence across the municipalities.

2.3 Results

There was large heterogeneity among family farms for the selected variables in the municipalities in the North and Northwest of Minas Gerais (Table 2.3). The range of minimum to maximum values indicates great variety of agricultural systems with also large variation within each of the variables given by the coefficient of variation (CV). The agricultural area allocated to annual crops clearly demonstrates this wide variation. With a mean of 14.2 ha, the farm area varied from 0.02 to 256 ha (Table 2.3).

Table 2.3 Descriptive analysis of the overall database of farm characteristics derived from the farm survey (n = 555).

Variable	Mean	Std. Dev.	CV (%)	Min	Max
Area (ha)	39.48	48.95	123.99	0.02	256
Annual crops (ha)	14.22	35.18	247.40	0	250
Horticulture (ha)	0.17	0.49	288.24	0	4.84
Grazed crops (ha)	12.50	20.89	167.12	0	183
Beef/dairy (#)	11.81	20.80	176.12	0	220
Pigs/poultry (#/class)	2.42	4.20	173.55	0	43
Equipment (class)	1.80	0.75	41.67	1	3
Collective action (class)	1.46	0.79	54.11	1	3
Access to inputs (class)	1.74	0.76	43.68	1	3
Market orientation (class)	2.27	0.79	34.80	1	3
Off-farm labour (class)	1.09	0.29	26.61	1	2
Off-farm area (class)	1.22	0.41	33.61	1	2

2.3.1 Farm typology

The PCA done for the entire sample of farms (n = 555) indicates that about 52% of the family farm variability was explained by the first two PCs. The remaining three components explained 27% of the variance so that the combined five components accounted for roughly 80% of the total variability among farms (Figure 2.1 A). Being independent, with low correlation among each other (Figure 2.1 B), these five components formed the basis for further categorisation of family farms across the study sites.

The first PC was highly correlated to the variables: area, annual crops, equipment, collective action, access to inputs and market orientation; whereas the second PC had high values for grazed crops and beef and/or dairy production. These two PCs described the most significant farm systems found, in terms of agricultural production, the first PC being related to soybean producers in Chapada Gaúcha and the second PC to extensive livestock systems in Montes Claros. The third PC represents farmers dealing with horticulture and/or poultry and pig production as the most important activities. The remaining fourth and fifth PC represents respectively two farm groups in which off-farm labour and area are highly important. Family farms were grouped into five clusters derived from the extracted five principal component scores as new variables for both municipalities.

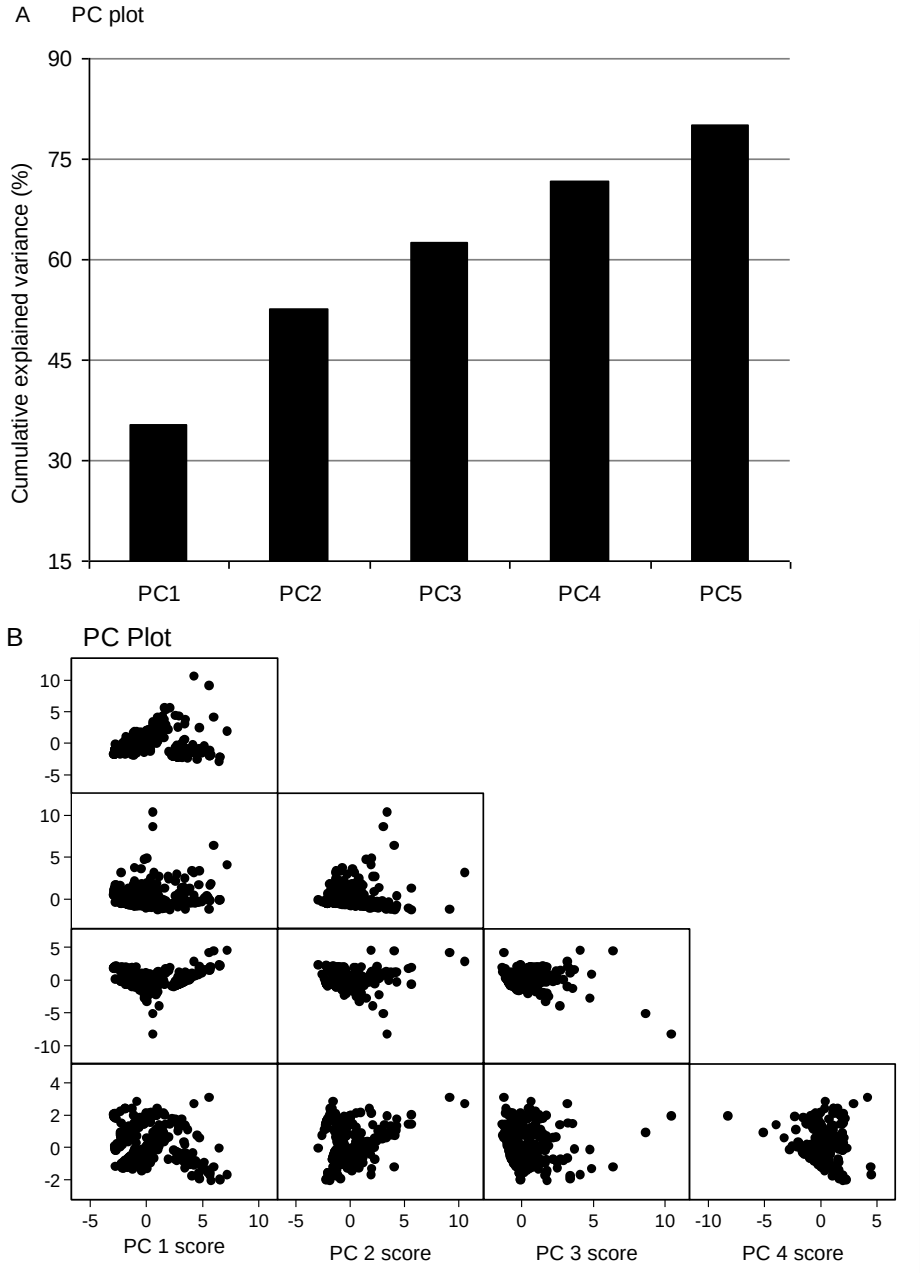

Figure 2.1 Results of the principal component (PC) analysis done on the entire survey data (n = 555): (A) cumulative percentage of variance explained by the selected PCs, and (B) PC scores for each observation.

Biophysical diversity between farm types

Farm type 1, which includes the soybean farmers in Chapada Gaúcha, represents the better endowed family farms. This group is composed of 71 farmers, all of whom were members of a soybean cooperative. They had the largest annual crop area with an average size of 81.5 ha (Table 2.4) which was used mainly for soybean (79%) and grass seed production (18%). These farmers were also well endowed in terms of equipment for soil preparation, crop management and harvest (Table 2.4). Farm type 2 was the largest group with 202 farmers. They were highly concentrated in Montes Claros (83%) and characterized by their larger livestock (meat and/or dairy) numbers and grazing area (Table 2.4). The annual crop area within this group was often linked to the animal production systems, mainly through maize which is important as a fodder crop during the dry season (April – September) when the grass supply is limiting.

Table 2.4 Values of the quantitative (mean) and qualitative (frequency) variables for each of the family farm types. Different lowercase letters define statistical differences ($p < 0.01$).

Variables	Type 1(a)	Type 2 (b)	Type 3 (c)	Type 4 (d)	Type 5 (e)
Area	116.7a	46.4be	14.2c	2.4d	49.1eb
Annual crops	81.5a	1.8b	1.2cd	0.8dc	49.3e
Horticulture	0.0ae	0.1bd	0.3c	0.09dbe	0.0eabd
Grazed crops	3.7acd	29.1b	4.0ca	0.8da	0.0e
Beef/dairy	7.8ace	25.0b	4.5cae	0.9de	2.3eacd
Pigs/poultry	4.1acd	1.5be	2.9cad	3.0dac	0.6eb
Equipment	3 (100%)ae	1+2 (96%)b	1+2 (99%)c	1 (82%)d	3 (100%)ae
Labour off	1 (100%)abce	1 (100%)bace	1 (100%)cbae	2 (68%)d	1 (100%)eabc
Area off	1 (100%)ab	1 (93%)bac	1 (85%)cb	2 (68%)d	2 (100%)e

With the second largest number of farmers (186), farm type 3 was composed mainly of farmers from Montes Claros (71%). They were mainly mixed farm systems with horticulture, poultry and pigs as the main activities (Table 2.4). Those more specialized in vegetable production were often found along the river streams in lower lands where soils are more fertile and water for irrigation is available. Cropping was dominated by maize (≈50%) used as fodder for poultry and/or pig production, followed by beans and cassava which contribute to the family household consumption.

Farm type 4, composed of 66 family farmers (91% in Montes Claros), had the smallest cropped area of all five farm types. Off-farm labour and land are important characteristics of Farm type 4 (Table 2.4). This group was comprised of the less endowed farmers where maize is the most important crop covering 56% of the annual crop area. Such farmers were frequently located in sites with poor agricultural potential, soils of poor fertility, hilly terrain and without water sources. As rainfed agriculture predominated, labour contracts were often temporary, except in irrigated areas (farm type 3 – horticulture). Sharecropping contracts were also important, often being the only available area for the most land constrained farmers (0.02 ha), and were commonly established with extensive livestock farmers (farm type 2) and labour-constrained mixed farmers (farm type 3).

Farm type 5 was the smallest group of family farms (30), all of which were concentrated in Chapada Gaúcha with over 90% of the annual crop area allocated to soybean production. This group shared similarities with farm type 1, except that they had smaller cropped area and the entire area was farmed under rental contracts (Table 2.4). Such "landless" farmers account for an important share of the soybean cooperative members (≈30%), who thus help to support its status as a family farm cooperative. This affords advantages when dealing with biodiesel feedstock contracts. Among such farmers are often a new generation of farmers from soybean families who inherited the family business.

Socioeconomic diversity between farm types

Regarding transaction costs, soybean farmers (farm types 1 and 5) performed better in all of the analysed features (Figure 2.2). Less resource endowed farmers (farm type 4) had smaller values associated with access to inputs and market orientation (Figure 2.2 B and 2 C), with the exception for collective action where non-soybean farms (farm type 2, 3 and 4) showed no differences with weakly developed forms of producers' organisation (Figure 2.2 A). Less endowed farmers (farm type 4) also had weak market orientation (Figure 2.2C); in that food crops were more important than cash crops. Such a farm strategy was recurrent in less-favoured areas, associated with fragile agricultural systems (limited rainfall, poor soils, etc.) and/or socioeconomic constraints such as poor cash and market access. This group of farmers tended to select

strategies for reducing income vulnerability based on activity and technology choices that involved low sunk cost. This permits high flexibility in resource allocation (Ruben and Pender, 2004). Often farmers' willingness to engage in cash crops, diversifying from food crops, is limited by household-related transaction costs, risks and access to credit (Key and Runsten, 1999; Pingali et al., 2005).

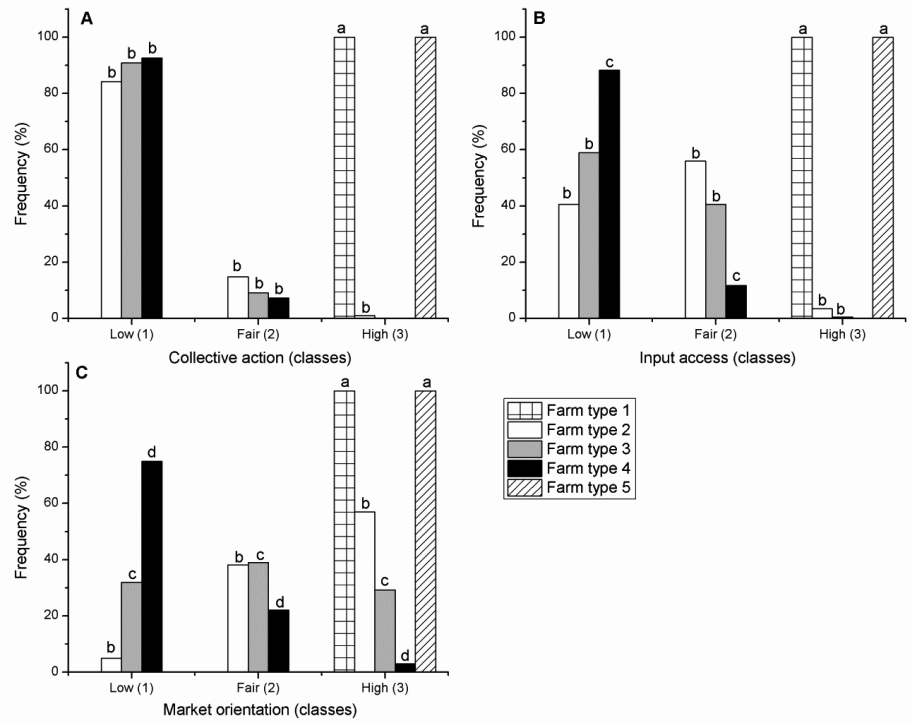

Figure 2.2 Relative frequencies for each family farm type regarding collective action (A), access to inputs (B) and market orientation (C) in each defined class. Different letters define statistical differences ($p < 0.01$).

Among the non-soybean producers, Livestock farmers (farm type 2) were more market oriented (Figure 2.2 C) with better access to production inputs, information and market options. Production was still rather extensive and meat and milk (often as cheese) were the most important farm products. Mixed farmers (farm type 3) were fairly market oriented (Figure 2.2 C). This group of farmers was often concentrated close to the city or to major districts with established markets where they could sell their

products without high transportation costs. Soybean farmers on the other hand, faced a completely different scenario. With highest values for all selected variables (Figure 2.2), these farmers marketed their produce through the cooperative which also provided inputs as technical assistance, fertiliser and pesticides.

The better performance of soybean farmers regarding transaction costs seems to play an important role in their successful engagement in the biodiesel feedstock chain (Watanabe et al., 2012). According to the biodiesel industry, in 2009 farmers from the soybean cooperative in Chapada Gaúcha accounted for over two thirds of the family farms biodiesel feedstock acquisitions in Montes Claros. Farmers and experts in this region see the biodiesel industry as an attractive market as it pays a bonus over the prevailing soybean prices to ensure that farmers do not sell their grain into alternative markets.

Non-soybean farmers (Farm types 2, 3 and 4), which were the majority (82%), had no established supply relation with the biodiesel industry. Across the country, farmers in semi-arid regions, as in Montes Claros, have been encouraged to grow castor bean due to its recognized tolerance to drought (Peres and Beltrão, 2006) and higher grain oil content (43-45%) when compared with soybean (17%) (NAE, 2005). However, our survey results show that the production of castor bean by family farmers and their participation on biodiesel market is evidently not an important activity. From a questionnaire applied in both municipalities, crop producers and experts underlined major constraints which hamper farmers' engagement in biodiesel feedstock production:

- Castor bean production causes trade-offs among current farm activities leading to changes in food and feed production strategies thus increasing risk associated with its production.
- Farmers that engage in castor production face lack of market options as they are only able to sell to the biodiesel producers. Furthermore, due to its toxic properties it does not have alternative uses as food or feed.
- Current contracts between farmers and the biodiesel company account for technical assistance, inputs (seeds), and logistic support during sowing (seed delivery) and harvest (transport to the processing place). Timing problems in the logistics cause losses for farmers due to them either missing the best sowing windows or to extended stocking periods.

2.4 Discussion

Recently, Brazilian policy has been challenged to increase biodiesel crop production, especially in semi-arid regions where family farmers are the majority. The aim of the policy is to ensure a sustainable supply of biodiesel feedstocks and, at the same time, allow family farmers to reap economic benefits from the biodiesel market. To be effective, the biodiesel policy should account for the diversity among farmers and their resources as these impact household decisions over land use, labour intensity and market orientation. Here we discuss different policy recommendations that we developed on the basis of improved knowledge of the diversity of family farms obtained through the farm typology. Farm and biodiesel crop features were combined to explore policy specifications for different farm types, from the perspective of improving both oil crop production and family farm engagement as biodiesel feedstock suppliers (Table 2.5).

Table 2.5 Policy recommendation and targeted farm types (FT).

Policy recommendation	Targeted family farms				
	FT1	FT2	FT3	FT4	FT5
Less specific biodiesel crop options synergic with livestock production		✓			
Bonus price for biodiesel crops	✓				✓
Improve farmers' access to land preparation equipment (machinery)			✓	✓	
Improve farmers' access to fertilizer and technical assistance				✓	
Enforced contract arrangements to cope with asset specificity of castor bean and lack of collective action among farmers		✓	✓	✓	

An important factor that influences farmers' ability to engage in biodiesel feedstock production is crop choice. Although the policy has promoted castor bean for family farmers, mainly due to its tolerance to semi-arid conditions, it results in major trade-offs with current crop activities (Florin et al., 2012). With a life cycle of about 150 to 180 days, and some varieties extending to 250 days, castor occupies the entire wet season which leaves no space for a second crop. After the first rainfall (October) farmers generally cultivate maize and beans which could be followed by a second harvest later in February, depending on the rains and the farmers' ability to invest. Although castor can be intercropped with shallow crops like beans (Beltrão et al., 2010;

Peres and Beltrão, 2006) it is unsuitable to be mixed with maize due to light competition. This implies trade-offs with animal production as maize is the main fodder crop. Although castor cake could be used as animal feed after oil extraction, it has to be detoxified resulting in further costs and demanding extra labour. Livestock farmers (farm type 2) are the most strongly affected due to the importance of maize in their production system. This constraint could be resolved through the development of less specific biodiesel crops such as sunflower which allow synergies between crop and animal production by providing feed (Table 2.5). Recently, a combined program between national research and extension agencies and biodiesel producers was launched with special focus on semi-arid regions of the country to explore and develop sunflower as a crop option for family farmers (MME, 2012a). With similar oil grain content to castor bean, sunflower has the advantage of not being toxic as animal feed thus offering better opportunities for integrated fuel and feed production (farm type 2).

Sunflower, which shows promise under semi-arid conditions, has also been explored as a biodiesel crop option for soybean farmers (farm types 1 and 5). With a short cycle (90 to 130 days) sunflower could follow soybean, early planted in October, being cultivated under the last quartile of the rainy season (Embrapa, 2000). This rotation has been promoted among soybean farmers with the objective of selling both sunflower and soybean to the biodiesel company with an increase over 100% in oil production per hectare. Main limitations are the water requirement in the second half of the sunflower life cycle which coincides with the end of the rains (March-April) and lower economic gains when compared with soybean. Short cycle soybean varieties could be an efficient way of dealing with rainfall distribution. However, farmers still lack economic incentives to engage in sunflower production. Due to the strong market orientation of soybean farmers, price incentives towards sunflower could be a way of fostering additional biodiesel crop production (Table 2.5).

Resource use intensification is usually considered a critical component of policy strategies to reduce socioeconomic-environmental trade-offs (Ruben and Lee, 2001). An important driver of resource intensification is to focus on the most limiting factor to the development of agricultural production (Pender et al., 1999). Shortage of investment capital is often a major constraint for improving labour and land productivity. Non-soybean farmers face limitations to expand their cropped area mainly due to labour

constraints for land preparation, and limitations on yield improvement caused by the lack of inputs such as fertilisers and technical assistance. Increasing farmers' access to inputs (fertiliser) and equipment (machinery), thus shifting towards more intensive food and feed production systems, might be a way to improve crop production thus allowing further engagement in cash crop production. Hence, policy instruments that can relax pressure on labour and improve soil fertility could enhance farmers' food and feed production along with their ability to produce biodiesel crops.

Mixed farmers (farm type 3) are mainly constrained in labour, which is often allocated into high value added horticulture activities with high rates of income/labour. A feasible strategy to engage these farmers in biodiesel crop production is through policies that relax labour demands associated with activities such as land preparation (Table 2.5). The access to land preparation equipment enables farmers to expand their cropped area thus creating room to grow biodiesel crops without compromising current – more profitable - production activities. As farmers within this group are constantly engaged in growing and selling their products, the required labour for biodiesel crop management could be ensured through sharecropping contracts with less endowed farmers (farm type 4).

Less endowed farmers (farm type 4), have limited access to inputs (Figure 2.2 B), and services. Policies that enable access to both of these could stimulate an increase in crop production and thus ensure a sustainable combination of food self-sufficiency and oil crop production. Farmers and other stakeholders agree that the low intensity of input use is one of the main reasons for the poor crop output associated to less endowed farmers. Access to fertilizer and technical assistance are recognized as effective intensification strategies to enhance crop production (Table 2.5). The intensification of the production system could allow farmers to engage in biodiesel crop production without compromising current food and feed activities. Access to land preparation equipment is also important to enable the expansion of the cropped area. With limited available crop land such expansion could be achieved through sharecropping contracts with better off farmers (farm type 2 and 3).

Asset specificity, defined as the degree to which an asset is specialized for a particular product or trade (Key and Runsten, 1999), is another issue associated with castor bean production. The biodiesel company located in Montes Claros is currently

the only market accessible for farmers that engage in castor bean production. High transportation costs and low collective action among farmers hinders access to alternative markets. In addition, the biodiesel company can operate through an array of different feedstocks such as oil crops and animal fat. This monopsonistic buying structure increases farmer's risk of potential opportunistic behaviour by the buyer.

As to the farmer-buyer relationship, one way of improving the farmers' position when dealing with the biodiesel company is through collective action. Producers' organisations can help to overcome market access barriers in integrated food-energy systems. Some of the arguments include easier and cheaper access to inputs, reduction of marketing costs, and improved bargaining power in negotiations with companies (FAO, 2010). Soybean farmers from Chapada Gaúcha (farm type 1 and 5) are able to negotiate a good price for a large quantity of soybean in a single contract through their cooperative. Through such an arrangement, soybean producers obtain better market conditions for sale of their harvest to purchase inputs. Although producer organisations can improve the farmers' position by reducing transaction costs, improving access to market information, and gaining economics of scale (Stockbridge et al., 2003), for several reasons, which are beyond the scope of this paper, they do not always function well.

In a context of weak collective action among farmers and high asset specificity related to castor bean production, better contractual arrangements are required to stabilize the farmer-buyer relationship (Dorward, 2001; Williamson, 2000; Williamson, 2008). Moreover, contract arrangements can be an effective way of providing credit, inputs, information and services to smallholders thus reducing risk and improving net returns (Key and Runsten, 1999; Williamson, 2008). Although efficient, contract arrangements have to be enforced to avoid contract default from either part. In the case of castor bean contracts between the biodiesel company and non-soybean farmers (farm types 2, 3 and 4), the company has failed to deliver seeds and collect the harvested product on the agreed dates (interview results). Such behaviour undermines trust between farmers and the company as it increases risk related to crop losses and delayed payments, thus leading farmers to avoid biodiesel contracts. A better contract enforcement seems key to strengthen the link between farmers and the biodiesel company thus ensuring a sustainable feedstock supply from family farmers (Tables 2.5).

2.5 Conclusion

The farm typology revealed that the definition of family farm encompasses a great diversity of farms and farming systems. Recognizing this heterogeneity is critical for an understanding of farmers' ability and willingness to engage in biodiesel feedstock production and must be taken into account during the policy design process. The majority of farmers (Livestock, Mixed and Less endowed farmers) face great challenges to participate in biodiesel markets. These farmers are mainly concentrated in semi-arid regions and are characterized by weak forms of collective action, limited market orientation, and poor access to inputs. With limited resources (land, labour and capital) farmers in this region face a number of setbacks which hamper their engagement in oil crop production. The cultivation of castor bean often implies trade-offs with current crop activities leading to changes in food and feed production strategies thus increasing risk associated with its production. In this context, the development of a farm typology proved to be essential to identify the key farm characteristics that influence options for biodiesel feedstock production, and to develop better targeted biodiesel policies.

Livestock farmers lack biodiesel crop options able to reduce trade-offs with current crop activities and that would allow synergies with food and feed production. Higher policy impact could be achieved by promoting alternative oil crops, such as sunflower, that hold the potential of combining oil and feed production.

Resource-providing contracts can also be an effective way of attracting farmers to biodiesel crop production. Mixed farmers, often constrained in labour, could benefit from production intensification policies that alleviate labour demands, thus allowing farmers to increase their cropped area to be occupied with a biodiesel crop. Less endowed farmers, also labour constrained, have limited access to inputs such as fertilizer and technical assistance. For these farmers intensification strategies should aim at soil fertility and crop management capacity building to improve food and feed production thus reducing the risk associated with non-traditional crops.

Biodiesel feedstock contracts are also an important policy instrument that needs adaptation. Although contractual arrangements could be a way of dealing with the lack of collective action and high castor bean asset specificity faced by non-soybean farmers (farm types 2, 3 and 4), the farmer-buyer relationship is often jeopardized by delays in the provision of seeds, the collection of harvest, and payment. Hence, there is a need for

better enforcement of biodiesel contracts which ensures the delivery of inputs and other services without implying further risks for farmers associated with crop and economic losses.

Soybean farmers (farm types 1 and 5) could improve oil crop production through the inclusion of sunflower as a second crop following short cycle soybean varieties. Although rainfall distribution plays an important role in the success of this double crop rotation, a policy instrument based on economic incentives (price bonus) is key to induce farmers to engage in sunflower production.

The selected typology approach has shown to be useful to identify agroecological and socioeconomic characteristics of different farming systems. Furthermore, the typology provides insights into major farm constraints, food and feed strategies, land use patterns and socioeconomic features across multiple farms and their implications for the effectiveness of biodiesel policy. On the basis of this diversity several options have been proposed for policy development and implementation. The article shows that insights in farm typologies can contribute to a better informed policymaking process.

CHAPTER 3

Exploring sustainable biodiesel crop options for smallholder farming in Brazil

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Abstract

In Brazil, local agricultural research agendas are increasingly challenged by the search for sustainable biodiesel crop options for family farmers, especially under semi-arid conditions. The aim of this paper is therefore to explore the sustainability of biodiesel crop production activities through a set of environmental and socioeconomic indicators in a semi-arid (Montes Claros) and more humid (Chapada Gaúcha) municipality in the state of Minas Gerais, Southeast Brazil. A technical coefficient generator (TechnoGIN) was used to assess current (maize, beans, soybean and grass seed) and alternative (castor bean and sunflower) crops grown with current and alternative production techniques. The quantification of the inputs and outputs was based on farm surveys, expert knowledge, literature and field experiments. Although castor bean and sunflower are economically competitive with maize in Montes Claros, feed and labour requirements may hinder farmers' adoption. In Chapada Gaúcha, the double cropping system soybean/sunflower presented small economic gains when compared to soybean; it also increases nitrogen losses and biocide residues. We conclude that the scope for alternative and sustainable biodiesel crops in family farms is limited. Their economic benefits are small or absent, while their introduction can lead to higher environmental impacts and there may be trade-offs with food and feed availability at the farm level.

Keywords: farming systems; biofuel; policy; semi-arid; family farms

3.1 Introduction

Worldwide biofuels have become one of the most dynamic and rapidly growing sectors of the global energy economy (UN, 2007; Scragg, 2009; Tomes *et al.*, 2010). There is increasing recognition that biofuel production can offer opportunities for countries to meet reduction of greenhouse gas emission targets, while empowering farmers through the generation of jobs and income in rural communities (Hazell and Pachauri, 2006; FAO, 2008).

In Brazil biofuel initiatives have recently targeted biodiesel as a way of combining renewable energy production with rural poverty reduction. A national program for production and use of biodiesel was created in 2004 framed by a set of regulations based on mandatory blending of biodiesel with fossil diesel (Brasil, 2005). Expectations on further expansion of the mandatory blending policy, from the present 5%, led to a fast development of the biodiesel industrial production capacity which is

able to supply two and a half times the current demand (Ubrabio, 2010; MME, 2012b). One of the main features of the policy is the inclusion of family farmers as feedstock suppliers to the biodiesel industry. Biodiesel producers which comply with feedstock supply from family farmers (Appendix 1) are granted a social fuel stamp, which implies tax exemptions and selling preference at the biodiesel auctions (MDA, 2011).

Although the number of family farmers engaged in biodiesel crop production increased over the last five years, reaching over 100,000 families in 2010, biodiesel crop options are still narrow as 95% of the feedstock supplied is soybean. Soybean farmers are concentrated in the South and Central-West Brazilian regions; together they account for 91% of the feedstock supplied. The semi-arid Northeast region, on the other hand, has the highest concentration of family farms in the country (50%) is responsible for only 5% of the total biodiesel feedstock acquisitions (MDA, 2011). Furthermore, this region has an agricultural GDP per capita that is seven times smaller than in the South and Central-West of Brazil (IBGE, 2006).

The Brazilian biodiesel policy is currently challenged by the search for alternative biodiesel crops that combine high oil productivity with better suitability for less endowed farmers especially under semi-arid conditions. This strategy aims to increase oil production per area, thus positively affecting the energy balance of the production activity, and at the same time increasing family farms' engagement. To be effective in engaging many family farms and increasing oil production such crops should be quantitatively assessed in combination with different production techniques and in terms of environmental and socioeconomic indicators. More qualitative assessments, as often reported in literature (Abramovay and Magalhães, 2008; Garcez and Vianna, 2009; César and Batalha, 2010; Hall *et al.*, 2011; Padula *et al.*, 2012; Watanabe and Zylbersztajn, 2012) are not adequate. One way of improving knowledge regarding the complex relationship between agricultural production, environment and economy is through integrated quantitative methods and tools. These methods allow exploration of suitable production activities taking into account farmers' objectives, resource availability and technical feasibility (de Wit et al., 1980; Hengsdijk and van Ittersum, 2002). Such analysis is based on the description of production activities under specific biophysical and technological conditions in terms of inputs and outputs which are known as technical coefficients (Hengsdijk *et al.*, 1999; Ponsioen *et al.*, 2006).

Inputs may include external nutrients, biocides and labour which together with the outputs can be expressed in their own physical units, and in monetary units. Besides crop production, outputs may include socioeconomic and environmental indicators such as labour use efficiency, cost-benefit ratios, nutrient losses and biocide residue (van Ittersum and Rabbinge, 1997). Moreover, although there are a number of studies that explore the agroecological potential of biodiesel crop options (Zheljazkov *et al.*, 2008; Baldwin and Cossar, 2009; Aranda-Rickert *et al.*, 2011; Dhyani *et al.*, 2011) limited work has been done towards the integrated analysis of socioeconomic and environmental aspects of crop activities under different environmental conditions and technology levels.

The objective of this paper is to explore the sustainability of current and alternative production activities through a set of environmental and socioeconomic indicators in two locations of Southeast Brazil. In this assessment a semi-arid municipality, Montes Claros, and a more humid municipality, Chapada Gaúcha, of Minas Gerais state were studied. Alternative production activities (biodiesel crops) and production techniques were assessed against current not so intensive - in the use of machinery, biocide, and fertilizer – production techniques of maize (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.) in Montes Claros and, the more intensive production of soybean (*Glycine max* L.) and grass seed (*Brachiaria spp.*) in Chapada Gaúcha. Findings from this analysis can shed light on promising opportunities and major constraints for biodiesel crops under different production techniques, to inform farmers and policy makers. A generic method and technical coefficient generator are used that can also be applied to other regions.

3.2 Material and methods

The description of key terminology used in this study is summarised in Table 3.1.

Table 3.1 Summary of the terminology used in the quantification of crop activities.

Terminology	Description
Production level	Level of primary output per unit area
Land unit	Relatively homogenous area in terms of landscape, soil characteristics and climate conditions
Production technique	A set of agronomic inputs required to realise a particular output level
Production activity	Crop or crop rotation cultivated on a particular land unit and characterised by a specific production technique
Current production activity	Production activity characterize by actual farmers' management in terms of crop choices and technology adoption
Alternative production activity	Production activities technically feasible but not yet widely applied by farmers
Target oriented approach	Technical optimal combination of inputs to realise a particular output level or production level
Technical coefficients	Input and output coefficients of a production activity

Source: van Ittersum and Rabbinge (1997) and Hengsdijk *et al.* (1999).

3.2.1 Modelling approach

The exploration of agroecological and socioeconomic sustainability of current and alternative production activities requires a comprehensive compilation of their inputs and outputs. It means that all inputs (i.e. labour, biocides, fertilizers and input costs) and outputs (i.e. yield levels and nutrient losses) associated to a particular crop with specific production technique and land unit have to be quantified. A comprehensive database was built based on information of current and alternative production activities from which different production activities can be assessed through the various possible combinations of crops, production techniques and land units. To generate such combinations and calculate the inputs and outputs a computer program (TechnoGIN) was used. TechnoGIN (Ponsioen *et al.*, 2006) is a technical coefficient generator which allows the quantification of inputs and outputs of a large number of current and alternative production activities. Although TechnoGIN was first developed for Ilocos Norte, Philippines (Ponsioen *et al.*, 2003), it has recently been re-designed as a more generic and flexible tool for further applications in other regions of Asia and Africa (Wolf *et al.*, 2004; Patil *et al.*, 2012; Reidsma *et al.*, 2012).

The input and outputs coefficients of current production activities in TechnoGIN are based on survey data. Alternative production activities, however, are quantified based on knowledge of the biophysical processes of plant and animal production, technical recommendations and land use related objectives following the so-called design criteria (Hengsdijk and van Ittersum, 2002). For these activities target yields were based on crop models (potential and water limited yields), field crop experiments (rain fed and irrigated), expert knowledge and literature. Inputs were determined using the so-called target-oriented approach, i.e., seeking the technical optimal combination of inputs to realise the target yield level (van Ittersum and Rabbinge, 1997).

3.2.2 Case study area

In Brazil, Minas Gerais is the largest state in the Southeast region with an area of 586,520 km^2 (Figure 3.1A). In this area different climatic conditions can be found, from semi-arid to humid, where also a wide variety of agroecological zones and a broad array of family farm types occur. The North of the state is a transition from cerrado towards semi-arid being one of the poorest regions of the state (Fontes *et al.*, 2009). The Northwest region, which is on the frontier of the Brazilian Central-West, is one of the most important crop producing regions, accounting for ca. 38% of the state soybean production (SEAMG, 2012).

Within each region one municipality was selected for this study, i.e., Montes Claros in the North and Chapada Gaúcha in the Northwest (Figure 3.1A). The criteria used to select these two municipalities were a high concentration of family farms, active biodiesel initiatives and suitable agroecological conditions for biodiesel crops (MAPA, 2012). Chapada Gaúcha is located at 15º17'S and 45º37'W, 725 km from the State capital Belo Horizonte. The tropical semi-humid climate, with 4-5 dry months, is characterized by average air temperatures above 18º C and average annual rainfall of 1286 mm. Montes Claros is located more centrally at 16°44'S and 43°51'W, 425 km from the capital. In this municipality tropical semi-arid condition can be found, with at least 6 dry months; the average temperature is above 18º C and annual rainfall amounts 1050 mm. Savannah (cerrado) is the predominant vegetation in both municipalities. Furthermore, there are also differences in soil and landscape characteristics between both municipalities.

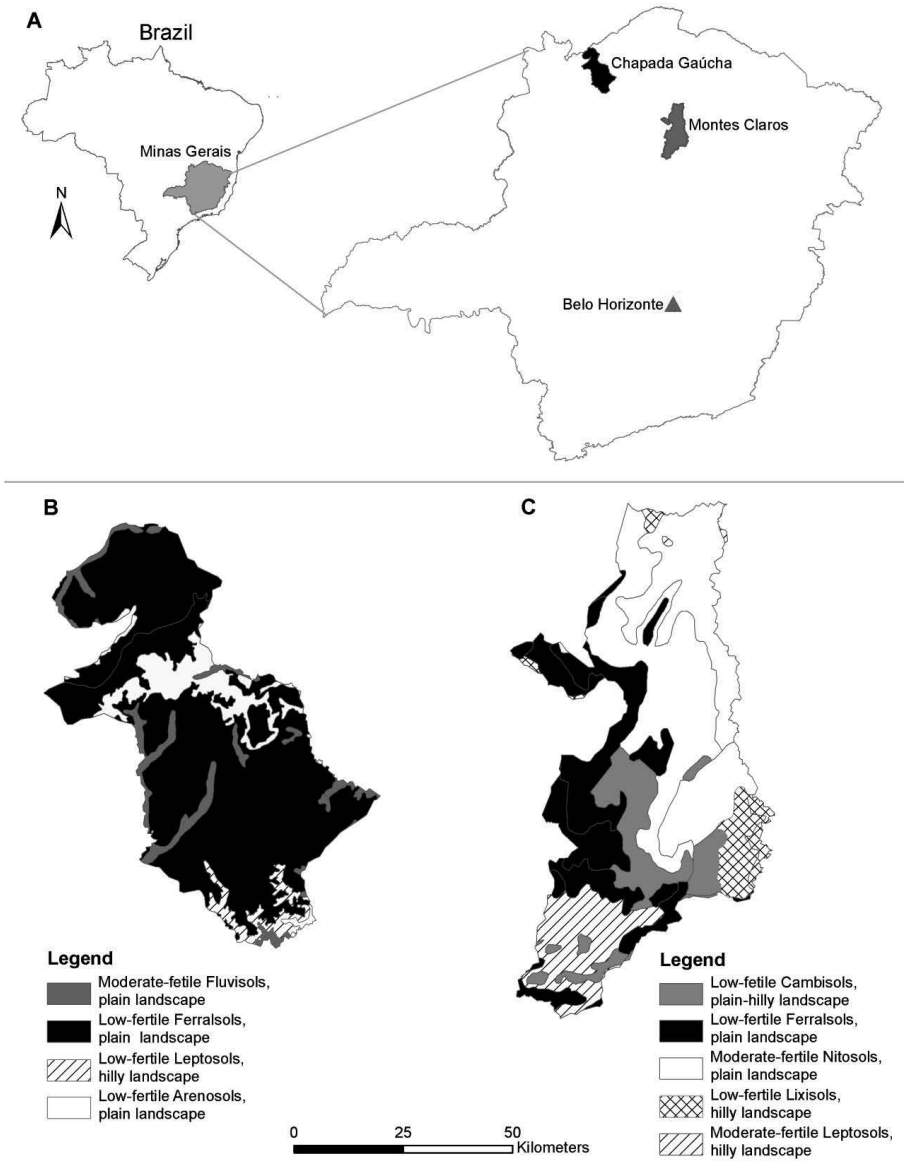

Figure 3.1 Map of Brazil with the State of Minas Gerais, its capital and research municipalities (A); soil and landscape features of Chapada Gaúcha (B) and Montes Claros (C).

Three different landscape features were selected from a soil and landscape database (UFV *et al.*, 2010) to characterize land units within the municipalities: (i) soil

fertility level: low (≤50% of base saturation) or moderate (>50% base saturation); (ii) soil type (FAO); and (iii) landscape topography (steepness): plain (≤8%), plain-hilly (8-20%) or hilly (20-45%). From the selected criteria nine different combinations can be derived, four occurring in Chapada Gaúcha and five in Montes Claros (Figure 3.1B,C).

In Chapada Gaúcha, the low-fertile Ferralsols with plain landscape are dominant (Figure 3.1B). This landscape combined with the use of fertilizer and lime, favours large scale mechanized production activities such as soybean and grass seed which combined account for 82% of the cropped area (IBGE, 2010).

Montes Claros has more diverse soil types with a more hilly landscape (Figure 3.1C). In this region shallow and rocky soils are common thus making agriculture more difficult. Less mechanized, small scale crop cultivation (plains) and extensive cattle production (hills) are the most important production activities. In this municipality maize and beans account for 78% of cropped area (IBGE, 2010).

3.2.3 Data collection

A farm survey was performed in all district zones in both Montes Claros (n = 10) and Chapada Gaúcha (n = 2) from 2010 to 2012. The survey was performed in two steps. First 555 farmers were interviewed with respect to their production activities, crop management, outputs, resource endowment (land, labour and capital), access to inputs, market orientation and collective action. From this database a farm typology was developed with the support of principal component and cluster analysis (Leite *et al.*, 2013). Five farm types were identified, from which four were selected to be explored in this study (Table 3.2). Mixed farmers (farm type 3) in Montes Claros and Chapada Gaúcha mainly refer to horticulture producers. This group of farmers is not prioritized by the biodiesel policy because of the low economic competitiveness of biodiesel crops compared with the locally marketable vegetables. Hence, this farm type was not explored in this study.

Table 3.2 Farm types characteristics.

Characteristics	Unit	Farm type 1	Farm type 2	Farm type 4	Farm type 5
Farm area	ha	116.7	46.4	2.4	49.1
Annual crops	ha	81.5	1.8	0.8	49.1
Graze crops	ha	3.7	29.1	0.8	0.0
Crops	-	Soybean, grass seed	Maize, beans	Maize, beans	Soybean, grass seed
Soil/Landscape	-	Ferralsols, Arenosols/Plains	Ferralsols, Nitosols/Plain	Ferralsols, Nitosols/Plain	Ferralsols, Arenosols/Plains
Land tenure	-	Owned	Owned	Sharecropped	Rented
Municipality	-	Chapada Gaúcha	Montes Claros	Montes Claros	Chapada Gaúcha

A second survey was performed covering 80 farmers in the two municipalities, accounting for the main production activities previously identified in the farm typology. Village leaders and extension agents assisted with the identification of concentration domains of a given farm type within each village, where farmers were then randomly selected. A total of 35 soybean/grass seed farmers (farm type 1 n = 20; farm type 5 n = 15) in Chapada Gaúcha and 45 maize/beans farmers (farm type 2 n = 20; farm type 4 n = 25) in Montes Claros were interviewed.

The second survey was used to assess the technical coefficients of each production activity including the quantification of all inputs required to achieve a certain output under the current production technique. Data on crop area, yields, labour and management, input use and costs, and output prices for an average year were collected. This database was also complemented with soil analysis (n = 64, 2009-2011), soil profile information (Radambrasil, 1986) and weather data (1979-2009) (INMET, 2012) at municipality level.

3.2.4 Design process: current and alternative production activities

Land units and crop options

Main *current* production activities were identified in each of the research areas through farm surveys (previous section). *Alternative* production activities were specified according to biophysical possibilities and their technical feasibility combined with land use-related objectives (Hengsdijk and van Ittersum, 2002).

The intensive soil tillage management associated with current production activities in Chapada Gaúcha (grass seed) and Montes Claros (maize and beans) limited

crop production to plain areas. As no alternative soil management is explored in the present study, and to account for potential soil losses on more steep landscape, alternative production activities were also restricted to plain areas (Table 3.3). Based on the farm survey and expert knowledge we concluded that the different soil types in each land unit did not have significant impact on yield levels of current and alternative production activities. We therefore considered one soil type per municipality.

Table 3.3 Design criteria and their variants for identifying production activities.

Design criteria	Variants
Land unit	Two: plain (Ferralsols + Nitosols), plain (Ferralsols + Arenosols)
Crop options	Eight: maize, beans, castor bean, spring sunflower, soybean, grass seed, summer sunflower (soybean/sunflower)
Production technique	Four: current, best farmers' technical means, improved, irrigated
Yield levels	Four: current, best farmers, water limited, potential

We assumed that crop options should be suitable with current farm infrastructure, thus not requesting further adaptation investments, e.g. new equipments. Moreover, there must be fairly established research and development agenda around novel crops, i.e. literature, technical assistance, experimental data and seeds, thus ensuring relatively reliable information to be used under different production techniques (NAE, 2005; MAPA, 2012). Although, oil crops such as macaúba palm (*Acrocomia aculeata* Mart.), sesame (*Sesamum indicum* L.) and jatropha (*Jatropha curcas* L.) show some promise in the region, lack of information and technology on crop production still constrains its introduction among farmers (Junqueira, 2011; Sousa *et al.*, 2011; Embrapa, 2012b). Main crop options considered to have an established R&D agenda, thus enabling capacity building, are peanut (*Arachis hypogaea* L.), cotton (*Gossypium hirsutum* L.), sunflower (*Helianthus annuus* L.) and castor bean (*Ricinus communis* L.) (de Castro and Lima, 2011). Cotton and peanut would imply major adaptations with investments in farm equipments. As a result of this, castor bean and sunflower were selected to be explored as alternative crops. Sunflower was explored as a single crop (spring sunflower) in both Chapada Gaúcha and Montes Claros. A double cropping system with soybean followed by summer sunflower was explored only in Chapada Gaúcha (soybean/sunflower – Table 3.3) where the rain season is longer (November to April). In general, single cropping systems are most common, especially in Montes

Claros where the wet period is about 150 days (November to March). Castor bean was considered suitable only in Montes Claros where family manual labour for crop harvest was available, as this crop still lacks appropriate machines.

Production techniques and yield levels

Different production techniques were also explored, i.e. current and alternative techniques (*best farmers' technical means*, *improved management* and *irrigated*) (Table 3.3). Alternative production techniques were based on near future possibilities (ca. 5 years), thus incorporating technologies available to farmers. It implies that management and use of inputs following technical recommendations are already available or in the R&D pipeline but not yet widely applied. Based on the less input intensive production activities in Montes Claros and the highly mechanized and intensive ones in Chapada Gaúcha, production techniques were designed to explore the effects of both intensification and a more rational use of inputs. Yield levels associated to different production techniques were defined based on farm surveys (*current, best farmers'*), water-limited and potential crop model simulations, field experiments and expert knowledge (*improved, irrigated*) (Table 3.3).

Current production technique was defined based on farm surveys and represents the average combination of inputs. *Best farmers production technique* represents ca. 5% of the surveyed farmers and accounts for a more input-intensive production system, i.e., higher levels of fertilizer, seed technology, biocides and machinery, leading to higher yield levels than under *current* production technique (Table 3.4). The *improved management* technique assumes a more rational use of inputs. A precision agriculture approach is incorporated in which requisites for crop growth and protection are met without deficiency or excess (Cassman, 1999) implying high efficiency in the use of nutrients and biocides. Nitrogen fertilizer recovery fraction was increased by 10% assuming an improved management based on a better synchrony between crop N demand and the N supply throughout the growing season (split fertilizer applications) when compared to current and best farmers' technical means (Cassman *et al.*, 2002; Kang, 2009). Different fertilizer types were not considered due to the still limited access by farmers and, the widespread use of urea as the primary source of N supply (farm survey). In this technique, biocide use was reduced also by 10% due to a better spraying

management combined with a pest/disease monitoring system (Table 3.4). The improved *irrigated* production technique was developed from the *improved management* considering available irrigation equipment on some farms; it was also defined using the target-oriented approach with improved yield levels and input use (Table 3.4).

Table 3.4 Relative change (%) of production activities characteristics under different production techniques (*current, best farmers, improved and irrigated*) and land units (Chapada Gaúcha and Montes Claros). Positive (+), negative (−) or neutral (0) changes are calculated as percentages of current values (100).

Production activity characteristics	Montes Claros				Chapada Gaúcha			
	Current	*Best farmers*	*Improve*	*Irrigate*	*Current*	*Best farmers*	*Improve*	*Irrigate*
Yield levels	Low	Best farmers	Water-limited	Potential	Low	Best farmers	Water-limited	Potential
Fertilizer recovery fraction	na	100	+10	+10	100	0	+10	+10
Biocide use	na	100	−10	−10	100	+20	−10	−10
Fuel use	na	100	0	0	100	+20	+100	+100
Labour demands - crop manag.	100	−80	−42	−42	100	+100	+200	+200

na – not applied

3.2.5 Quantification of production activities using TechnoGIN

TechnoGIN calculates a series of input-output relationships which can be used in a resource use efficiency analysis. It is a Microsoft Excel based program where the calculations rules are programmed in Microsoft Visual Basic. There are three main types of technical coefficients which can be generated: (i) input requirements in physical and economic terms, i.e. fertilizer, biocide, seed, labour, and costs; (ii) physical production, mainly referring to crop yield; (iii) environmental impacts, i.e., biocide use, water requirement and nutrient balances (Ponsioen *et al.*, 2006). In this study socioeconomic (crop production, labour requirements and gross margins) and environmental (nutrient balance and biocide use) indicators were assessed.

Target yields

Yield levels (water-limited and potential) set for alternative production techniques in each land use type were defined in TechnoGIN mainly using crop growth models built into the Decision Support System for Agro-Technology (DSSAT) (IBSNAT, 1993; Jones *et al.*, 2003). Previous studies which calibrated and tested DSSAT in the State of Minas Gerais for soybean (Rodrigues *et al.*, 2013), beans (Oliveira *et al.*, 2012) and maize (Costa *et al.*, 2009; Pereira *et al.*, 2010) were used to perform further simulations for Chapada Gaúcha and Montes Claros. Simulated yields, from 1979 to 2009, were averaged and used to set target yield levels in TechnoGIN.

A different approach for estimating yield levels was used for castor bean, grass seed and sunflower; for these crops modelling efforts and literature are scarce. Yield levels for castor bean were defined based on expert knowledge from extension services in the North of Minas Gerais under rainfed (farmers' experience) and irrigated conditions (field experiments). A similar approach was used to attain grass seed yield levels. Extension agents from a soybean/grass seed cooperative in Chapada Gaúcha were interviewed together with farmers to explore crop yields under different production techniques. For sunflower, the crop model OILCROP-SUN, which had been tested in Brazil (Rolim *et al.*, 2001), was used to simulate yields during spring (single cropping systems) and summer (double cropping system). To calibrate OILCROP_SUN an experiment was carried out in Vicosa – Minas Gerais, while a series of 27 experiments from different Brazilian locations in the states of Minas Gerais, Goiás, Distrito Federal, São Paulo and Paraná were used for model validation (Appendix 2). Sunflower yields were simulated (1979-2009) for different sowing dates with a weekly time step from August 25th to March 30th accounting for spring (Montes Claros and Chapada Gaúcha) and summer (Chapada Gaúcha) sowing periods.

Nutrient balances

Nutrient balances (N, P and K) were calculated in kilograms per hectare, for each production activity, based on the incoming (fertilizer, manure, symbiotic bacteria and mineralization) and outgoing (crop uptake and nutrient losses) flows of nutrients. Crop nutrient uptake is calculated using the QUEFTS model (Janssen *et al.*, 1990) integrated in TechnoGIN. In QUEFTS nutrient uptake is calculated assuming a

balanced supply of N, P and K defined by the crop yield level and nutrient concentrations in crop residues and harvestable products (Nijhof, 1987). Nutrient losses due to leaching, denitrification, volatilisation and fixation are calculated as a share of the nutrient inputs which are assessed based on soil and weather conditions, i.e. soil texture, aerobic/anaerobic conditions and precipitation (Cantarella, 2007; Ernani *et al.*, 2007; Novais *et al.*, 2007). Nutrient balances for current production activities are calculated based on current yields and fertilizer rates (farm survey) and calculated nutrient losses. Alternative production activities use a similar method, but now nutrient inputs are calculated using the target-oriented approach which is defined by target yield levels and estimated nutrient losses (Ponsioen *et al.*, 2003).

To evaluate QUEFTS the current fertility status of soils, assessed through soil analysis, was used to calculate nutrient inputs following literature recommendations. These values were then compared with those calculated by the QUEFTS model (Table 3.5). The presented statistical analysis indicates that the built-in nutrient balance component performs well in estimating nutrient inputs when compared to soil analysis recommendations. This also provides a good basis for reliable estimations of nutrient rates of alternative production activities.

Table 3.5 Nitrogen (N), phosphorus (P) and potassium (K) inputs in kg ha^{-1} according to soil analysis (current recommendation) and TechnoGIN (calculated), and the statistical indicators for model performance across the six crops.

Crops	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
	Current	Calculated	Current	Calculated	Current	Calculated
Maize	60	54	26	33	37	33
Beans	50	44	13	11	17	21
Castor	60	48	17	18	25	23
Sunflower	80	89	39	45	58	63
Soybean	15	10	48	50	75	76
Grass seed	38	37	35	31	33	28
Statistics (*n* = 6)						
RMSE[1]		14.8		14.0		10.1
ME[2]		0.9		0.9		1.0

[1]RMSE = Root Mean Square Error (Appendix 2)
[2]ME = Modelling Efficiency (Appendix 2)

Water Balance and biocide residue index (BRI)

The water balance is an important model component used to estimate irrigation requirements of alternative production activities. It was calculated per dekad (10 days period) based on water inflows (precipitation, irrigation) and losses, which consist of actual evapotranspiration (ET), calculated by the multiplication of crop coefficients and reference ET. Reference ET is calculated using the Penman-Monteith equations (Allen *et al.*, 1998) and long term daily weather data (1979-2009) (INMET, 2012). Furthermore, soil water content is limited by the soil water holding capacity defined by soil texture. When the balance is negative in a certain period or dekad there is a water shortage, which could be supplemented with irrigation.

Biocide residue index (BRI) is defined by the use of biocides (kg or l of active ingredient ha^{-1}), toxicity index and soil persistence characteristics. It is used as an environmental risk indicator associated with biocide use and calculated as: BRI = [biocide (g ha^{-1}) × active ingredient fraction (kg kg^{-1}) × toxicity index × persistence index active] ÷ 100. Values below 100 are considered to be safe, between 100 and 200 permissible and above 200 unsafe (Vasisht *et al.*, 2007).

Labour requirements and gross margin

Labour requirements are defined for each production activity and include labour for land preparation, crop establishment, management and harvest. Labour demands were specified in labour days (8 hours) per hectare in Montes Claros (manual labour) and hours per hectare in Chapada Gaúcha (mechanized labour).

Gross margin was also calculated for each production activity and was defined by crop income derived from crop yields and prices, minus the costs of all variable inputs such as hired labour, machinery, fertilizer, biocides, seeds and fuel. The information related to costs (fertilizer, biocides, etc.) and crop prices was obtained from the farm survey as representative for an average year (current production activities) and literature (alternative production activity) in which a five year average (2007 to 2011) was used (CONAB, 2012; IEA, 2012a). The exchange rate used (US$ 1.00 = R$ 1.75) was based on an average of daily values from March 2011 to July 2012 (BCB, 2012).

3.2.6 Sensitivity analysis of crop prices

A sensitivity analysis was performed for prices of the alternative crop options under the *current* production technique to explore to what extent changes could impact the economic attractiveness (gross margins) of biodiesel crops against current ones. This analysis was limited to crop prices based on three main criteria: (i) the database mainly includes biophysical inputs (i.e. fertilizer, biocides, seeds, labour requirements and fuel) which have limited annual variation and are tightly associated with farmers' management; (ii) yield levels of different crops are often correlated as climate related events, e.g. drought, hail, floods, affect all crops; (iii) crop prices showed to be a relevant component of gross margins (ca. 31% - farm survey) which are likely to vary, due to local, regional or global factors, regardless of farmers' management. Gross margins of biodiesel crops under *current management* were explored through the stepwise (plus or minus 5%) increase of crop prices and compared against current crop options in Montes Claros and Chapada Gaúcha.

3.3 Results

3.3.1Crop yields and gross margins

Crop yields associated with current and alternative production techniques differ in the two land units. Yield gaps, i.e., the difference between potential (*irrigated*), and *curren*t yield levels are relatively large in Montes Claros where current production activities are managed under low input and technology use (machinery, seeds, fertilizer and biocides) than in Chapada Gaúcha (Figure 3.2A,B). As a result, when comparing *current* with *best farmers*, yield levels increase on average by 200% in Montes Claros and 68% in Chapada Gaúcha.

Water supply in the *irrigated* production technique positively affects yield levels in both locations (Figure 3.2A,B). There is an average yield increase of 110% in Montes Claros and 75% in Chapada Gaúcha from the *best farmers* to *irrigated* production technique. Despite the significant impact on crop yields, irrigation adoption does not always lead to proportional economic benefits. Costs associated with water supply, mainly energy, outweighed gains from crop yields leading to a decrease in economic returns (Figure 3.2C,D). Beans is the only crop for which irrigation seems to be a reasonable economic choice (Figure 3.2C). There are two main reasons for this, i.e., the

high price of beans, and the relative short beans cycle (90-110 days) leading to less water demand, about 370 mm ha^{-1} which is relatively small when compared to castor demanding 640 mm ha^{-1} (ca. 180 days crop cycle) and the double cropping systems soybean/sunflower, demanding 970 mm ha^{-1}.

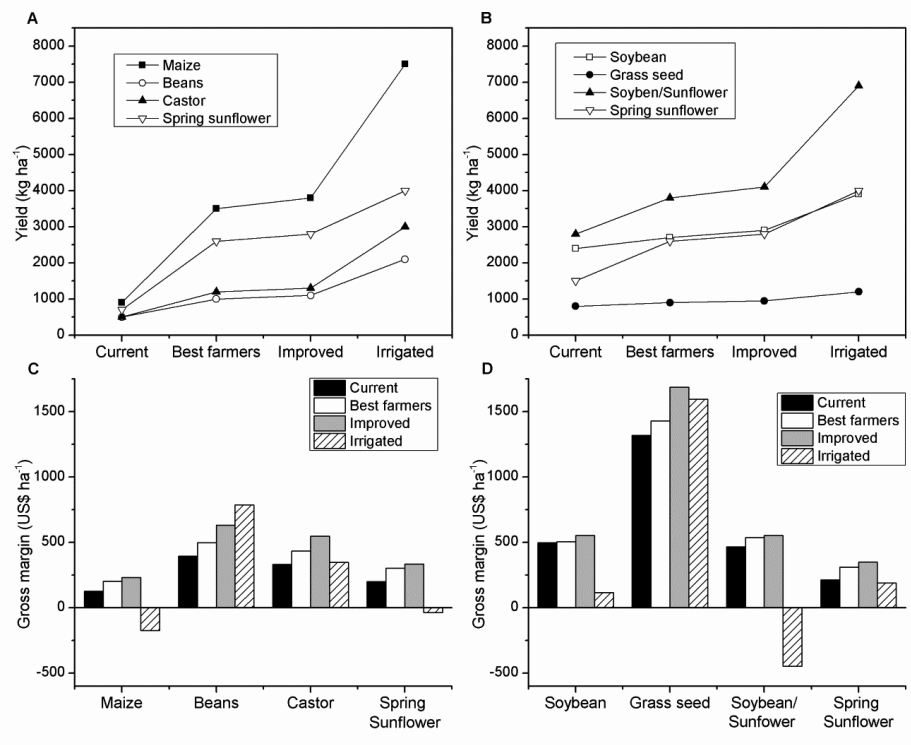

Figure 3.2 Yield levels (A and B), gross margins (C and D) for current and alternative production activities with different production techniques in Montes Claros (A and C) and Chapada Gaúcha (B and D).

Gross margins associated with alternative crops, i.e., castor beans and sunflower, in Montes Claros show higher economic gains when compared with maize under current and alternative production techniques (Figure 3.2C). Besides being the most economically attractive crop, beans contribute substantially to family food subsistence and only production surpluses are sold in local markets. This is also the case for maize which is used as animal feed. In Chapada Gaúcha, alternative production activities, i.e.,

spring and summer sunflower (soybean/sunflower), present minor economic gains compared to soybean and grass seed (Figure 3.2D). Spring sunflower is not a competitive crop option; only for the *best farmers'* production technique and when sown during summer in rotation with soybean (soybean/sunflower) it yielded higher gross margins (6%) than soybean monoculture. This economic gain, however, relies on short cycle (90-110 days) soybean varieties which allow sunflower to be sown in the second half of February when crop yields can still reach 1,000 kg ha^{-1} (Figure 3.3). Sunflower yield levels drop considerably with sowing dates from January 19th onwards, mainly due to water shortage associated with the end of the rain period (Figure 3.3).

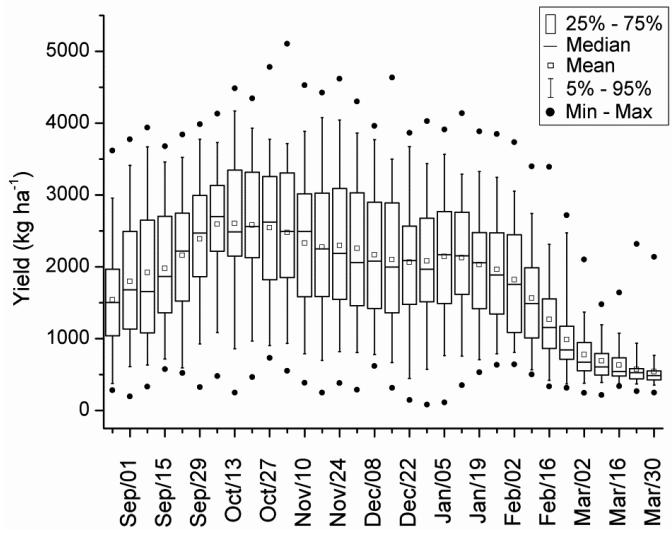

Figure 3.3 Box-plot of the simulated sunflower yields from 1979 to 2009 under rainfed conditions in Chapada Gaúcha with different sowing dates

The sensitivity analysis based on crop gross margins under current production technique show that prices of castor bean and sunflower would have to increase by ca. 17% and 74%, respectively, to become economically competitive with beans in Montes Claros (Figure 3.4A). In Chapada Gaúcha summer sunflower prices cultivated after soybean (soybean/sunflower) would have to increase by 20%, whereas in a single cropping system (spring sunflower) this difference would have to increase to ca. 57% (Figure 3.4B).

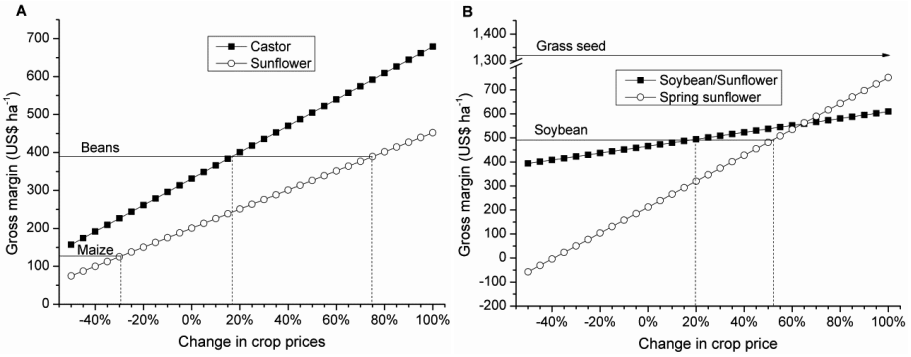

Figure 3.4 Sensitivity analysis of gross margins based on the increase (steps of plus or minus 5%) of crop prices of alternative production activities in Montes Claros (A) and Chapada Gaúcha (B).

3.3.2 Labour requirements

Labour requirements differ substantially between both municipalities. Mechanized production activities in Chapada Gaúcha show a progressive increase in labour demands from *current* to *irrigated* production techniques (Figure 3.5B). This is caused by the intensification of biocide use (number of sprays) in *best farmer's means* management, pest and disease monitoring strategies in *improved* and labour associated with *irrigation* practices. Grass seed, however, shows limited labour response in alternative production techniques relative to other production activities in Chapada Gaúcha. This is because 70% of labour requirements of grass seed are associated with crop harvest, which is not affected by alternative production techniques.

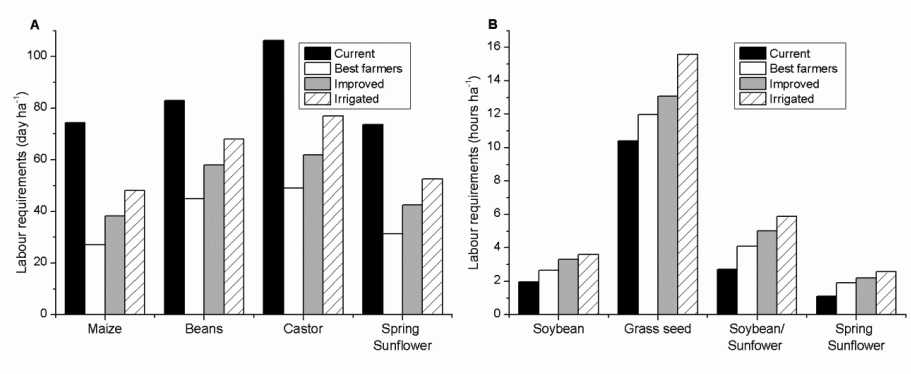

Figure 3.5 Labour requirements for current and alternative production activities with different production techniques in Montes Claros (A) and Chapada Gaúcha (B).

In Montes Claros where current production activities are based primarily on family manual labour, there is a decrease in labour demands from current to alternative production techniques (Figure 3.5A). From *current* to *best farmers' means*, labour requirements decrease by more than half. This results from the substitution of manual labour for land preparation (hired machinery) and weeding activities (biocide use). Castor bean shows the greatest difference in labour between current and alternative production activities as its longer cycle (210 days) is associated with higher labour requirements for weed control (Figure 3.5A). For all production activities there is an increase in labour demand from *best farmers' means* to *irrigated* production technique which is related to pest and disease monitoring and manual weeding (*improved*), and water supply management (*irrigated*).

3.3.3 Biocide residues and nitrogen losses

Results from the selected environmental indicators show a consistent increase in nitrogen losses and biocide residues with the intensification of production activities in both research locations (Figure 3.6). Chapada Gaúcha shows higher levels for the selected environmental indicators than Montes Claros for all production techniques. *Best farmers'* management presents higher values of biocide residue index (BRI) than other production techniques in both municipalities. Unsafe values of BRI are associated to soybean/sunflower, grass seed and maize. A more rational use of biocides (*improved*) is effective for most of the crops, with BRI values brought to the permissible zone

(100≤BRI≤200) (Figure 3.6A,B). The soybean/sunflower rotation, despite the lower BRI values under *improved* management, remains an unsafe production activity.

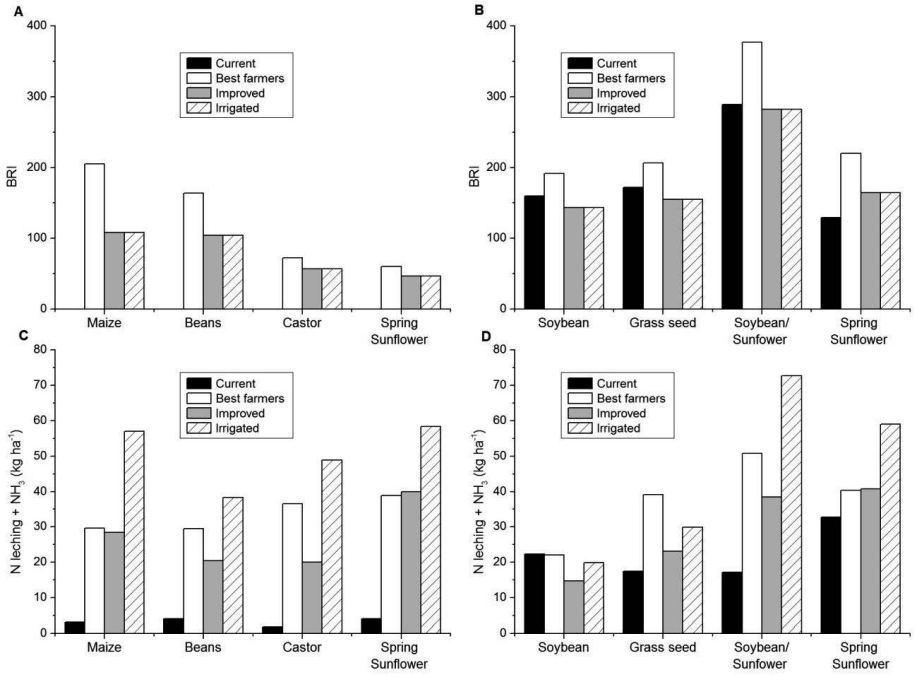

Figure 3.6 Biocide residue index – BRI (A and B) and nitrogen losses (C and D) for current and alternative production activities with different production techniques in Montes Claros (A and C) and Chapada Gaúcha (B and D).

Nitrogen losses are affected mainly by the rate of use and management of fertilizers. For most of the crops there is an increase in nitrogen losses from *current* to *best farmers' means* (Figure 3.6C,D). Soybean, however, shows no increase in losses because of the similar nitrogen fertilizer rates in all production techniques (Figure 3.6D). The *improved* management of fertilizer based on the split N applications decreases N losses relative to *best farmers' means*. Such decrease, however, is less evident for spring sunflower and maize (Figure 3.6C,D). These crops require higher rates of fertilizer under *improved* management due to higher yield levels (Figure 3.2A,B). The close relation between nitrogen losses and yield levels results in the highest N losses per ha for *irrigated* production activities. This is associated with

nitrogen requirements calculated to satisfy potential crop yield demands. The double cropping system soybean/sunflower results in the highest losses of nitrogen of all production activities, amounting 73 kg ha^{-1} under *irrigated* management (Figure 3.6D).

3.4 Discussion

3.4.1 Socioeconomic indicators

Although biodiesel crops have been promoted among farmers as a way of boosting farm income (MDA, 2011), the results indicate that the economic benefits of such activities are not evident. Gross margins for the selected production activities show that in Montes Claros the highest economic returns come from beans, which is an important subsistence crop (just as maize). Although not as profitable as beans, maize plays a key role as a fodder crop supporting animal production activities in all identified farm types in Montes Claros. Among the biodiesel crops in this region castor bean is economically more attractive than sunflower. However the integration of oil and feed production, which is regarded as an important enabling component of castor bean production in the North of Minas Gerais (Silva Jr. *et al.*, 2012), is limited due to its toxicity and the lack of safe and economically feasible detoxification methods (Severino, 2005). Moreover, castor bean labour requirements (mainly associated with weeding and harvest) are ca. 38% higher than from maize, beans and sunflower (Figure 3.5A). This feature increase competition for land with current crops as labour is constrained among family farmers in the region (Finco and Doppler, 2011; Florin *et al.*, 2012).

Intensification strategies are regarded as an effective way of dealing with resource related constraints (e.g. labour) associated with small scale farming systems (Dixon *et al.*, 2001; de Ridder *et al.*, 2004). For the selected crop activities in Montes Claros, the combination of mechanized equipment for land preparation, fertilizer use and biocide use lead to an improvement in yield levels of about 200% with 70% reduction in labour requirements from *current* to *best farmers means* (Figure 3.5A). This could allow farmers to engage in biodiesel crop production, e.g. castor bean, without compromising current food and feed demands. However, cash constraints coupled with limited access to credit and inputs (fertilizer, machinery, seeds, etc.) often

undermine farmers' ability to invest in higher input farming systems (Tittonell and Giller, 2013).

Sunflower, although less profitable than castor bean, has been acknowledged as a promising biodiesel crop (Ribeiro and Carvalho, 2006). Low labour requirements (similar to maize) and its potential to combine oil and feed (i.e. cake after oil extraction) led the inclusion of sunflower in the most recent R&D agendas, with a focus on semi-arid regions (MME, 2012a).

In Chapada Gaúcha, sunflower gross margins when cultivated during the spring, as a single crop, are considerably lower than that of current crops (soybean and grass seed) under both current and alternative production techniques (Figure 3.2D). The double cropping system soybean/sunflower presents minor economic benefits compared with single soybean. This shows that the addition of a summer crop (sunflower) does not result in substantial economic gains as revenues from sunflower are almost completely absorbed by its production costs. Furthermore, this double cropping system can only be a feasible option when farmers use short cycle soybean varieties allowing sunflower to be sown late in February before yields levels drop below 1,000 kg ha^{-1} (Figure 3.3).

Economic gains of alternative production activities based on major changes in crop prices seems not a likely scenario (Figure 3.4A,B). Moreover, in the last decade crop prices have been fairly stable, except for two peaks of castor and beans prices (Figure 3.7). Therefore, market driven changes of current gross margins able to shift the economic competitiveness of current and alternative production activities seems not plausible.

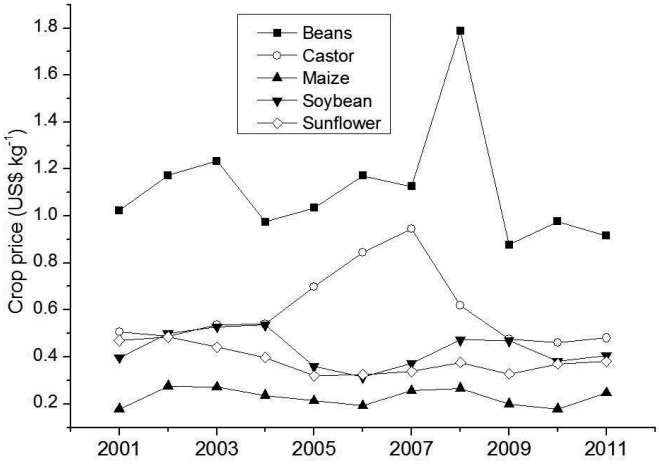

Figure 3.7 Annual crop prices from 2001 to 2011. Source: (CONAB, 2011; IEA, 2012a). Crop prices were updated on the basis of the consumer national price index (INPC: www.ibge.gov.br).

3.4.2 Environmental indicators

Agricultural intensification has been recognized as a way to address the increasing concerns on global food security (Cassman, 1999; Tittonell and Giller, 2013; van Ittersum *et al.*, 2013). The provision of food, fibre and bioenergy from agricultural systems, which are essential for human wellbeing, can also be the source of environmental impacts, including loss of wild life habitat, water pollution and biocide poisoning (Power, 2010).

In both research areas, nitrogen losses increase from current to alternative production techniques (Figure 3.6C,D). This increase in losses is particularly high for production activities in Montes Claros, where no fertilizer is used under *current* crop management (Figure 3.6C). Such losses, however, come with gains in crop production in the same piece of land. This can lead to higher nitrogen use efficiency (NUE) from the applied N inputs, by reducing the amount of N losses from organic and inorganic N pools, when compared to monoculture activities (Raun and Johnson, 1999; Cassman *et al.*, 2002). The ratio between yield levels and N losses (yield kg ha^{-1} ÷ N losses kg ha^{-1}) is on average 23% higher for soybean/sunflower than the summed individual values of spring sunflower and soybean monocultures. It means that N losses per kilogram of grain are reduced by 23% if sunflower follows soybean, instead of being cultivated in the spring. Anderson *et al.* (1997) found that double cropping activities can be an

effective way of reducing N loss from soil profiles, thus reducing the potential environmental contamination.

In Brazil, high nitrogen losses are mainly caused by volatilization of ammonia (NH_3) which is mainly affected by agroecological conditions and the surface application of urea fertilizer (Cantarella *et al.*, 2001; Vitti, 2003; Lara Cabezas *et al.*, 2008; Lara Cabezas and Souza, 2008). Although improving synchrony between N supply and crop demand (split N applications) with *improved* management (Figure 3.6C,D) proof to be an efficient way of limiting N losses; further gains in NUE could be achieved using slow release fertilizers, i.e. nitrate N instead of urea. Cantarella *et al*. (2003) found nitrogen volatilization losses up to 44% with urea compared to 2% losses with the use of ammonium nitrate fertilizers. Despite being effective, the popularity of such fertilizers remains low among farmers due to the costs (Shaviv, 2005), which in Brazil can be up to 100% higher than urea (CONAB, 2012).

From the energy perspective, there is an overall understanding that a double cropping system of soybean followed by sunflower is opportunistic, as it allows the increase of oil production without compromising current soybean areas (Ribeiro and Carvalho, 2006). However, environmental impacts of biocide use in this production activity are often overlooked. Farmers commonly adopt spray strategies based on combining multiple biocides (pesticides, fungicides and herbicides), as a way to save labour and prevent pest/disease outbreaks. This management leads to the use of less specific biocides which affect non-target species, e.g. natural enemies. Results from biocide residue index (BRI) show that, despite the implementation of a more rational management and use of biocides (*improved* production technique) unsafe values of BRI can still occur with the soybean/sunflower rotation (Figure 3.6B). An important reason for the high values of BRI could be the monocropping of soybean for the last 30 years in Chapada Gaúcha. Crop diversification, although a way to reduce pest infestations (Krupinsky *et al.*, 2002), is limited for economic reasons. Moreover, there are pests common for soybean and sunflower (Moscardi *et al.*, 2005) which could jeopardize positive effects of introducing another crop in the rotation.

The implementation of soybean integrated pest management (IPM), which was first introduced in Brazil in the 1970's, is likely to be the most effective strategy to reduce biocide residues (Oliveira *et al.*, 1988; Gazzoni, 1994; Panizzi, 2006; Moscardi

et al., 2009). Soybean fields in the South of Brazil showed that pesticide use can be reduced by 50% to 78% through pest monitoring, combined with biological control, and minimal use of non-persistent and pest specific biocides (Kogan *et al.*, 1977; Corrêa-Ferreira *et al.*, 2010). However, the limited availability of commercial biological agents and the lack of crop resistant varieties coupled with farmers' constraints in knowledge and trained labour still hamper further development of IPM (Kogan, 1998; Hoffmann-Campo *et al.*, 2000).

3.5 Conclusion

The results obtained in this study indicate that, although it has been claimed that biodiesel crops are able to enhance rural income, such economic gains are not evident when systematically compared with current crops such as beans (Montes Claros), and soybean and grass seed (Chapada Gaúcha) under different production techniques. Sunflower and castor bean are economically competitive with maize in Montes Claros where current production activities are less input intensive. Feed requirements and labour availability seem to be important determinants of farmers' choice when biodiesel crop production is considered. In this region intensification strategies (alternative production techniques) can be a way of dealing with labour limitations and increasing gross margins and yield levels. However cash constrains coupled with limited access to credit and inputs must be overcome.

In Chapada Gaúcha the double crop rotation soybean/sunflower is economically competitive only with the *best farmers' means* production technique, although with limited increases in gross margins when compared to soybean monoculture. Moreover, there are also environmental drawbacks associated with this double crop activity. *Improved* management proved to be effective in limiting nitrogen losses. On the other hand, a rational use of biocides seemed not sufficient to reduce the level of residues.

The selected model-based approach using TechnoGIN was useful in assessing an array of activities in terms of sustainability indicators, thus enabling to inform discussion on both socioeconomic and environmental aspects of the investigated production activities. It also allows insights in the impact of alternative production techniques available in the R&D pipeline but not widely adopted by farmers. The resulting quantitative assessment can inform recommendations to farmers' and be a

basis for policy making. Additional insight could still be gained from whole-farm studies which incorporate farmers' objectives and constraints leading to more insight and recommendations for the identified farm types in the research areas.

CHAPTER 4

Exploring sunflower (*Helianthus annuus* L.) yields in northern Minas Gerais: a crop model based approach

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This chapter has been submitted as:
João Guilherme Dal Belo Leite, João Vasco Silva, Flávio Barbosa Justino, Martin K. van Ittersum. Exploring sunflower (Helianthus annuus L.) yields in northern Minas Gerais: a crop model based approach. Scientia Agricola (2013).

Abstract

Pushed by the Brazilian biodiesel policy, sunflower production is increasingly regarded as an option for family farmers to increase their income, especially under semi-arid conditions. Traditional (experimental) research agendas are challenged by the increasing demand for information that could be supportive of decision making at different levels. The objective of this study is to evaluate the performance of OILCROP-SUN as to the simulation of sunflower development and growth under Brazilian conditions and, to explore sunflower yield levels and variability over an array of sowing dates in the northern region of Minas Gerais. For model calibration an experiment was conducted in Viçosa – Minas Gerais, in which two sunflower genotypes (H358 and E122) were cultivated on a clay soil. Growth components (leaf area index, above ground biomass, grain yield) and development stages (crop phenology) were measured. A database composed of 27 sunflower experiments from different Brazilian regions was used for model validation. The spatial yield distribution of sunflower was mapped using ordinary kriging in ArcGIS. OILCROP-SUN simulated satisfactorily sunflower yields with, however, relatively poor results regarding leaf area index, above ground biomass and crop phenology. Simulated yield levels were higher and the sowing window was wider for northwestern municipalities, where sunflower could be cultivated as a second crop (double cropping) at the end of the rainy season. In northeastern municipalities, on the other hand, sunflower yields were lower and constrained to a narrow sowing window. The hybrid H358 had higher yields for all simulated sowing dates, growth conditions and selected municipalities.

Keywords: family farms, biodiesel, modelling, semi-arid

4.1 Introduction

Sunflower has been considered a promising option as a biodiesel crop for family farming systems especially in the semi-arid regions of Brazil. Its tolerance to dry spells, high oil content (35-50%) and short cycle (75-100 days), which could allow double cropping systems, are among the favourable crop characteristics (Leite et al., 2005; Ribeiro and Carvalho, 2006).

Government bodies are keen to implement policies able to promote rural development, thus boosting economic development at local and regional level.

Recently, a national project has been unfolded with a particular aim of technology transfer and capacity building among farmers and extension agents as to the sustainable production of sunflower under semi-arid conditions. This project will be implemented by government extension services located in the Northeast region of the country with further funding from a national energy company (MME, 2012a). The northern region of Minas Gerais is of particular interest due to its potential for sunflower cultivation (MAPA, 2002), diversity of climatic zones (from humid to semi-arid), and family farming systems it possesses (Leite et al., 2013).

The launch of the National Program of Production and Use of Biodiesel (PNPB, in Portuguese) brought new opportunities for the socioeconomic inclusion of family farmers and created an increasing demand of supportive knowledge for agricultural decision making at different levels. Traditional agronomic research through experimentation, which is site and season specific, time consuming and expensive, often fails to generate sufficient data to meet these increasing needs (Jones et al., 2003).

Crop growth simulation models are a useful tool to explore and simulate future cropping systems and to enhance understanding of their behaviour. The use of systems approaches in the development of such models provides quantitative insights about the eco-physiological processes which occur at crop level, making these tools highly suitable to understand the underlying mechanisms of crop development and growth. Furthermore, they can help to better target empirical studies thus setting an agenda for experimental research (Bouman et al., 1996; van Ittersum et al., 2003b).

Previous studies have used crop growth simulation models to assess the impact of climate change (e.g. van Ittersum et al., 2003a) or different crop management strategies (e.g. Singh et al., 1994) on crop yield and other simulated environmental outputs. Specifically for sunflower, different sowing dates were simulated to assess the intra-annual yield variability under the ecological conditions of southern Brazil, thus leading to technical recommendations about optimal window of opportunities for planting (Rolim et al., 2001).

The objective of this study is to evaluate the performance of OILCROP-SUN for the simulation of sunflower development and growth components under Brazilian conditions and to explore sunflower yield, and its variability, over an array of sowing dates in the northern region of Minas Gerais. Such analysis aims at creating awareness

on the suitability of crop growth simulation models in supporting traditional research agendas. Furthermore, it is also useful to shed light on the sustainability of sunflower cultivation in different climatic conditions, either in single or double cropping systems.

4.2 Materials and methods

4.2.1 Model overview

OILCROP-SUN is a process-oriented crop model which simulates, with a daily time step, sunflower development and growth (Villalobos et al., 1996). It is a CERES-type model which belongs to the Decision Support System for Agro-technology Transfer (DSSAT). DSSAT provides a framework for cropping systems analysis where different crop models can be built into a platform with compatible input files, data structure and modes of operation (IBSNAT, 1993; Jones et al., 2003).

Crop development is divided in three different phases: sowing to emergence, emergence to first anthesis and first-anthesis to physiological maturity. Cumulative thermal time regulates the duration of each phase (Robinson, 1971), while photoperiod only interferes with the flower bud initiation (e.g. Goyne and Schneiter, 1988). Crop development is regulated by three genotype-specific genetic coefficients (P1, P2 and P5) that can be modified by the user (Table 4.1). Leaf appearance, expansion and senescence are used to estimate leaf area index (LAI) during the growing period and are modelled as a function of temperature as well.

Photosynthesis is modelled based on the concept of radiation use efficiency (RUE), i.e. the rate of conversion of intercepted radiation into new biomass, which varies with crop phenology (Trapani et al., 1992). Biomass accumulation over time is reduced by the most constraining factor, namely temperature, water or nitrogen, and biomass is partitioned among the growing organs by means of partitioning coefficients. Finally, sunflower yield is computed by the product of grain number, grain weight and plant population. Plant population is experimentally defined, whereas grain number and weight are controlled by three genotype-specific genetic coefficients (G2, G3 and O1) which, also, can be manipulated by the user (Table 4.1).

4.2.2 Model calibration

A field experiment was conducted in Viçosa (20º 44' S, 42° 50' W, 670 m a.s.l.), Southeast of Minas Gerais. The experiment was sown on 25th November 2011 on a clay soil under rainfed conditions, covering an area of 400 m^2. Two treatments were applied corresponding to different genotypes, namely Embrapa 122 (E122, conventional cultivar) and Hélio 358 (H358, hybrid), currently being tested and cultivated as biodiesel crops in North of Minas Gerais. Each treatment was sown in an area of 200 m^2 which was split in four replications of 50 m^2 (5 × 10m). The experiment was set in a randomized block design (4 replications = 4 blocks) containing, in each block, one replication of each genotype. Plant population at sowing was 5 plants m^{-2}, corresponding to a spacing of 0.7 × 0.285 m. The supply of macro-nutrients was calculated based on soil analysis and expected yield levels and was split into two applications. The first occurred at the time of sowing in which 16, 56 and 32 kg N, P and K ha^{-1} were applied. The second was performed 21 days after emergence, in which 120, 30 and 120 kg N, P and K ha^{-1} were applied.

At physiological maturity, which was registered on 6th and 12th March 2012 for E122 and H358, respectively, sunflower grain yield was estimated based on destructive sampling of 40 sunflower plants per genotype. Crop phenology was registered every five days, following the scale suggested by Schneiter and Miller (1981). LAI and above-ground biomass accumulation were measured seven times throughout the growing period from a sample of 20 sunflower plants per genotype to evaluate the capability of the model to reproduce the observed values and patterns. LAI was estimated based on the relation between leaf area and leaf weight (specific leaf area) of 10 leaves in each plant randomly selected throughout the stem. For quantifying above-ground biomass, the entire aerial part, i.e. stem, petiole, leaves, bracts and capitulum, of the sampled plants in each period were oven dried (65±5 °C) until constant weight.

In addition to experimental data, weather data and soil profile information were used as inputs to calibrate OILCROP-SUN for the studied genotypes. Maximum and minimum air temperature (ºC), solar radiation (MJ m^{-2} d^{-2}) and precipitation (mm), which are the minimum weather input requirements to run DSSAT (Hoogenboom, 2000), were obtained from a conventional meteorological station located at the Federal University of Viçosa (UFV). Information about soil texture (% clay and silt) and soil

organic carbon (%) throughout the soil profile of the experimental site was obtained from Rodrigues (2011).

The calibration of OILCROP-SUN consisted of the estimation of the six genotype-specific genetic coefficients for E122 and H358 (Table 4.1), which was done manually and following a stepwise approach. The development coefficients P1, P2 and P5 were calibrated by adjusting simulated first anthesis and physiological maturity dates to the observed ones. Afterwards, the yield coefficients G2, G3 and O1 were adjusted taking into consideration literature reference values (Villalobos et al., 1996; Rolim et al., 2001; Rinaldi et al., 2003). The obtained genetic coefficients are presented in Table 4.1.

Table 4.1 Calibrated genetic coefficients of the studied sunflower genotypes, E122 and H358.

Treatments	P1	P2	P5	G2	G3	O1
E-122	260.0	1.30	715.0	1500	6.50	75
H-358	305.0	0.90	790.0	1700	6.50	75

Where P1 = Length of the juvenile phase (°C day) with base temperature of 4 °C. P2 = Photoperiodic coefficient (day h^{-1}). P5 = Duration of the first flowering to the physiological maturity stage (°C day). G2 = Maximum number of grains per capitulum. G3 = Potential kernel growth rate during the filling phase (mg day^{-1}). O1 = Maximum kernel oil content (%).

To evaluate the deviation between model simulations and observed experimental values during the calibration exercise the percentage of absolute deviation (PAD) was used. PAD is defined as the absolute deviation between simulated (x_i) and observed values (x_i^0). Similarly to Hazell and Norton (1986), it is assumed that a satisfactory calibration is achieved with PAD values ≤ 15%. PAD can be estimated as follows:

$$PAD(\%) = 100 \times \frac{\left(\sum_i |x_i - x_i^0|\right)}{\left(\sum_i x_i^0\right)} \quad \text{Eq.1}$$

4.2.3 Model evaluation

Data from field experiments conducted in the states of Minas Gerais, Goiás, São Paulo, Paraná and Distrito Federal during 2004 to 2011 (Embrapa, 2012) with the genotypes E122 and H358 was used to test the model suitability to simulate sunflower yield and phenological stages. All experiments were rainfed, although some benefited from supplementary irrigation in case of extreme drought. For each experimental site,

weather data was obtained from conventional weather stations of the 5th Meteorological District of INMET. Due to lack of more detailed weather data, a zone with 100 km radius around the weather station was considered a climatically homogeneous area. Information about the variation of physical soil properties throughout the soil profile was taken from the RADAM-Brazil project database (Radambrasil, 1986) and Jacomine et al. (1979).

A computer simulation experiment was created with OILCROP-SUN, for each experiment. The cross-validation exercises consisted of model-runs with the previously calibrated genetic coefficients for Viçosa under different experimental and environmental conditions, i.e. model results were compared with independent datasets. The model evaluation (Jamieson et al., 1991; Loague and Green, 1991) was performed using two statistical indexes, namely Root Mean Square Error (RMSE) and Modelling Efficiency (ME), similarly to Rinaldi et al. (2003). The generic mathematical formulation of the mentioned statistical indicators is as follows:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=i}^{n}(Pi - Oi)^2}{n}} \cdot \frac{100}{O} \qquad \text{Eq.2}$$

$$\text{ME} = \frac{[\sum_{i=1}^{n}(Oi - O)^2 - \sum_{i=1}^{n}(Pi - Oi)^2]}{\sum_{i=1}^{n}(Oi - O)^2} \qquad \text{Eq.3}$$

where *Pi* stands for the predicted values, *Oi* for the observed values and *O* for the observed mean values. RMSE measures the difference between simulated and observed data. Simulations are considered to be excellent with RMSE <10%, good between 10-20%, fair between 20-30%, and poor >30%. The lower limit for both RMSE and ME is zero. The maximum value for ME is 1. If ME is less than zero the simulated values are worse than simply using the observed mean values. A positive value for ME, on the other hand, indicates that the model performs better than simply applying the observed mean (Loague and Green, 1991).

4.2.4 Model application

OILCROP-SUN was used to simulate yield levels of the two sunflower genotypes, E122 and H358, in 14 different municipalities in the northern region of Minas Gerais, as shown in Figure 4.1. Weather data for the period 1979 - 2009 (INMET, 2012) was used to

study the inter-annual variability of sunflower potential, water-limited and water- and nitrogen-limited yield levels for all municipalities. According to van Ittersum et al. (2003b), potential yields reflect the bio-physical potential of the region and are computed based on the growth-defining factors (e.g. solar radiation, temperature and sowing date). Water- and/or nutrient-limited yield levels are further affected by water and nutrient availability, defined as growth-limiting factors. In this study three yield levels are explored: (i) potential; (ii) water-limited and; (iii) water- and nitrogen-limited. Those can be implemented in OILCROP-SUN by turning off or on the soil-nitrogen and/or the soil-water subroutines in the model. Simulations were performed for 32 different sowing dates, with a weekly time step, between the end of August and the end of March to explore optimal sowing periods for sunflower across the studied region.

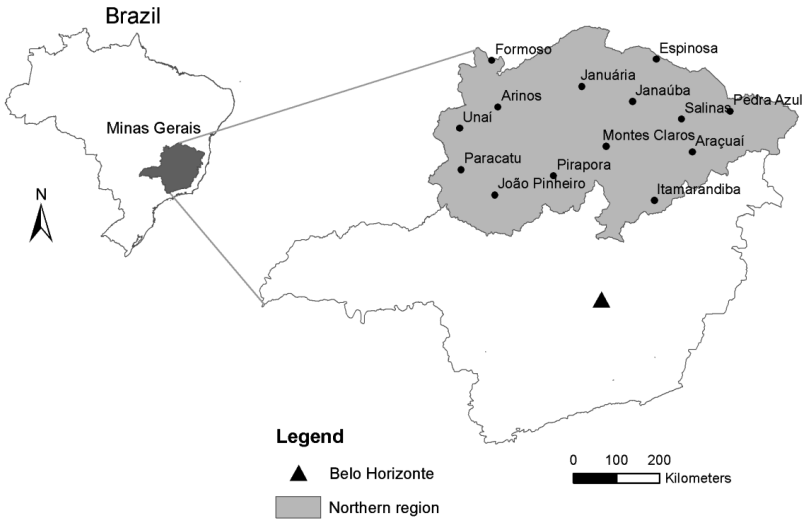

Figure 4.1 Northern region of Minas Gerais with the location of the 14 municipalities for which crop model simulations were performed.

A single soil profile, classified as dystrophic red-yellow Oxisol, was used across the entire region (Table 4.2) due to its predominance in North of Minas Gerais (Jacomine et al., 1979). Moreover, an application of 75 kg of nitrogen, 15 kg at sowing and 60 kg 30 days after sowing, was used as standard fertilizer management strategy exclusively for water- and nitrogen-limiting simulations. Such nutrient management is based on most

common farmers' practice and literature information (Embrapa, 2012). Additional water supply through irrigation was not considered. For water-limited production situations fertilizer inputs were not considered as the soil-nitrogen sub-routine was switched off.

Table 4.2 Soil profile information used in the northern region of Minas Gerais according to Jacomine et al. (1979).

Soil profile (m)	Texture (%)			Org. C (%)
	Clay	Silt	Sand	
0-0.2	31	5	64	0.70
0.2-1.2	31	5	64	0.36

The spatial distribution of sunflower water- and nutrient-limited yield levels was assessed based on average simulations of 31 years (1979 – 2009) for all selected municipalities in the northern region of Minas Gerais (Figure 4.1). Sunflower yield variability was then mapped using the ordinary 'kriging' method in ArcGIS 10, similarly to Vieira and Gonzalez (2003); Pringle et al. (2004); and Lu and Fan (2013).

4.3 Results and Discussion

4.3.1 Calibration and evaluation of OILCROP-SUN

Crop development and growth components

The calibration procedure resulted in satisfactorily agreement between the observed and simulated values for the variables yield, first anthesis and physiological maturity. However, the model performed poorly in simulating LAI and above ground biomass for both genotypes, wit PAD values higher than 15% (Table 4.3). As shown in Figure 4.2, simulated LAI and above ground biomass were always underestimated by OILCROP-SUN throughout the growing season. This indicates that the model might not able to simulate relatively high LAI for water- and nitrogen-limited production levels, although similar sunflower values of LAI had been reported in the literature (Gimeno et al., 1989). Above ground biomass is a function of LAI (Whitfield et al., 1989) and was hence also underestimated by the model due to limited solar radiation interception during crop growth.

Table 4.3 Observed and simulated values for crop development (days after planting – DAP) and growth components (dry matter – DM) of each genotype (E122 and H358) followed by the percentage of absolute deviation (PAD).

Genotype	Variable	Observed	Simulated	PAD (%)
E122	First anthesis (DAP)	61	61	0
	Physiological maturity (DAP)	98	98	0
	Leaf area index [a]	2.6	1.5	42
	Above ground biomass [b] (kg DM ha^{-1})	6600	4700	29
	Yield (kg ha^{-1})	3860	3940	2
H358	First anthesis (DAP)	67	67	0
	Physiological maturity (DAP)	108	108	0
	Leaf area index [a]	4.3	2.1	51
	Above ground biomass [b] (kg DM ha^{-1})	9400	6500	31
	Yield (kg ha^{-1})	5000	4890	2

[a] Average leaf area index during the growing season. Observed values correspond to the average of seven experimental measurements. Simulated values represent the average simulated LAI for the same dates when field observations were measured.

[b] Average above ground biomass during the growing season. Observed values correspond to the average of five experimental measurements. Simulated values represent the average simulated above ground biomass for the dates when field observations were measured.

In OILCROP-SUN leaf area dynamics was indirectly adjusted in the calibration procedure along with the genetic coefficient P1, which defines the length of the vegetative growth period. It is suggested that improved model simulations could be achieved through the calibration of leaf area dynamics, i.e. specific leaf area, LAI growth rate and assimilate partitioning. A similar approach had already been implemented in different models (e.g. van Laar et al., 1997; Boogaard et al., 1998).

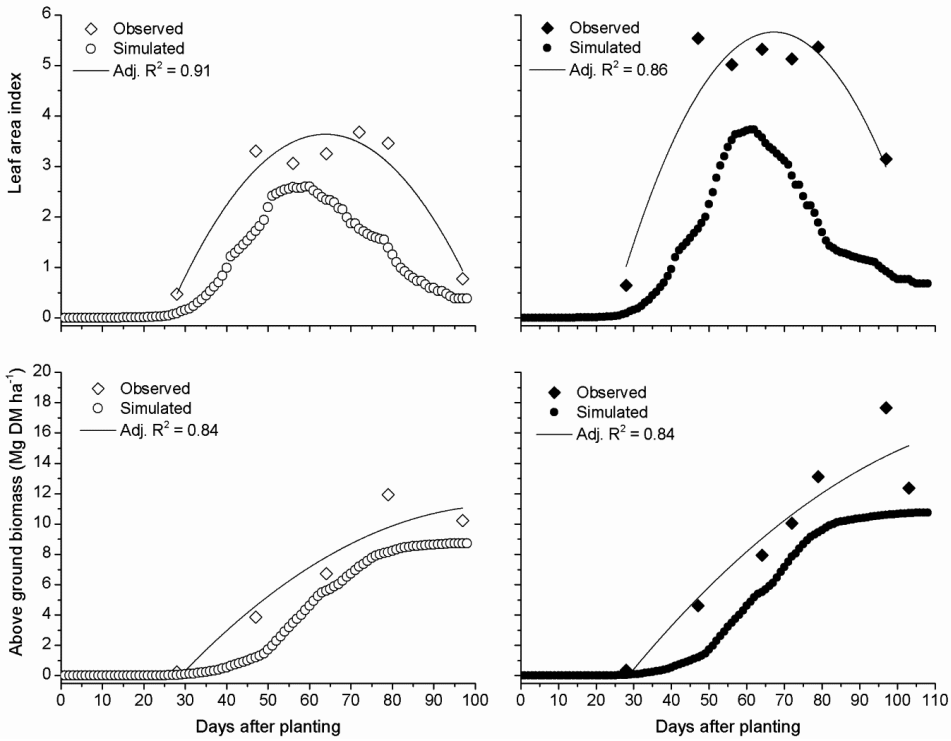

Figure 4.2 Observed and simulated leaf area index (LAI) and above ground dry matter (DM) for both genotypes over the growing cycle (days after planting – DAP). Open and closed data points refer to genotypes E122 and H358, respectively.

Consistent underestimation of LAI values was also found with the CERES-MAIZE model (Lizaso et al., 2003), which also belongs to the DSSAT framework. A new leaf area model to simulate expansion, longevity and senescence of maize (*Zea mays* L.) leaves was implemented resulting in enhanced model simulations. Such an approach could be tested for OILCROP-SUN using whole-plant analysis to experimentally study and quantify sunflower leaf dynamics, similarly to Dosio et al. (2003).

The hybrid genotype (H358) has a longer growth cycle (108 days) than the conventional cultivar (E122 = 98 days) (Table 4.3). This, combined with greater LAI values, contributes to higher yield and above ground biomass production of H358. Moreover, the higher accumulation of assimilates from emergence to first anthesis

makes a substantial contribution to sunflower grain filling at the end of the growing period (Hall et al., 1989).

Statistical evaluation of model performance

The model had a good performance in simulating sunflower yields for both genotypes according to the selected statistical indicators (Table 4). Crop phenology, on the other hand, was poorly simulated by the model. The negative values for modelling efficiency (ME) are an indication of the unreliability of the simulated values of first anthesis and physiological maturity (Table 4.4).

The inability of the model to simulate observed values for sunflower phenology might also be affected by inherited uncertainty associated with the observed values. Across the different experiments used to validate the model, crop development was observed by different experimentalists, thus creating potential imprecision as there is often no consensus on how to identify, for instance, whether sunflower plants achieved physiological maturity (Connor and Sandras, 1992). Grain yield estimation, on the other hand, is less vulnerable to experimental inaccuracies.

Table 4.4 Observed and simulated sunflower yields (kg ha^{-1}) and development stages (days after planting – DAP) followed by statistical indicators.

	Observed			Simulated		Statistics	
	N	Mean	St.dev.	Mean	St.dev.	RMSE	ME
E122							
First anthesis (DAP)	8	51	7	55	3	14.2	−0.3
Physiological maturity (DAP)	5	80	8	93	8	18.7	−3.9
Yield (kg ha^{-1})	11	1615	753	1638	675	14.2	0.9
H358							
First anthesis (DAP)	16	57	7	63	4	13.7	−0.5
Physiological maturity (DAP)	9	93	13	105	10	19.5	−1.2
Yield (kg ha^{-1})	15	2072	730	2209	707	12.0	0.9

4.3.2 Regional yield variability

Simulated sunflower yield ranges show to be remarkably sensitive to regional characteristics, which in this case are associated to rainfall amount and distribution. Northwestern municipalities have higher yield levels for most of the simulated sowing periods (Figure 4.3). The difference between regions can be ca. 1000 kg ha^{-1} after sowing in November which is the optimal date for most of the region (Figure 4.3D). For the northeastern part of Minas Gerais, which is known for its water shortage (i.e. up to 50% lower than the northwestern region) sowing dates are often the only strategy available for farmers to maximize crop production by reducing risks of crop failures.

With the rainy season for most of the selected municipalities starting between the second half of October and the first half of November, crop productivity tends to reach its peak after sowing in this period (Figure 4.3D,E). August sown sunflower has a low productivity with yields across the whole region not greater than 800 kg ha^{-1} (Figure 4.3A). There is an increase in crop yields after sowing in September as a response to higher rainfall, reaching nearly 1200 kg ha^{-1} and up to 1600 kg ha^{-1} in a constrained southern area (Figure 4.3B). From sowing dates later than end of October a clear pattern could be identified with sunflower yield decreasing from the northwestern to the northeastern areas (Figure 4.3C-F). Planting dates later than February resulted in uniform and low sunflower yields across the whole region (Figure 4.3G,H).

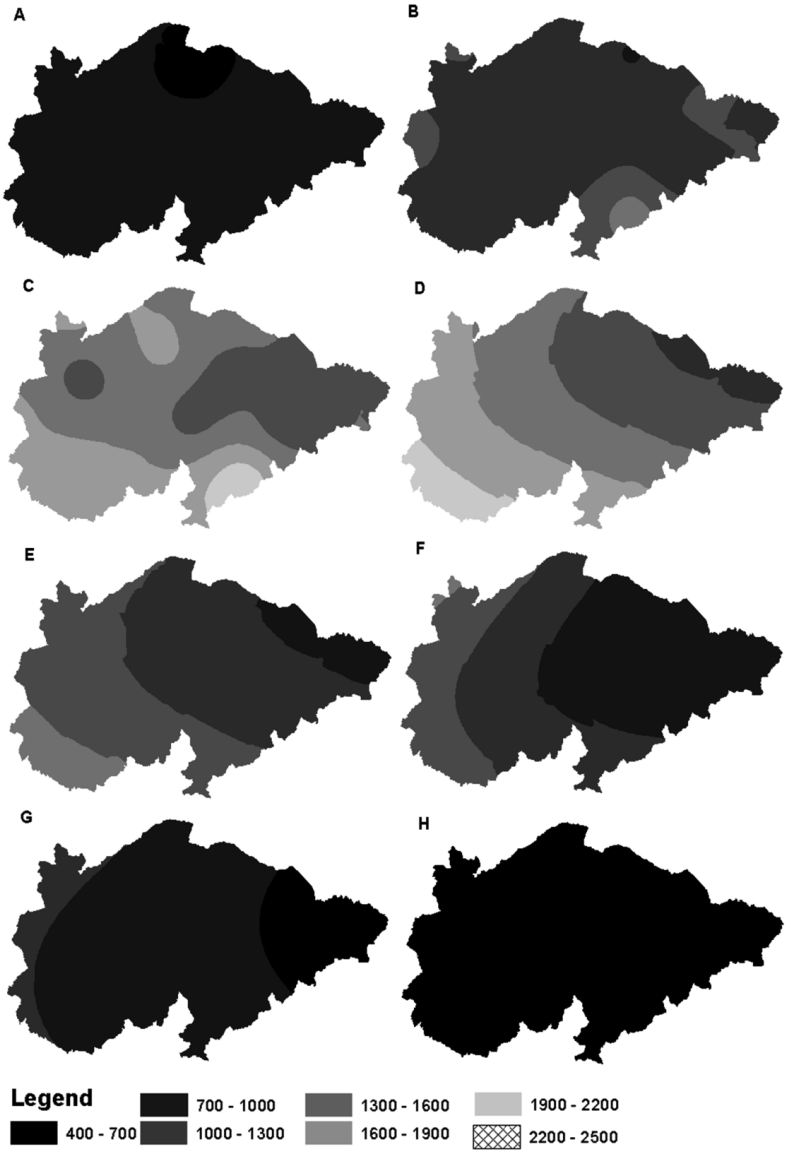

Figure 4.3 Water- and nitrogen-limited sunflower yield levels in the northern region of Minas Gerais after different sowing dates (A – Aug 23, B – Sep 22, C – Oct 27, D – Nov 24, E – Dec 22, F – Jan 26, G – Feb 23, H – Mar 30) presented as averages of two genotypes (E122 and H358).

4.3.3 Genotype and crop management

Besides regional yield variability, there was also a consistent difference between sunflower yield levels when the two genotypes were compared under different growth conditions (Figure 4.4). The hybrid performed better for most of tested sowing periods, except for periods with substantial water constraints, mainly at the end of the rainfall period when both varieties performed similarly. When water and nitrogen are non-limiting (potential growth conditions) the hybrid genotype performed better across the entire period of simulation. These findings are in line with the literature which point at a better performance of hybrid sunflower genotypes in Minas Gerais and other Brazilian regions (Ribeiro and Carvalho, 2006; Embrapa, 2012).

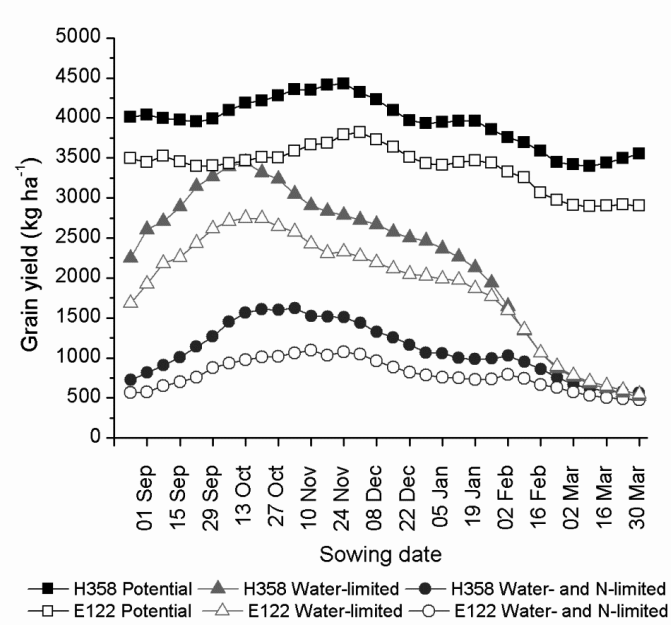

Figure 4.4 Simulated sunflower yield levels under water and nitrogen-limited water-limited and potential conditions after different sowing dates presented as averages of 14 municipalities.

There is a significant response of sunflower yields to higher levels of fertiliser (i.e. nitrogen) applications with an increase in crop productivity from 1000 and 1500 kg ha^{-1}, under water- and nitrogen-limited conditions, to 2800 and 3500 kg ha^{-1}, under

water-limited conditions, for E122 and H358 respectively (Figure 4.4). Maximum yields were obtained under potential conditions with sunflower yields of about 4500 kg ha^{-1} for the hybrid genotype when sown between October and November (Figure 4.4).

Irrigation could be a key factor to improve sunflower yields in the northeastern region. In fact, there are some municipalities, such as Janaúba and Januária in the East with high radiation levels that can perform better in terms of sunflower yield levels than those in the northwestern region, such as Unaí and Paracatu (Figure 4.5). This is because in the absence of growth-limiting and reducing factors (biotic: weed, pest, disease; and abiotic: pollution, toxicity) growth-defining factors determine maximum production (van Ittersum et al., 2003b). Water, however, is frequently a scarce and expensive resource (Postel et al., 2001). Hence, the economic feasibility of irrigated systems is often constrained to high value added crops (i.e. vegetables, fruits). In a present irrigation project in the North of Minas Gerais, bulk traditional crops such as maize, beans (*Phaseolus vulgaris* L.), cassava (*Manihot esculenta* Crantz) and rice (*Oryza sativa*), account for only ca. 20% of the irrigated area, while vegetables and fruits, mainly banana (*Musa spp.*), cover nearly 70% of the total irrigated area (DIJ, 2006).

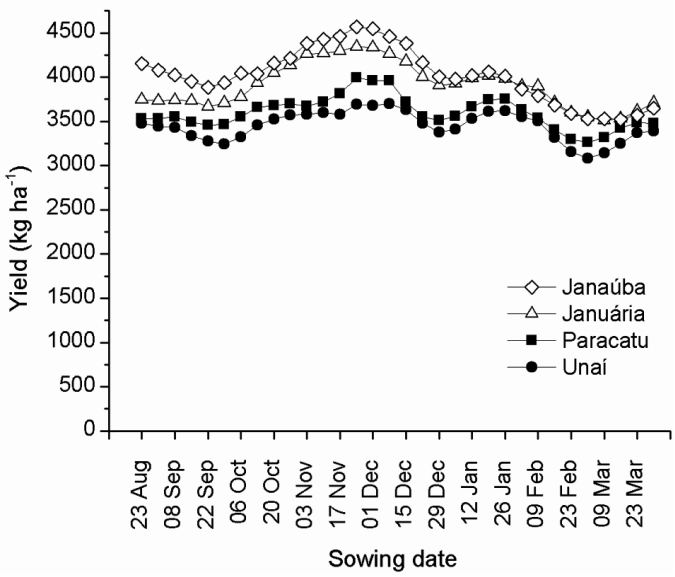

Figure 4.5 Potential sunflower yield levels for municipalities in the northwestern (Paracatu and Unaí) and northeastern (Janaúba and Januária) regions of Minas Gerais.

4.3.4 Local and inter-annual yield levels

Although sunflower has been regarded a promising crop in the light of the biodiesel policy (Ribeiro and Carvalho, 2006); it is still uncertain whether it will become a sustainable option for farmers, especially in more semi-arid regions.

Simulated sunflower yield levels for the municipality of Pedra Azul, one of the driest in the database with less than 1000 mm average annual rainfall, shows that the window of opportunity to maximize yields is constrained to a short sowing period, which extend from 6 to 20 of October especially for H358 genotype (Figure 4.6). The simulated yields for this sowing period are 1500 kg ha^{-1} for H358 and 1000 kg ha^{-1} for E122. Although there is still a large variability of yields over the years due to rainfall variation, sunflower productivity tends to decrease in any other sowing period. Potential conflicts could emerge as this optimum period also coincides with the sowing of current crops (e.g. maize and beans). Family farmers, which are targeted by the biodiesel policy in the northern region of Minas Gerais, are often resource (i.e. land, labour and cash) constrained (Leite et al., 2013). Hence, their engagement in production of sunflower for the biodiesel industry could lead to potential land use trade-offs with current crop

activities with further impacts on food and feed production of the farm household (Florin et al., 2012). Furthermore, the availability of quantitative studies which systematically compare the economic and environmental sustainability of biodiesel crops against current ones is still limited.

The municipality of Unaí, on the other hand, has a more favourable rainfall amount and distribution (1398 mm average annual rainfall). This municipality is one of the most important crop producing regions in the state, where soybean (*Glycine max* L.) features as the most important crop (SAEMG, 2012). The window of opportunity to maximize sunflower yields is clearly wider than in Pedra Azul, in case a hybrid genotype is cultivated. Optimal yield levels could be attained in a sowing period between October and December reaching up to ca. 1700 kg ha^{-1} for the genotype H358 (Figure 4.6). Although the economic competitiveness of sunflower with soybean is still questionable, there seems to be room for the inclusion of sunflower in a rotation with current crops or in double cropping systems. For the latter, sunflower could be cultivated as a second crop following early planted soybean or maize. The success of such arrangement, however, relies on the combination of short cycle varieties which allow sunflower to be sown until mid-February, when water- and nitrogen-limited yields are ca. 1000 kg ha^{-1} with the hybrid genotype.

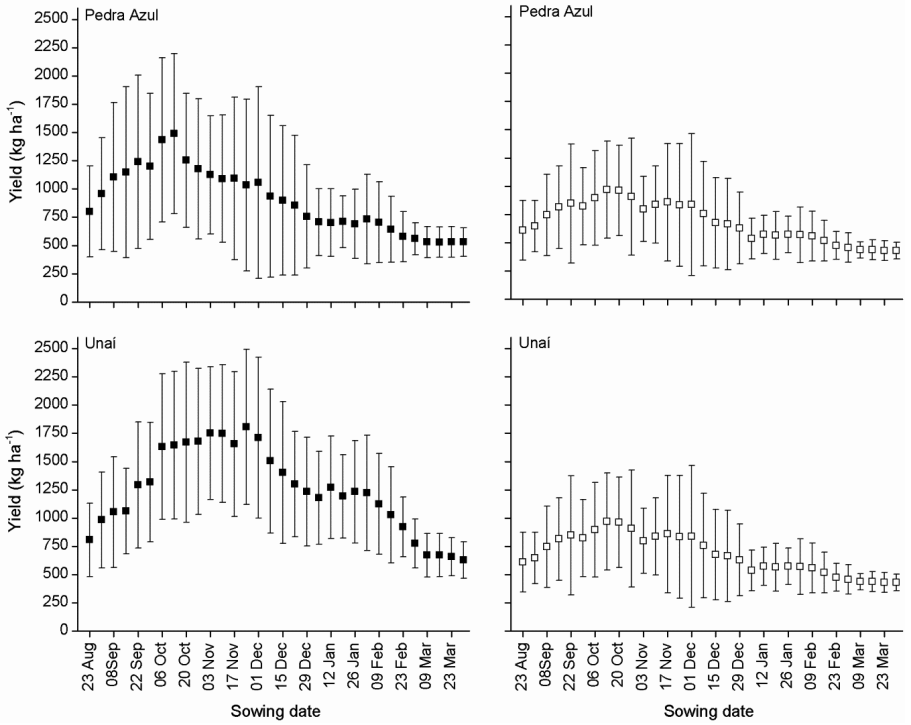

Figure 4.6 Water- and nitrogen-limited sunflower yield levels (genotypes: H358; E122) in the municipalities of Pedra Azul (Northeast) and Unaí (Northwest). Dots represent averages (n = 31) and bars represent standard deviations. Full and open data points stand for H358 and E122, respectively.

Short cycle sunflower genotypes such as E122 are often claimed to be best suited for double cropping systems, thus being less likely to be affected by the shrinking water availability towards the end of the rainy season. We simulated, however, that the hybrid genotype (H358), has higher yields (50 to 100 kg ha^{-1}) in both municipalities after late sowing, when rainfall decreases significantly (Figure 4.6). This result does not rule out the impact of crop cycle, which can indeed be an effective strategy for crop production within short rain periods (Bazza, 2001), but highlights that for the simulated growth conditions and genotypes such advantage was not observed.

4.4 Conclusions

The crop model OILCROP-SUN was effective in simulating sunflower yields for the northern region of Minas Gerais. It, however, consistently underestimated LAI and above ground biomass which seems to be the major model limitation. Furthermore, the simulation of crop phenology (first anthesis and physiological maturity) was moderately accurate.

Simulated sunflower yield levels presented a spatial pattern across the northern region of Minas Gerais, with higher yields attained in the northwestern area where the sowing window to reach optimal crop production is wider than in the Northeast of the region. Coupled with lower yields, farmers in the Northeast, often constrained in land, labour and capital, might also face trade-offs between sunflower and current crops due to the concentration of activities in the beginning of the rainy season. Double cropping systems, with sunflower being cultivated as a second crop could be a feasible option for farmers in the northwestern region where sunflower sown up to mid-February can still yield ca. 1000 kg ha^{-1}.

The hybrid genotype (H358) had higher yields for all simulated sowing dates, municipalities and growth conditions (water- and nitrogen limited, water-limited and potential) when compared with the conventional cultivar (E122).

CHAPTER 5

Integrated assessment of biodiesel policies aimed at family farms in Brazil

This chapter has been submitted as:
João Guilherme Dal Belo Leite, João Vasco Silva, Martin K. van Ittersum. Integrated assessment of biodiesel policies aimed at family farms in Brazil. Agricultural Systems (2013).

Abstract

With many of the less endowed people in Brazil living in rural areas, local governments have intensified their efforts to design and implement effective policies that boost rural development. In 2004, a national program for production and use of biodiesel was launched aiming at increasing income among less endowed family farmers across the country. With expectations being built on further expansion of the mandatory blending of biodiesel with fossil diesel, national and local government bodies are challenged by the search for strategies able to enhance biodiesel crop production through the wider cultivation of crops that produce more oil than soybean (e.g. sunflower and castor bean) and by improving the engagement of less endowed farmers, especially in semi-arid regions. Therefore, the objective of this study was to perform an *ex-ante* integrated assessment of the socioeconomic and environmental impacts of five biodiesel policy scenarios towards different farm types in a semi-arid and more humid region of Southeast Brazil. The applied modelling framework in the assessment of different policy scenarios was a combination of a technical coefficient generator (TechnoGIN) and a bio-economic farm model (FSSIM). We explored the impact of market-driven (bonus price policy), input provision (fertiliser and land preparation policy), oil production (oil mill policy) and environmental policy scenarios on soybean farmers (farm type 1 and 5) in Chapada Gaúcha and maize/beans farmers (farm type 2 and 4) in Montes Claros. The effects of the different policies on farm gross margins, oil crop production, labour requirements, nitrogen losses and biocide residues were assessed. Farmers in Chapada Gaúcha responded positively in terms of oil crop production (up to 171% increase) and gross margins (up to 40% increase) to all explored policy scenarios. However, the cultivation of sunflower in this region, mainly in double cropping systems, was associated with unsafe values (> 200) of the biocide residue index. The scope for biodiesel crops on small, less endowed farmers in Montes Claros was less evident than in Chapada Gaúcha. Most effective policy scenarios include the provision of inputs such as fertiliser and land preparation. In this region farmers have limited access to fertiliser, machinery and biocides, thus strategies that enable farmers to increase their cropped area (i.e. the land preparation policy more than doubled the crop area) and crop yield levels (i.e. the fertiliser policy almost quadrupled crop yields) have more potential to benefit farming systems, as was confirmed and quantified in our results.

Key words: biofuel; farming systems; sustainability; modelling; bio-economic

5.1 Introduction

Over the last decade the Brazilian government has intensified its efforts to introduce policies aiming at the reduction of poverty across the country. Rural areas, which have relatively high levels of less endowed people (IBGE, 2011b), have been targeted by such policies designed to reduce social and economic disparities. A strategy to boost rural development was the creation of the national program for production and use of biodiesel (PNPB in Portuguese) in 2004 (Brasil, 2005). Such program was followed by a set of regulations leading to a mandatory blending of biodiesel with fossil diesel from 2% to today's 5%. The biodiesel legislation further establishes tax reductions and selling preferences at biodiesel auctions for biodiesel producers that comply with a minimum quota of feedstock acquisition (15 - 35%) from family farmers, which are then granted with the so-called "social fuel" stamp (MDA, 2012).

From the energy point of view, the biodiesel policy has achieved its goals mainly as a way of strengthening the Brazilian renewable energy matrix, currently accounting for 45% of the country domestic supply, and improving the country's fuel self-sufficiency (EPE, 2011). However, when considering the reduction of socioeconomic disparities, the outcomes of the biodiesel policy are still questioned. Roughly 95% of feedstock acquisition from family farms is soybean, which has rather low oil content (ca. 18%) and is produced mainly in the South and Central-West regions of the country. As a consequence, semi-arid regions (e.g. Northeast), which have the highest concentration of family farmers in Brazil, account for ca. 5% of the total biodiesel feedstock acquisition (MDA, 2011). Moreover, these regions have an agricultural per capita GDP that can be seven times smaller than more humid areas in South and Central-West regions of Brazil (IBGE, 2006).

With expectations being built on further expansion of the mandatory blending of biodiesel, national and local government bodies have been challenged by the search for strategies which could enhance biodiesel crop production through the expansion of crops that are more oil productive than soybean (e.g. sunflower – 45% oil) and by improving the engagement of less endowed farmers under semi-arid conditions. Currently there is a need for knowledge on how family farmers would respond to

different policies that could be used to improve family farms' uptake of biodiesel feedstock production. With growing interest from governments and agencies on the *ex-ante* assessment of new policies, science has developed tools that enable a better informed agricultural and environmental policy making process (de Wit et al., 1980; Louhichi et al., 2010; van Ittersum et al., 2008; van Ittersum et al., 1998). Bio-economic farm models have been proposed and applied as an effective way of assessing the impact of policy changes on economic, environmental and social indicators of agricultural systems (Blazy et al., 2010; Finger et al., 2010; Glithero et al., 2012; Janssen et al., 2010; Janssen and van Ittersum, 2007; Mosnier et al., 2009; Reidsma et al., 2012). A bio-economic farm model is defined as a model which links farmers' decision towards resource management with current and alternative production activities describing input-output relationships and associated externalities (Janssen and van Ittersum, 2007).

In Brazil, although various disciplinary (Abramovay and Magalhães, 2008; César and Batalha, 2010; Schaffel et al., 2012; Watanabe et al., 2012) and multi-disciplinary (Finco and Doppler, 2011; Florin et al., 2012) studies have been done to explore the impacts of the biodiesel policy, no integrated assessments of socioeconomic and environmental aspects have been performed. Therefore, the objective of this study is to perform an *ex-ante* integrated assessment of the socioeconomic and environmental impacts of five biodiesel policy scenarios towards different farm types in a semi-arid and more humid region of Southeast Brazil. The method employed is generic and can be applied for other policy questions in different regions.

5.2 Material and Methods

The *ex-ante* integrated assessment used in this study follows the structure and some of the tools proposed by the SEAMLESS integrated framework (van Ittersum et al., 2008) to assess land use policies and technologies, from field-farm to regional scale in the European Union. In this framework individual model and data components were adapted and linked to enable their application under various situations, locations and for different purposes (Janssen et al., 2010).

The applied modelling framework in the presented study is a combination of a technical coefficient generator, TechnoGIN (Ponsioen et al., 2006), and a bio-economic

farm model, FSSIM (Louhichi et al., 2010). TechnoGIN runs at field and crop level and uses a mechanistic approach based on knowledge of the agroecological processes to simulate the impact of different production activities on socioeconomic and environmental indicators. FSSIM uses the technical coefficients, which are specific inputs required to realize defined outputs, generated by TechnoGIN in a farm level analysis in which the impact of policy changes on farmers' decision can be assessed through an optimization function. Resources (i.e. land, labour and cash) are thus allocated to optimize one or multiple farmers' objectives subject to a set of constraints. A database, developed from a farm survey, was created and used to develop a farm typology which further underpins the technical coefficients and bio-economic analysis (Figure 5.1).

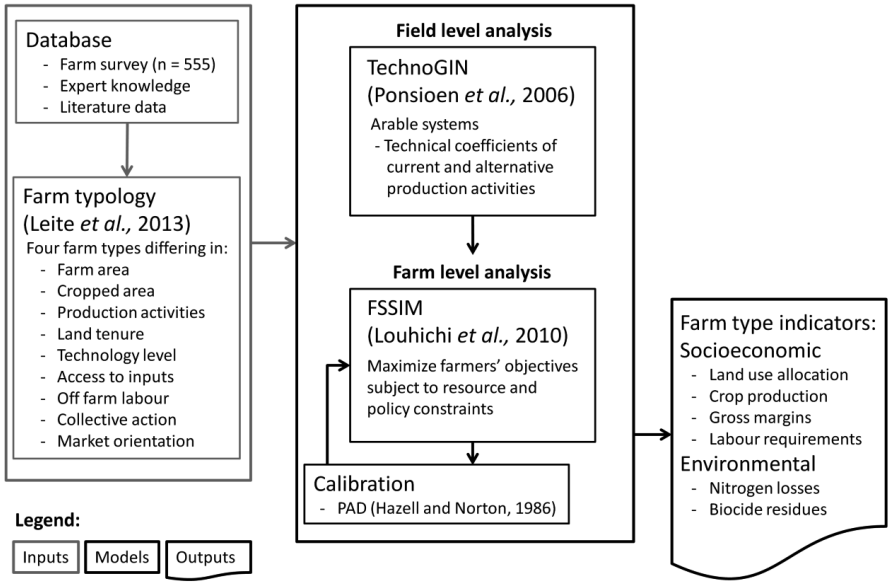

Figure 5.1 Modelling framework.

5.2.1 Case study area and data collection

In Brazil, Minas Gerais is the largest state in the Southeast region with an area of 586,520 km^2 (Figure 5.2). In this area different climatic conditions can be found, from semi-arid to humid, and hence a wide variety of agroecological zones and family farm types occur. The North of the state is a transition from cerrado towards the semi-

arid being one of the poorest regions of the state (Fontes et al., 2009). The northwestern region, which is on the frontier of the Brazilian Central-West, is one of the most important crop producing regions, accounting for ca. 38% of the state's soybean production (SAEMG, 2012).

Within the northern and northwestern region, respectively, the municipalities Montes Claros and Chapada were selected for this study (Figure 5.2). The criteria used to select these two municipalities were a high concentration of family farms, active biodiesel initiatives and suitable agroecological conditions for the cultivation of biodiesel crops (MAPA, 2012b). Chapada Gaúcha is located at 15º17'S and 45º37'W, 725 km from the state capital Belo Horizonte. The tropical semi-humid climate, with 4-5 dry months, is characterized by average air temperatures above 18º C and average annual rainfall of 1286 mm (1979 – 2009). In this region plain (< 8% slope) Ferralsols and Arenosols are predominant. Montes Claros is located more centrally at 16°44'S and 43°51'W, 425 km from the capital. In this municipality tropical semi-arid conditions can be found, with at least 6 dry months; the average temperature is above 18º C and the average annual rainfall amounts 1050 mm (1979 – 2009). The landscape is plain to hilly (≤ 45% slope) and most common soils are Ferralsols, Cambisols, Nitosols and Leptosols. Savannah (cerrado) is the predominant vegetation in both municipalities.

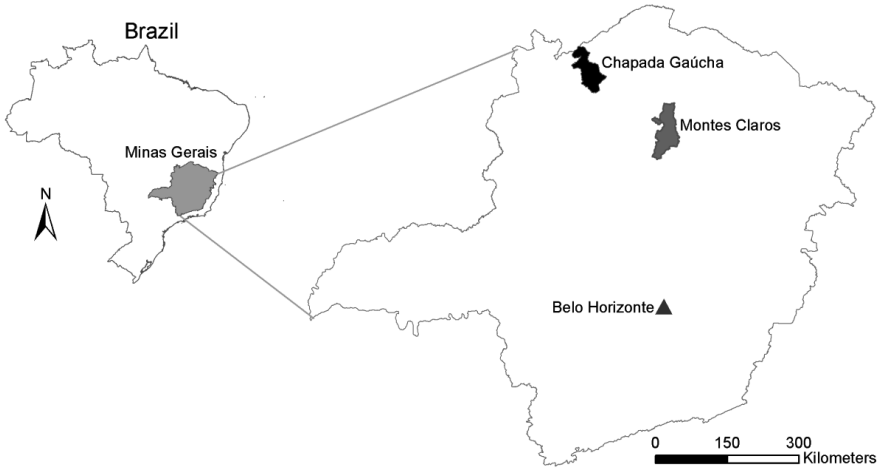

Figure 5.2 The state of Minas Gerais in the Southeast region of Brazil (left); and the research municipalities in the North and Northwest regions of the state (right).

A farm database was formed based on a survey of 555 family farmers, 360 from Montes Claros and 195 from Chapada Gaúcha, designed to capture the overall agro-ecologic and socioeconomic features of family farm production activities. The farm survey was performed in all 12 district regions identified in the research area, being two in Chapada Gaúcha and 10 in Montes Claros; from 2010 to 2012 farmers were interviewed through individual visits and group meetings. From this dataset a farm typology was developed (Leite et al., 2013; Table 5.1).

A second survey was performed with 80 farmers in the two municipalities, covering the main production activities previously identified in the farm typology. Village leaders and extension agents assisted with the identification of concentration domains of a given farm type within each village, where farmers were then randomly selected. A total of 35 soybean/grass seed farmers (farm type 1 n = 20 and farm type 5 n = 15) in Chapada Gaúcha and 45 maize/beans farmers (farm type 2 n = 20 and farm type 4 n = 25) in Montes Claros were interviewed. Along with farmers, experts such as agronomists, technicians and researchers from the state extension agency (Emater) and research department (Epamig) in northern Minas Gerais together with community leaders and organisations (i.e. farmers' associations and cooperatives) were also interviewed to gain knowledge on most suitable biodiesel policy scenarios for the near

future (ca. 5 years). Our understanding of suitable policies refers to effective policies that could increase farmers' engagement and production of biodiesel crops while considering socioeconomic and environmental criteria.

5.2.2 Farm Typology

Diversity is one of the most prominent characteristics of smallholder farming systems. As a consequence, each farming system deals with distinct decision-making problems which require specific if not unique solutions (Köbrich et al., 2003; Ruben and Pender, 2004). To address such feature of smallholder farmers, policy studies use categorization methods (i.e. typologies) to group farmers into recommendation domains which are composed of a group of homogeneous farmers (e.g. Andersen et al., 2007; Blazy et al., 2009; Hazeu et al., 2011).

A farm typology (Table 5.1) was constructed with the support of principal components and cluster analysis (Leite et al., 2013). In this study four of the five farm types were explored that are relevant, from the biodiesel policy perspective, and representative of the diversity of the farming systems in the North and Northwest of Minas Gerais state.

Table 5.1 Farm types characteristics.

Characteristics	Unit	Farm type 1	Farm type 2	Farm type 4	Farm type 5
Municipality	-	Chapada Gaúcha	Montes Claros	Montes Claros	Chapada Gaúcha
Farm area	ha	116.7	46.4	2.4	49.1
Annual crop area	ha	81.5	1.8	0.8	49.1
Grassland area	ha	3.7	29.1	0.8	0.0
Crops	-	Soybean, grass seed	Maize, beans	Maize, beans	Soybean, grass seed
Soil/Landscape	-	Ferralsols, Arenosols/Plains	Ferralsols, Nitosols/Plain	Ferralsols, Nitosols/Plain	Ferralsols, Arenosols/Plains
Land tenure	-	Owned	Owned	Sharecropped	Rented
Access to inputs	-	High	Low	Low	High
Market orientation	-	High	Fair	Low	High

Source: Leite et al., (2013)

Main farming systems in Chapada Gaúcha are based on an annual rotation of soybean followed by grass seed (farm types 1 and 5). These crops are managed under intensive use of inputs (i.e. machinery, fertilizer, biocides) and farmers differ mainly in

crop area and land tenure (Table 5.1). In Montes Claros, farms are less intensive in the use of inputs. Better endowed farms (i.e. larger farm area) combine crop with cattle livestock production on grassland (farm type 2); whereas less endowed farms (farm type 4) are constrained to maize and beans production with low market orientation, thus playing an important role in the farm household self-sufficiency (Table 5.1).

5.2.3 Technical coefficient generator – TechnoGIN

TechnoGIN (Ponsioen et al., 2006) allows the quantification of inputs and outputs of a large number of *current* and *alternative* production activities. Although TechnoGIN was first developed for Ilocos Norte, Philippines, it has recently been re-designed as a more generic and flexible tool for applications in other regions of Asia and Africa (Patil et al., 2012; Reidsma et al., 2012; Wolf et al., 2004). The input and outputs coefficients of *current* activities in TechnoGIN are based on survey data. *Alternative* production activities, however, are quantified based on knowledge of the biophysical processes of plant and animal production, technical insights and land use related objectives (Hengsdijk and van Ittersum, 2003). For these activities yield levels were defined based on crop models (potential and water–limited yield levels), field crop experiments (rain fed and irrigated), expert knowledge and literature (Leite et al., Unpublished results).

In TechnoGIN nutrient balances (N, P and K) were calculated based on the incoming (fertilizer, manure, symbiotic bacteria and mineralization) and outgoing (crop uptake and nutrient losses) flows of nutrients. Crop nutrient uptake is calculated using the QUEFTS model (Janssen et al., 1990) incorporated in TechnoGIN. In QUEFTS, nutrient uptake is calculated assuming a balanced supply of N, P and K defined by the crop yield level (target yields) and nutrient concentrations in crop residues and harvestable products (Nijhof, 1987). Nutrient losses due to leaching, denitrification, volatilization and fixation are calculated as a share of the nutrient inputs which are assessed based on crop (e.g. nitrogen fixing legumes), soil and weather conditions (i.e. soil texture, aerobic/anaerobic conditions and precipitation). Nutrient balances for *current* production activities were based on current yields and fertiliser inputs (farm survey) and calculated nutrient losses. *Alternative* production activities use a similar method, but now nutrient inputs are calculated using the target-oriented approach (van

Ittersum and Rabbinge, 1997); i.e. a technical optimal combination of inputs is defined to realise a target yield level. Biocide residue index (BRI), which is an environmental risk indicator associated with biocide use, is also calculated by TechnoGIN. It is calculated as: BRI = [biocide (g ha^{-1}) × active ingredient fraction (kg kg^{-1}) × toxicity index × persistence index active] ÷ 100. Values below 100 are considered to be safe, between 100 and 200 permissible and above 200 unsafe (Vasisht et al., 2007).

Labour requirements for land preparation, crop establishment, management and harvest were calculated together with gross margins associated with each crop activity. Labour demands were specified in labour days (8 hours) per hectare. Gross margins were derived from crop and livestock yields (kg ha^{-1}) and prices, minus costs of all variable inputs (hired labour and machinery, feed (i.e. cottonseed) and calves acquisition, medication, fertilisers, biocides, seeds and fuel). The information related to costs (fertilizer, biocides, etc.) and prices of livestock and crop products was obtained through the farm survey as representative of an average year (*current* production activities). Costs of *alternative* production activities were derived from the literature (IEA, 2012a), in which a five year average (2007 to 2011) was used. The exchange rate used (US$ 1.00 = R$ 1.75) was based on an average of daily values from March 2011 to July 2012 (BCB, 2012).

5.2.4 Bio-economic farm model – FSSIM

Model structure

The Farm System SIMulator (FSSIM) is a generic bio-economic farm model which can be applied to assess socioeconomic and environmental impacts of different policies for distinct farm types and agroecological conditions (Louhichi et al., 2010). FSSIM is a static, linear programming model designed to maximize the gross margin of a given farm type, represented by an "average farm" (Kanellopoulos et al., 2010) while subjected to a set of constraints. The "average farm" represents all farms that belong to the same farm type. The general mathematical formulation is given below:

$$\begin{aligned} &\text{maximize} && z = r'x - c'x \\ &\text{subjected to} && Ax \leq b, \qquad x \geq 0 \end{aligned} \qquad \text{Eq.1}$$

where z is the objective value, i.e. total gross margin, of a given farm type; r is the n × 1 vector of production activities revenues; x is the n × 1 vector of simulated levels of production activities; c is the n × 1 vector of variable costs; A is the m × n matrix of technical coefficients; b is the m × 1 vector of available resources and policy defined upper bound constraints (Kanellopoulos et al., 2010; Louhichi et al., 2010).

FSSIM is used in this study as an exploratory, normative model, i.e. we aimed to assess consequences of policy scenarios in terms of one or more objectives rather than predicting farm responses to these scenarios (Janssen and van Ittersum, 2007). In this approach optimal resource allocation is defined in order to satisfy one or multiple objectives, subjected to a series of constraints (e.g. Berentsen et al., 2003; ten Berge et al., 2000; Traoré et al., 2009).

Input-output coefficients of different farm types and production activities, calculated by TechnoGIN, are stored in the FSSIM database, built in a Microsoft Access file. This database is further complemented with available farm resources, socioeconomic and policy constraints and major farmers' objectives. This combined database is also known as FSSIM-AM which stands for Agricultural Management component (Janssen et al., 2010). The model is configured with a Mathematical Programming component (FSSIM-MP), developed within GAMS modelling environment (Louhichi et al., 2010), which solves mathematically the problem of resource allocation for each farm type and policy scenario by maximizing the objective function. The model further calculates, in each farm type and policy scenario, the associated socioeconomic and environmental impacts.

Model parameterization

Base year scenario

Current production activities, quantified by TechnoGIN, together with farm resources and constraints were all considered for the base year which was developed from the farm typology and farm surveys. Soybean and grass seed in Chapada Gaúcha (farm types 1 and 5), and beans, maize and grassland in Montes Claros (farm types 2 and 4) were defined as current crops (Table 5.2). For landless farmers (farm type 5) a land rental cost was fixed. Crop activities on less endowed farms (farm type 4), with limited access to arable land, were cultivated under sharecropping contracts with better-

off farmers (often farm type 2) in which one third of the harvested crop was paid to the land owner (Table 5.2). In this arrangement the land owner also provides farmers (farm type 4) with land preparation and crop seeds.

For farm types 1 and 5, which are highly market oriented (Table 5.1), profit maximization was considered the most important farmers' objective. Farmers in Montes Claros (farm type 2 and 4), on the other hand, have fair to low market orientation. It means that only a share of the farm household production will be marketed after household food and feed demands have been satisfied. To address such feature feed and food constraints were added to FSSIM. A minimum area of beans was set to meet farm household consumption, which was based on average family (5 persons) intake (FIEP, 2006) and current beans yield levels (farm survey). The maize area was also set to a minimum required to comply with current livestock feed demands in each farm type (farm survey). In farm type 2, 70% of current cropping area (ca. 1.3 ha) was allocated to maize production; whereas in farm type 4, 50% of current cropping area (ca. 0.4 ha) was reserved for maize (Table 5.2). Hired in labour was set as an option for farmers in farm type 2 during peak-labour periods of the year, such as land preparation and weeding. Constrained in land, farm type 4 could sell labour, but limited to 40 labour days per year (farm survey; Table 5.2).

Farm types 1 and 2 were constrained by an environmental set aside area (Brasil, 2012). In Chapada Gaúcha grass seed cultivation was restricted mainly by farmers' access to specialized harvest equipments combined with their ability to comply with strict seed production regulations, established by the Brazilian Agriculture Ministry. A non-arable area was defined for farmers in Montes Claros due to a combination of land steepness (up to 45%) and shallow soils (i.e. Cambisols and Leptosols), which are incompatible with current farmers' soil tillage management. This area is often used for extensive cattle livestock production (farm type 2), which is raised on native or planted grass species (i.e. *Brachiaria* spp.) (Table 5.2).

Table 5.2 Model parameterization.

Parameterization	Farm type 1	Farm type 2	Farm type 4	Farm type5
Production activities				
Current crops	Soybean and grass-seed	Maize, beans and grassland	Maize and beans	Soybean and grass-seed
Alternative crops	Sunflower and soybean/sunflower	Sunflower and castor bean	Sunflower and castor bean	Sunflower and soybean/sunflower
Rented land	na	na	na	120 US$ ha^{-1}
Sharecropping	na	na	⅓ of harvested crop	na
Labour hired in	na	14 US$ ld^{-1}	na	na
Objective function	Max. gross margins US$ yr^{-1}	Max. gross margins US$ yr^{-1}	Max. gross margins US$ yr^{-1}	Max. gross margins US$ yr^{-1}
Farm resource constraints				
Farm area	≤ 117 ha	≤ 46 ha	≤ 2.4 ha	≤ 49 ha
Available labour	≤ 112 ld m^{-1} *	≤ 44 ld m^{-1} **	≤ 44 ld m^{-1} **	≤ 56 ld m^{-1} *
Set-aside area	≥ 0.2 × farm area	≥ 0.2 × farm area	≥ 0.2 × farm area	na
Grass seed	≤ 0.4 × cropped area	na	na	≤ 0.2 × cropped area
Non-arable land	na	≥ 0.5 × farm area	≥ 0.5 × farm area	na
Household food demand	na	≥ 0.23 ha of beans	≥ 0.23 ha of beans	na
Animal feed demand	na	≥ 1.3 ha of maize	≥ 0.4 ha of maize	na
Labour sold out	na	na	≤ 40 ld yr^{-1}	na

na – not applied;* Mechanized labour days (8 hours) per month; ** Non-mechanized labour days (8 hours) per month

Baseline scenario

The current biodiesel policy is specified in the baseline scenario together with the inclusion of alternative (biodiesel) crops as options into the farm model (Table 5.2). The criteria used to select those crops were based on their suitability with current farm equipment, thus not requesting further adaptation investments. Moreover, there must be a fairly well established research and development agenda around novel crops, i.e. literature, technical assistance, experimental data and seeds, thus ensuring reliable information to be used under different production techniques (MAPA, 2012b; NAE, 2005). Apart from the inclusion of alternative biodiesel crops, everything else is the same as in the base year.

Among the alternative crops, castor bean was not explored for farmers in Chapada Gaúcha mainly due to the lack of suitable harvest equipment and manual

labour. Moreover, a double crop rotation (soybean/sunflower) was explored only in Chapada Gaúcha where the rainy season is longer (November to April) and a second crop can potentially be cultivated. In general, single cropping systems are most common, especially in Montes Claros where the wet period is about 150 days (November to March).

In FSSIM the sunflower area (cultivated after soybean) in Chapada Gaúcha was limited to 50% of the total soybean area. That is because such double cropping system is considered to be feasible only in combination with short cycle soybean varieties (90-110 days) which account for ca. 50% of farmers genotype mix. When following long cycle (150 days) soybean varieties, sunflower yield levels can be reduced by more than half (ca. 500 kg ha^{-1}) due to water shortage at the end of the rainy season (Leite et al., Unpublished results).

Model evaluation

Model evaluation based on the comparison of model outputs (baseline) with observed farm production activities (base year) is a key step to verify the reliability of the produced results (Janssen and van Ittersum, 2007). Main reasons for poor model outcomes are insufficient description of the systems and an inappropriate database. To evaluate the deviation between model simulations and observed farmers' practices the percentage of absolute deviation (PAD) was used. PAD is defined as the absolute deviation between simulated (x_i) and observed activity levels (x_i^0) per unit of actual activity level (Hazell and Norton, 1986):

$$PAD(\%) = 100 \times \frac{\left(\sum_i |x_i - x_i^0|\right)}{\left(\sum_i x_i^0\right)} \qquad \text{Eq.2}$$

Similarly to Hazell and Norton (1986), it is assumed that models which reproduce the base (calibrated) year activity levels with PAD values ≤ 15% can be used satisfactorily for forecasting purposes. PAD values for the base year and baseline varied from 3 to 6% among all farm types (Table 5.3), thus ensuring reliability of the model forecasts.

Table 5.3 Evaluation of model simulation performance for the base year and baseline given by the percentage of absolute deviation (PAD) in all farm types. Alternative crops considered in the baseline simulations are in *italics*.

	Production activity	Activity level (ha)		PAD (%)
		Base year (x_i^0)	Baseline (x_i)	
Farm type 1	Soybean	47.7	48.5	3
	Grass seed	34	32.8	
	Soybean/sunflower	0	0	
	Sunflower	0	0	
Farm type 2	Maize	1.2	1.3	6
	Beans	0.6	0.6	
	Grassland	29.1	29.8	
	Castor	0	0	
	Sunflower	0	0	
Farm type 4	Maize	0.4	0.4	5
	Beans	0.4	0.4	
	Castor	0	0	
	Sunflower	0	0	
Farm type 5	Soybean	40.1	39.2	3
	Grass seed	9.0	9.8	
	Soybean/sunflower	0	0	
	Sunflower	0	0	

Policy scenarios

The biodiesel policy has often been reformulated with the aim of expending farmers' engagement and production of biodiesel feedstocks (e.g. MDA, 2012). Currently, biodiesel producers granted with the social fuel stamp have to buy 15-35% of their feedstock from family farmers. The policy allows a series of different inputs provided by biodiesel producers to be accounted as oil crop acquisitions, i.e. fertilizer, lime, seed, bags for harvest and land preparation equipment (MDA, 2012). Among stakeholders there is no agreement on what would be the most efficient strategy to increase oil crop supply. Farmers' technical assistance combined with seeds and harvest bags are often included into actual biodiesel crop contracts. However, strategies able to enhance crop production at the farm level are still regarded with scepticism among biodiesel producers. Farmers and stakeholders agree that a wider access to inputs, i.e. fertilizer and land preparation equipment, could increase profitability and diminish risk associated with land use trade-offs between current – more traditional – crop activities and biodiesel crops. There are also claims that a more market-oriented approach based

on bonus prices for oil crops could be a better strategy to engage farmers. Farmers' association and cooperatives argue that small scale oil extraction units could be an effective way of adding value to biodiesel feedstocks with further gains in transportation efficiency. Crashing the biodiesel feedstock locally could reduce current transportation distance (ca. 1,400 km) by 75%, as currently the biodiesel producer in the region needs to send the purchased feedstock (i.e. mainly soybean) to a vegetable oil mill in the southwestern part of the state (Watanabe et al., 2012). Government bodies, on the other hand, are increasingly pushed by the design of environmental policies able to enhance the contribution of agricultural systems to sustainable development at large. With increasingly globalized food, feed and fuel markets the need to attend to environmental criteria has also grown, hence governments are challenged by the implementation of effective policies able to enhance agricultural sustainability. From the described context, different policy scenarios are proposed for which the outcomes, in terms of socioeconomic and environmental indicators, will be compared to the baseline situation.

The "bonus price" policy scenario explores whether a more market-oriented approach could be effective in increasing farmers' engagement towards biodiesel crop production (Table 5.4). Although limited, there are indications in the literature that higher prices could foster farmers to engage and/or expand their biodiesel cropped area (Finco and Doppler, 2011). This scenario was implemented with the increase of current prices of alternative crop activities by 25%.

Table 5.4 Summary description of the explored biodiesel policy scenarios.

Scenario	Description	Applied region
Bonus price policy	Increase in biodiesel crop prices by 25%	Montes Claros/Chapada Gaúcha
Fertiliser policy	Provision of soil nutrients (NPK)	Montes Claros/Chapada Gaúcha
Oil mill policy	Access of a small scale oil mill	Montes Claros/Chapada Gaúcha
Land preparation policy	Access to land preparation equipment	Montes Claros
Environmental policy	Limits environmental exposure to biocide residues and nitrogen losses	Chapada Gaúcha

The "fertiliser" policy scenario consists of input provision (Table 5.4). In both research areas current yields of sunflower and castor bean are relatively low. Expert consultation combined with model simulations and field experiments (Leite et al.,

Unpublished results) showed that yield levels could be increased under a more intensive management of inputs, mainly fertilizer (Table 5.4). In this policy, soil nutrients (fertilizer and lime) would be provided aiming to guide farmers towards best farmers' technical means. Implementation consists of zero costs for fertilisers, which leads the increase of yield levels of spring sunflower (Montes Claros: 700 to 2600 kg ha^{-1}; Chapada Gaúcha: 1500 to 2600 kg ha^{-1}), summer sunflower (Chapada Gaúcha: 400 to 1100 kg ha^{-1}) and castor bean (Montes Claros: 500 to 1200 kg ha^{-1}).

In the "oil mill" policy scenario, farmers' access to small scale vegetable oil mills is considered (Table 5.4). In this scenario oil crop extraction units would be placed strategically to reduce transportation distances between biodiesel and crop producers. Such equipment would be under the management of local cooperatives and farmers' associations. In FSSIM sunflower and castor bean grain yields were transformed into oil yields in which 45% oil content is assumed for both crops (Nobre et al., 2013; Zheljazkov et al., 2008). For each crop, oil production was then multiplied by 0.80 to account for the inefficiency of the extraction method (Pathak et al., 1988; Singh and Bargale, 2000). Sunflower and castor bean oil prices were defined at the same level as soybean oil price, which is considered - by the biodiesel producer - the most economically feasible crop. In this arrangement farmers would have access to the cake – after oil extraction – that could be used as organic fertilizer (castor bean) or animal feed (sunflower). In the farm model, sunflower cake is included as an output with a yield of 35% of current grain production (Oliveira and Cáceres, 2005). For farm type 2 sunflower cake is defined as an option to fulfil farm demands of feed protein sources (i.e. cottonseed) currently purchased by farmers during the end of the dry season (i.e. August to September) when grass availability is drastically reduced. For other farm types sunflower cake is defined as a cash co-product which could be sold locally as feed for livestock farmers (e.g. farm type 2).

The "land preparation" policy is based on farmers' access to land preparation equipment, i.e. tractor, plough and disc plough (Table 5.4). There is a strong belief among stakeholders and farmers in Montes Claros (farm types 2 and 4) that biodiesel feedstock production could be facilitated with the provision of land preparation. Farmers' limited access to inputs (Table 5.1) as land preparation equipment might constrain their ability to engage in alternative crop activities without compromising

current ones. Under such conditions farmers tend to engage in less risky strategies based on traditional production activities (i.e. maize and beans) thus ensuring food and feed demands of the farm household (Ruben and Pender, 2004). This policy was implemented in the model by setting labour requirements for land preparation to zero for sunflower and castor bean up to 2 ha. Moreover, this scenario was only explored for farmers in Montes Claros where access to farm machinery and equipment is limited.

Lastly, the "environmental" policy incorporates indicators associated with biocide residues and nitrogen losses (Table 5.4). In Brazil local government bodies are keen to develop environmental policies able to enhance the sustainability of agricultural systems (MAPA, 2012a). Currently there is lack of *ex-ante* policy assessment to evaluate *current* and *alternative* production activities, thus enabling a better informed policymaking process together with improved recommendations for farmers. More input intensive farmers, as those found in Chapada Gaúcha (farm type 1 and 5), often lack effective methods and tools to evaluate the impact of production activities at farm level. Local experts agree that environmental impacts associated with nitrogen losses and biocide residues are likely to be the most important in the region. With this policy *current* and *alternative* production activities would have their environmental emissions of nitrogen and biocides quantified at the farm level. A constraint is added in FSSIM to limit production activities associated with unsafe values of biocide residue index (BRI $\geq$ 200). Nitrogen losses are also used as an indicator which can shed light over the management of soil nutrients in each farm type.

5.3 Results

5.3.1 Land use and cropping patterns

In the baseline scenario there was no response of any farm type to the current policy scenario in terms of uptake of alternative crop activities (Figure 5.3). This corresponds fairly well to the current situation in the research areas where the uptake of biodiesel crops (i.e. sunflower and castor bean) by farmers is still limited (Table 5.3). Current land use patterns are characterized by soybean and grass seed in Chapada Gaúcha (Figure 5.3A,B), and maize, beans and grassland in Montes Claros (Figure 5.3C,D). In our simulations most of the farm types, however, responded positively to a bonus price. In this policy scenario prices of biodiesel crops were increased by 25% in

both research areas. In Chapada Gaúcha farmers engaged in the cultivation of sunflower in a double cropping system following soybean (i.e. soy/sun) with an area of 24 ha for farm type 1, and 19 ha for farm type 5 (Figure 5.3A,B). In Montes Claros, livestock farmers (farm type 2) were attracted to castor bean production, for which the price is nearly double the price of sunflower (Figure 5.3C). Less endowed farmers (farm type 4) that rely on sharecropping were less affected by a bonus price policy (Figure 5.3D). In this group, production costs of current crop activities are low as land preparation and seeds are already granted by the land owner, thus reducing the competitiveness of biodiesel crops.

The provision of soil nutrients, under the fertilizer policy scenario, seems to be an effective strategy to engage farmers in biodiesel crop production. The combination of increased yield levels associated with higher rates of soil nutrients use than in the baseline, combined with a reduction in the production costs (zero cost for fertilisers) was responsible for the introduction of sunflower as a single crop in all farm types (Figure 5.3). Sunflower replaces soybean in Chapada Gaúcha (Figure 5.3A,B) and part of the beans area used as a cash crop in Montes Claros (Figure 5.3C,D).

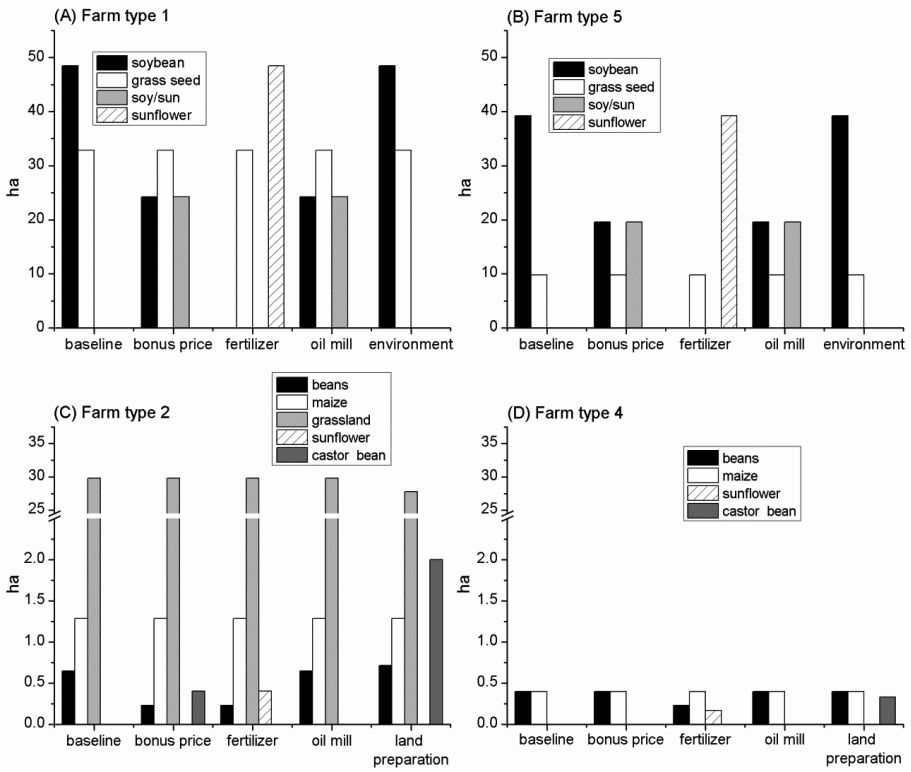

Figure 5.3 Land use and cropping patterns for different farm types and biodiesel policy scenarios. Soy/sun corresponds to the double cropping system soybean/sunflower. Farm type 1 and 5 are located in Chapada Gaúcha and farm type 2 and 4 in Montes Claros.

The oil mill scenario, which assumes that farmers would become vegetal oil suppliers, is an interesting option only for farmers in Chapada Gaúcha. The added valued associated with the vegetal oil production combined with sunflower cake (co-product) increased farmers' reward for the double cropping system. The production of sunflower in this region, although economically attractive, is limited when environmental indicators are taken into account (environmental policy scenario) (Figure 5.3A,B). Hence, whether the policy scenario considers a bonus price, oil mill or fertilizer, the environmental effects of sunflower production should not be overlooked (Section 5.3.4).

In Montes Claros the land preparation policy significantly affected farmers' cropped area. The extent of change depended on available resources (land, labour and

cash) and hence differed between farm types 2 and 4 (Figure 5.3C,D). Better endowed livestock farmers (farm type 2) more than doubled their cropped area (from 1.9 to 4.0 ha), when compared with the baseline. Such expansion, however, led to the decrease in the grassland area (Figure 5.3C). Less endowed farmers (farm type 4), which depend on sharecropping and farm household available labour, expanded their cropped area by ca. 40% (from 0.8 to 1.1 ha).

5.3.2 Gross margins and crop oil production

The explored policy scenarios showed limited impact on farm' gross margins compared to the baseline situation. Fertilizer provision for farm types 1 and 5, and fertilizer and land preparation for farm types 2 and 4, respectively, were the most effective options for increasing farms' gross margins, although effects on farm types 2 and 4 were small (Figure 5.4).

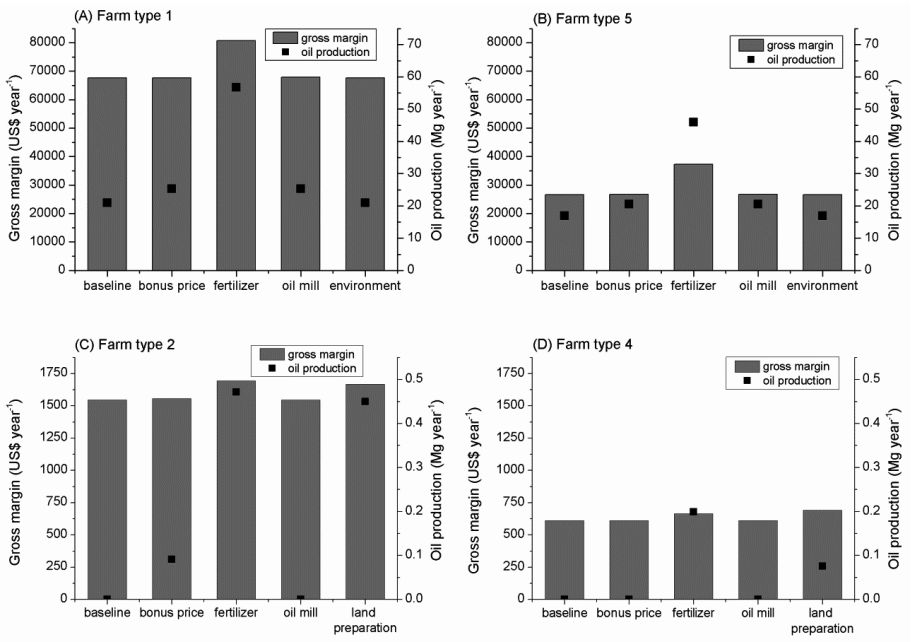

Figure 5.4 Gross margins and oil production for different farm types and biodiesel policy scenarios. Oil production is calculated by multiplying crop production by the oil concentration (soybean × 0.18; sunflower × 0.45; castor bean ×0.45).

In Chapada Gaúcha economic benefits were higher than in Montes Claros (Figure 5.4A,B), and gross margins increased by 19 to 40% for farm type 1 and 5, respectively. The economic gains were more modest in Montes Claros, where the increase in gross margins ranged from 10% in the fertilizer policy scenario (farm type 2) to 13% in the land preparation policy scenario (farm type 4) (Figure 5.4C,D).

Oil production increased much more than gross margins did. Farmers in Chapada Gaúcha could enhance oil production by 171% through substituting soybean by sunflower (with higher oil content) under the fertilizer policy scenario (Figure 5.4A,B). In Montes Claros, where no oil crop is cultivated in the baseline, higher oil production was also achieved under the fertilizer scenario, in which sunflower was cultivated by both farm types (Figure 5.4C,D).

5.3.3 Labour use

The impact of different biodiesel policy scenarios on labour requirements for farmers in Chapada Gaúcha (farm type 1 and 5) was limited (Figure 5.5A,B). The bonus price and oil mill policy scenarios caused labour demands to peak in February and May, periods in which spring sunflower is sown and harvest, respectively. Such increase in labour demands is, however, still fairly small if compared with current labour use by farmers in other periods of the year (Figure 5.5A,B).

Differently from farmers in Chapada Gaúcha where labour is associated with mechanized activities, in Montes Claros farming systems are mainly non-mechanized. Therefore, crop production can be limited by farmers' available labour (Figure 5.5C,D). This was the case of farm type 2 in which farmers hire in labour mainly in October (land preparation) and December (weeding) when demand exceeds farm available labour (Figure 5.5C). In the land preparation policy scenario there is a peak in labour requirements in October due to an increase in the cropped area with castor bean (Figure 5.5C). Labour demands in the following months were not affected as farmers on farm type 2 are only responsible for land preparation (sharecropping); other activities – including crop establishment, management and harvest - are carried out by less endowed farmers (farm type 4). Constrained in land, farmers in farm type 4 have low labour demand in October. During this period this farmers sell out their labour to better endowed farmers (e.g. farm type 2). This is also the case for December when farmers

divide their time between sharecropping activities and selling labour (10 days) to other farmers (Figure 5.5D). December is also the only period when this group of farmers became constrained in labour under the land preparation policy, driven by the increase in the sharecropped area (Figure 5.5D).

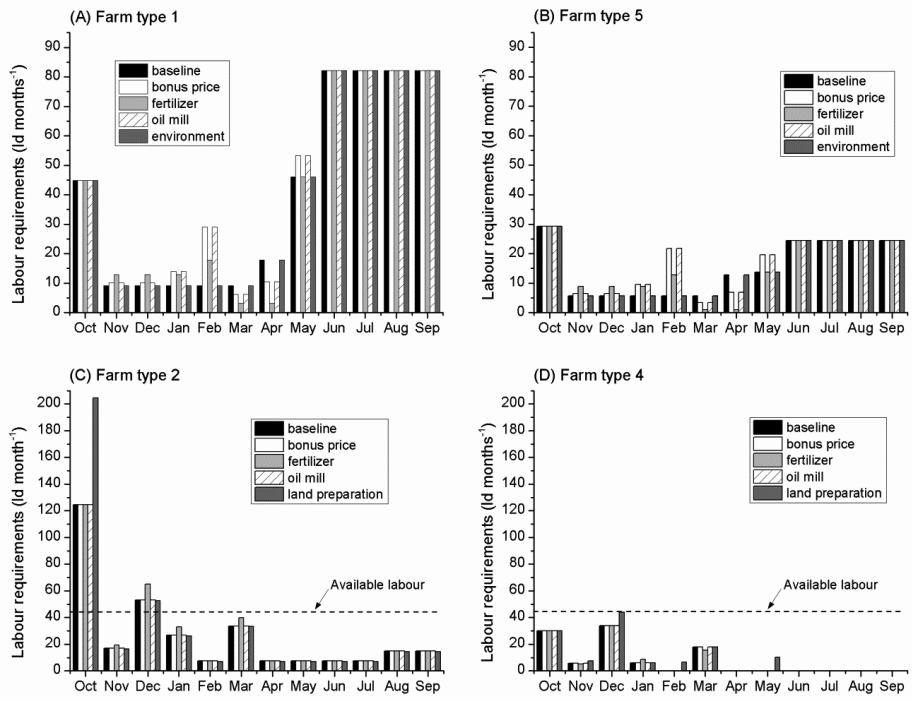

Figure 5.5 Monthly labour days (ld = 8 hours) requirements for farm types 1 and 5 (mechanized labour hour) in Chapada Gaúcha; and farm types 2 and 4 (man labour hour) in Montes Claros.

5.3.4 Biocide residues and nitrogen losses

Biodiesel crop production, despite attractive under different policy scenarios, deserves attention when environmental indicators are taken into account. Farmers in Chapada Gaúcha (farm types 1 and 5) that engage in more intensive production systems (using more fertiliser and biocides) have their production of sunflower, whether as a single (spring sunflower) or double cropping system following soybean, constrained by the environmental policy. The reason for such limitation is the unsafe values of biocide

residue index (BRI) observed in the bonus price, fertilizer and oil mill policy scenarios (Figure 5.6A,B). Crop activities with BRI values above 200 per hectare were considered unsafe, thus not selected by the farm model in the environment scenario. Higher values of BRI are associated with the double crop systems soybean/sunflower (soy/sun) - nearly 300 per hectare – as in this system biocides are first sprayed on soybean and later on sunflower.

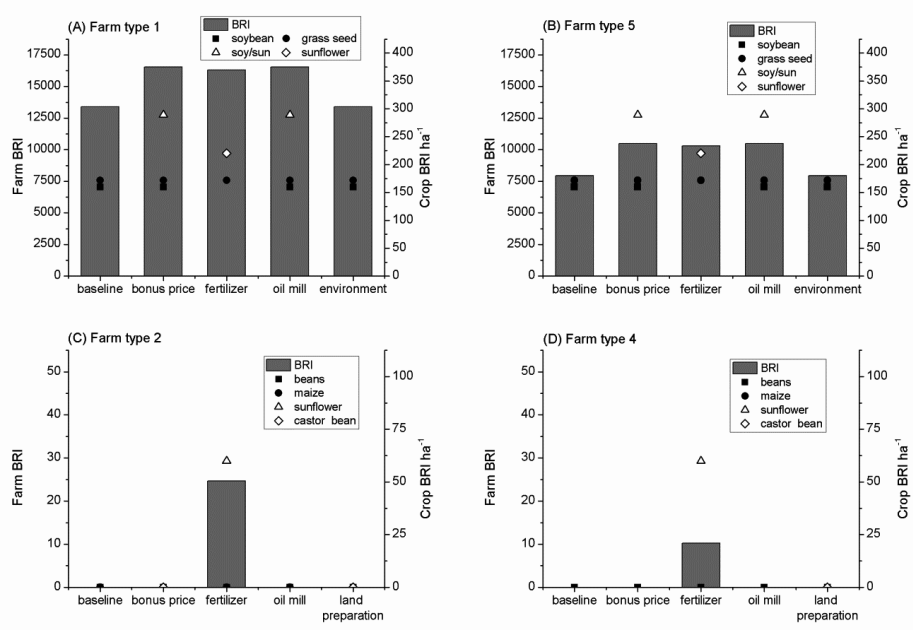

Figure 5.6 Farm and crop biocide residue index (BRI) on different farm types and for biodiesel policy scenarios.

The environmental policy constrain was not applied in Montes Claros, where farmers rarely use any type of biocide. This is reflected in the farm and crop BRI values, which are considerably lower than those observed in Chapada Gaúcha (Figure 5.6C,D). In Montes Claros biocides are only used under the fertilizer policy to control sunflower related pests and diseases.

Nitrogen losses can be positively affected by biodiesel crops. Sunflower following soybean in the double cropping system (bonus price and oil mill policy scenarios) reduced total farm nitrogen losses by nearly 8% when compared to the

baseline in Chapada Gaúcha (Figure 5.7A,B). In this cropping system sunflower received no N inputs when following soybean, which increased N use efficiency. However, in the fertilizer policy scenario, in which sunflower is cultivated as a single crop and received soil nutrient inputs, farm nitrogen losses increased by 50 and nearly 70% for farm types 1 and 5, respectively, when compared to the baseline. An important reason for such increase is the replacement of soybean by sunflower, that has higher N emissions (ca. 81%) than soybean (Figure 5.7 A,B).

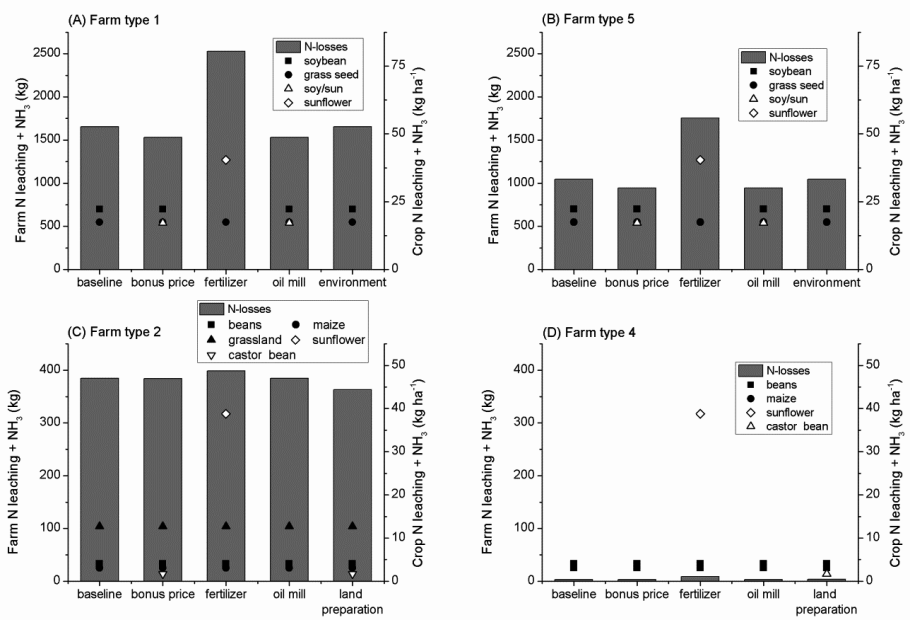

Figure 5.7 Farm and crop nitrogen losses on different farm types and biodiesel policy scenarios.

Similarly to BRI, nitrogen emissions on farm types in Montes Claros are smaller than those observed in Chapada Gaúcha (Figure 5.7C,D) as farmers commonly use no fertiliser .

5.4 Discussion

5.4.1 Farmers' response to policy scenarios

So far the response (e.g. in terms of oil production, farm income) of small scale farmers to different biofuel policies globally has been limited (WB, 2008). In different regions, large scale farming systems are more competitive in accessing information and credit, and in delivering feedstock production (Elbehri et al., 2013). Similarly, our results indicate that larger, better endowed soybean farmers in Chapada Gaúcha (farm type 1 and 5) are likely to respond more positively to all explored policy scenarios in terms of oil crop production and gross margins than maize/beans farmers in Montes Claros (farm type 2 and 4). The most effective scenario seems to be the fertilizer policy, in which farmers in Chapada Gaúcha substantially increased oil production and gross margins by up to 170 and 40%, respectively. Such effects are associated with the provision of soil nutrients, currently rarely applied on sunflower which is considered by farmers as a minor crop, thus boosting crop yield and economic returns.

The potential of biodiesel crops for farmers in Montes Claros (farm type 2 and 4) is less evident than in Chapada Gaúcha. The most effective scenario for farm type 2 (fertiliser policy) and farm type 4 (land preparation) increased gross margins by up to 13%, which is about four times less than in Chapada Gaúcha. A main reason for such poor outcome is that small scale family farmers in Montes Claros, like others in many regions of the world, allocate an important share of their resources (e.g. labour and land) to food and feed self-sufficiency (Jakobsen et al., 2007; Jolly and Gadbois, 1996; Lu et al., 2004; Milgroom and Giller, 2013). Hence, biodiesel crops would only impact the cash crop area, which in Montes Claros is limited to 50 and 20% of the total cropped area for farm type 2 and 4, respectively. Such impact is further diluted by other income earning activities such as selling labour (farm type 4) and cattle livestock (grassland; farm type 2).

5.4.2 Policy impacts: labour and environmental indicators

Farm household labour availability is acknowledged as one of the most important inputs of small scale farming systems (Delgado and Ranade, 1987; Ruthenberg, 1976). The extent of farmers' land cultivation is associated with their ability to supply sufficient labour to meet periodic labour requirements from specific

crop and livestock management activities (Gill, 1991; White et al., 2005). Biodiesel policies that affect labour availability can thus have a significant impact on both socioeconomic and biophysical characteristics of the farm household (e.g. Pingali et al., 2008). Less intensive production systems in Montes Claros, with limited access to inputs such as land preparation equipment can be significantly affected by scenarios which enhance farmers' available labour, i.e. the land preparation policy. In this scenario farmers were able to double their cropped area along with the creation of labour opportunities (hiring in labour -sharecropping) to compensate for farmers' labour deficit on crop management activities (i.e. weeding). With more labour for land preparation there is also an increase in available sharecropping areas, thus benefiting land constrained farmers (farm type 4) who perceived positive impact on gross margins from this policy.

The development and implementation of any biodiesel policy should also comply with environmental criteria (Rossi and Cadoni, 2012). Among the selected environmental indicators, biocide residue index (BRI) is most concerning. Unsafe values of BRI (> 200 ha^{-1}) are associated with farmers in Chapada Gaúcha (farm type 1 and 5), especially in the double cropping system soybean/sunflower. A main reason for the high BRI values is the long term cultivation of soybean (ca. 30 years) with a narrow or no rotation, combined with recent events of weed resistance (i.e. *Conyza* spp., *Digitaria insularis*, *Lolium multiflorum*) to herbicides associated with genetically modified glyphosate-resistant soybean varieties (Heap, 2013). Under such conditions farmers are compelled to apply higher doses and/or more toxic herbicides to suppress weed populations (e.g. Mortensen et al., 2012).There are also negative effects associated to common pests and diseases to soybean and sunflower (Moscardi et al., 2005) such as the severity of *Sclerotinia sclerotiorum* which is amplified by the double cropping system. Although there is evidence that integrated pest management (IPM) could reduce the use of biocides by up to 50% (Corrêa-Ferreira et al., 2010), the wide spread adoption of such management is still hindered by farmers' limited access to information and technology, i.e. technical assistance, resistant varieties, biological products (Hoffmann-Campo et al., 2000).

The effects of the double cropping system on nitrogen losses, on the other hand, seem to be positive as N losses are reduced when sunflower is cultivated after soybean.

In this cropping system sunflower takes up available nitrogen from soil profiles, reducing the risk of environmental contamination, and thus increasing nitrogen use efficiency (Drinkwater et al., 1998). Higher nitrogen losses are, for all farm types, associated with the fertilizer policy scenario. The level of losses, however, is relatively low (up to 40 kg ha^{-1} for sunflower) if compared with some of those reported in the literature, as for example the European average of 81 kg ha^{-1} EU-27 (Velthof et al., 2009).

In Montes Claros, farmers (farm type 2 and 4) have the lowest values of nitrogen losses among the studied farm types. Lowe N losses are caused by the absence of farmers' use of fertiliser on current crop activities (i.e. maize, beans and grassland). In this region, soil nutrient mining is acknowledge by local experts and farmers as the main cause of soil fertility decline, which helps to explain current low crop yield levels (< 1000 kg ha^{-1}). The fertilizer policy scenario can be a way of enhancing soil fertility and crop yields, thus reversing current soil nutrient deficits and contributing to the sustainability of cropping systems. Moreover, in this policy scenario food and feed crops could also benefit from intercropping with biodiesel crops, hence enhancing the impact of fertilizer use on total farm crop production.

5.4.3 Modelling approach

Identifying main drivers of farm household decision making is a key element in the design and implementation of any modelling chain (Hazell and Norton, 1986). Different farm types might also have different objectives, which should be taken into account in the selected modelling approach. Apart from market driven farmers (Chapada Gaúcha), for whom profit maximization is a major objective, small scale family farmers (Montes Claros) often aim at risk minimisation. Although risk was not directly quantified in our study, main aims such as ensuring food and feed self-sufficiency were identified and included as constraints in the model, thus improving the validity of our simulations. Moreover, risk associated with price and yield variability of alternative crops was previously assessed (Leite et al., Unpublished results). The most obvious risk was the reduction of sunflower yield levels when cultivated after soybean in a double cropping system. To deal with this issue, spring sown sunflower was

constrained to be cultivated only with short cycle soybean varieties, thus limiting the risk of crop losses due to water shortage at the end of the rainy season.

5.5 Conclusions

The biodiesel policy scenarios explored in this study were defined based on knowledge of current farming systems, farmers' objectives and constraints derived through a farm survey and a survey amongst farmers and a range of other stakeholders from the research area. Our simulations showed that such scenarios can be effective in increasing farmers' engagement in the production of biodiesel crops. However, the impacts of such policies vary across different farm types and differ depending on whether the focus is on input provision, feedstock price or environmental criteria.

Farmers in Chapada Gaúcha (farm type 1 and 5) respond positively, in terms of oil production and gross margins, to all explored policy scenarios. The provision of soil nutrients, under the fertiliser policy scenario, enabled farmers to achieve the highest values of oil production and economic returns. In this scenario, spring sown sunflower was the most competitive crop. From an environmental perspective the cultivation of sunflower in this region, especially in double cropping systems with soy, should be considered with caution. The biocide residue index values from soybean and sunflower reach unsafe values, thus raising concern over the sustainability of this cropping system.

In Montes Claros, the scope for biodiesel crops under the explored policy scenarios is limited, if compared to Chapada Gaúcha. In this region farmers (farm type 2 and 4) were less responsive to the oil mill and bonus price policy scenarios for which, the added value associated to biodiesel oil crops was not sufficiently high to be competitive with traditional crops (i.e. beans). Input provision policies (land preparation and fertiliser) had relatively large impacts on farmers' socioeconomic and environmental indicators. In the land preparation scenario, farmers' labour (farm type 2) and land (farm type 4) constrains were relaxed, thus allowing farmers to increase their cropped area, oil crop production (i.e. sunflower and castor bean) and gross margins. Under fertiliser provision, sunflower became the most likely alternative for both farm types 2 and 4. This scenario is particularly important as it reverses current soil nutrient deficits with more general benefits to the cropping systems.

The selected modelling framework based on the combination of TechnoGIN and FSSIM was instrumental for the integrated assessment of agricultural policies. The outcomes provide insights on the socioeconomic and environmental effects of different policy scenarios, hence contributing to a better informed policy making process.

CHAPTER 6

Linking family farmers to biodiesel markets in Brazil: can producer organisations make a difference?

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João Guilherme Dal Belo Leite, Jos Bijman, Maja Slingerland, Martin K. van Ittersum. Linking family farmers to biodiesel markets in Brazil: can producer organisations make a difference? Outlook on Agriculture (2013).

Abstract: The biodiesel policy in Brazil is part of the government's main ambition to boost rural development through the creation of market opportunities for family farmers. In many regions, the uptake of biodiesel crops is limited as farmers and biodiesel producers are faced with high transaction costs. We explore producer organisations (POs) as a way of reducing such costs. Our findings indicate that the scope for POs in filling the gap between farmers and the biodiesel market is limited due to organisation and farm-specific characteristics coupled with the low value added and high risk of biodiesel crop production.

Key words: transaction costs, collective action, policy, rural development, biofuel

6.1 Introduction

In recent years the Brazilian government has been engaged in the reduction of poverty levels across the country, particularly in rural areas. To reach this goal, a national program for production and use of biodiesel (Brasil, 2005) was launched in which biodiesel producers are granted tax reductions if complying with a minimum quota of their feedstock acquisitions from family farmers. However, the uptake of biodiesel crops by family farmers is still limited (Leite *et al.*, 2013) and feedstock is mainly supplied by better endowed soybean farmers (MDA, 2011). Transaction cost for biodiesel producers and farmers are high. Farmers' dispersion over large areas increase costs of providing inputs (e.g. technical assistance, seeds) and collecting outputs (i.e. biodiesel feedstock). Moreover, less endowed farmers face high costs in accessing credit and market information (Poulton *et al.*, 2010; Wiggins *et al.*, 2010).

Producer organisations (POs) can be an effective way of dealing with high transaction costs (Hellin *et al.*, 2009; Shiferaw *et al.*, 2011). By acting collectively, farmers can benefit from economies of scale, increased bargaining power and reduced information costs (Dorward, 2001; Ton *et al.*, 2007). Although POs could also provide these benefits for biodiesel transactions, in Brazil rural organisations are often absent or unsuitable, which has been claimed to be an important limitation for family farmers' access to biodiesel markets (Abramovay and Magalhães, 2008; Watanabe *et al.*, 2012; Leite *et al.*, 2013).

In the task of linking farmers to markets, POs can be supported by 'outsiders', such as government bodies, donors and NGOs, who provide essential services for

market engagement (e.g. technical assistance, market information, credit; Markelova *et al.*, 2009). It remains, however, uncertain what type and how much outside support a PO may need to function properly (Collion and Rondot, 2001; Chirwa *et al.*, 2005). Understanding the complex relationship between the functioning of a PO and the level and type of support from outsiders is often key to successfully connecting farmers to market opportunities. Useful insights could be gained by studying the characteristics of both the PO and the member-farms, as these determine, to a large extent, the transaction costs associated with farmers' access to markets (Pingali *et al.*, 2005). Such knowledge can help farmers, policy makers and other stakeholders in developing strategies to link farmers to market. Furthermore, this knowledge can be used to explore opportunities for and shortcomings of POs in the face of the emerging biodiesel market in Brazil. Thus, this paper explores the following research questions: (i) what functions can the PO exert on behalf of farmers given PO's structure and farm characteristics?; (ii) what role do outsiders have in supporting POs to access input and output markets?; and (iii) what lessons can we draw for the emerging biodiesel market? To address these research questions a series of case studies on POs has been used.

6.2 Theoretical background

6.2.1 Transaction costs in rural areas

Family farmers living in areas where markets are not well developed and market support institutions are not present face high transaction costs (Ton *et al.*, 2007; Markelova *et al.*, 2009; Poulton *et al.*, 2010). Transaction costs are the costs of contact, contract and control (North, 1990). In other words, transaction costs are the costs that transaction partners must incur to inform themselves about market conditions, which consist of finding and exchanging information; the cost of negotiating an agreement, including bargaining over the terms of trade; and the cost of monitoring and enforcing contract compliance.

The level of transaction costs faced by farmers varies with farm-specific characteristics (Pingali *et al.*, 2005). Small scale farmers have a competitive advantage over large commercial farmers by more efficiently accessing and monitoring family labour (Binswanger and Rosenzweig, 1986). However, their small scale leads to high unit transaction costs in accessing capital, market information, technical assistance and

input/output markets (Poulton *et al.*, 2010). Their scale also influences the extent to which farmers can bear risk and deal with uncertainty. Most smallholders engage in diversified production systems, selecting activities and technologies with low sunk costs, in order to reduce income vulnerability (Ruben and Pender, 2004). The level of transaction costs faced by farmers also differs according to their location. In areas with well-developed inputs and output markets, reliable transport and communication infrastructure (high potential areas), farmers face lower transaction costs than in regions without these conditions (low potential areas; Pingali *et al.*, 2005). The characteristics of the product also affect transaction costs. Perishable crops entail higher transaction costs, as farmers have fewer options for waiting for better prices and more trustworthy traders. These costs are also higher when a crop is cultivated for a specific customer, thus increasing farmers' risk of being exploited (high asset specificity; Masten, 2000).

6.2.2 Producer organisations

Transaction costs can be reduced using particular contractual or ownership arrangements (Williamson, 2000; Dorward, 2001; Stockbridge *et al.*, 2003; Williamson, 2008). One of these arrangements involves collective action. When farmers transact collectively with a third party, the transaction costs and risks for both parties may be reduced as the Producer Organisation (PO) provides farmers with access to market information, technology and innovation (Stockbridge *et al.*, 2003; Shiferaw *et al.*, 2011). In addition, through enhanced economies of scale and bargaining power, farmers are able to negotiate better terms of trade (Barrett, 2008; Bernard and Spielman, 2009). POs can also reduce farmers' costs of compliance to high quality standards, and participation in procurement systems by overcoming volume and coordination problems (Poulton and Lyne, 2009). Next to economic and technical services, POs may also perform advocacy and local development functions (Table 6.1).

Table 6.1 Functions and services provided by producer organisations (POs).

PO functions	PO services
Advocacy	Representative role during the decision making process; lobbying on behalf of members in negotiations with donors, governments and the private sector
Economic and technical	Access to input and output markets, financial services, storage support, processing, technical assistance, and market information
Local development	Support local development through employment, education (schools), welfare (e.g. health services), and management of common property resources

Source: Rondot and Collion (2001); Stockbridge *et al*. (2003)

The functions and services that are provided by the PO not only rely on farmers needs, but also on the organisational characteristics. There are several factors that can influence the function of the organisation, such as group size, system boundaries and shared norms (Agrawal, 2001). This paper focuses on PO characteristics associated with group homogeneity and the organisation's legal structure. These features are essential in the PO's ability to access external support, manage common resources, and agree on core business activities (Hansmann, 1996; Penrose-Buckley, 2007). Regarding to the legal structure, POs can be divided in formal and informal organisations (Penrose-Buckley, 2007). Informal POs consist of farmer groups that are not registered and therefore have no legal rights as an organisation. Registered POs such as cooperatives and associations can more easily enter into formal contracts, access credit, and influence governmental policies. In this case the PO can either intermediate the services that are provided to its members (e.g. access to credit and training), but also access subsidies and services aimed at the organisation itself. Therefore, formal POs can more easily invest in human and physical resources. The formalisation process, however, depends on the balance between foreseen benefits and the necessary efforts and costs of the registration, which varies depending on the particular social, political and legal context.

Group homogeneity gives an indication to what extent farmers share a common interest in the management of natural or economic resources (Baland and Platteau, 1996; Hansmann, 1996). When members of the PO have similar production activities the costs of collective decision making are lower. Moreover, the PO is better able to address human and economic resources towards the core business activity.

6.2.3 The role of outsiders

Despite POs capability in providing farmers with different services, their effective involvement in markets often relies on the support of public and private outsiders (Shiferaw *et al.*, 2011). Outsiders often support group capacity building through the provision of pre- and post-harvest services (Markelova *et al.*, 2009; Poulton *et al.*, 2010). It is a challenge, however, to provide the proper amount of support. POs can be jeopardized by the provision of either too much or too little services. While some POs fail due to a lack of member trust and managerial skills (Wade, 1988); others become too dependent on external support (e.g. financial; Shepherd, 2007). This could isolate the organisation from the market context, resulting in collapse as soon as support is withdrawn. When the state provides services, there is a risk that the PO is used as an instrument of public service delivery, thus becoming vulnerable to political affiliation (Key and Runsten, 1999).

A common approach on how and how much to support POs does not exist. The delivery of the right kind and amount of services will vary according to specific needs (Rondot and Collion, 2001), which are determined, to a large extent, by organisation and farm characteristics. While POs involved in the production of high value products, such as vegetables and fruits, are challenged to assure consistent supply and high quality products, the main function of bulk crop POs is joint selling, which requires economies of scale and bargaining power (Poulton *et al.*, 2010). Farm location and group homogeneity affects the PO's ability to access urban and regional markets and manage core business activities (Stringfellow *et al.*, 1997; Markelova *et al.*, 2009).

Outsiders can also act in favour of POs by creating market opportunities, such as buying products from the PO or ensuring a minimum price (Figure 6.1b). For instance, in food procurement policies and other food supply arrangements both government and private business use price incentives as a strategy to initiate collective action among farmers (MDA, 2013). Such instruments belong to the political and economic environment which can play a significant role in group formation (Thorp *et al.*, 2005).

6.2.4 Conceptual framework

In emerging supply chains, such as the biodiesel chain in Brazil, there is often lack of knowledge on essential services needed to enable family farmers to tap into the

new market opportunity and on proper service providers. Furthermore, uncertainty exists on what functions POs can be expected to fulfil and how they can be supported by outsiders.

The relationship between the function of the PO and the amount of support from outsiders is affected by the level of transaction costs faced by farmers. The geographical dispersion of smallholder producers dramatically increases the costs of servicing small farmers. Farmers' location also affects their access to inputs, output markets and market information. Market and product type can also determine the level of transaction costs faced by farmers. These costs are associated with product perishability and specific investments aimed at attending to quality, volume and coordination standards which, all together, increase the risk (for farmers) of opportunistic behaviour from buyers (Markelova *et al.*, 2009). The structural characteristics of the PO influence its ability to provide and access different services, thus affecting its function and required support. In our approach, PO and farm characteristics are in the centre of the analysis thus defining the function of value chain actors (Figure 6.1a).

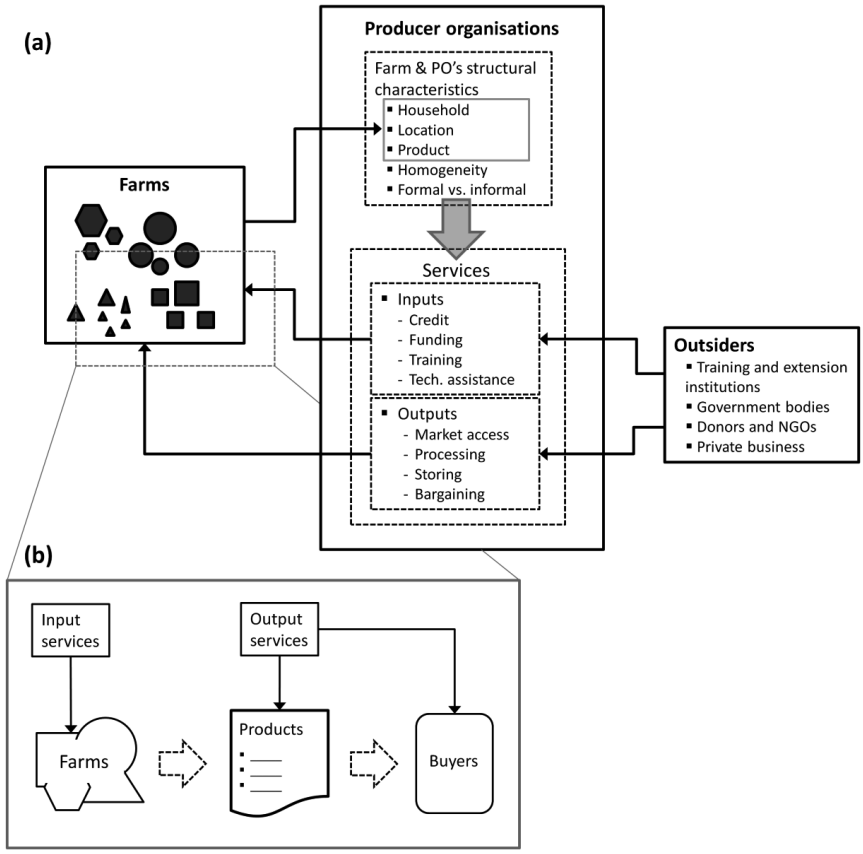

Figure 6.1 Conceptual framework of the relationship between farms, producer organisations (POs) and outsiders (a); and farm to buyer flow of products and services (b).

POs can provide or intermediate access to inputs, such as credit, funding, training and technical assistance; and access to output markets including storage, processing, and bargaining for better market conditions (Figure 6.1a). In this process POs can be supported by public and private outsiders. The level and type of support will vary according to the services that are already provided by the PO - which are affected by farm features - and its structural characteristics. While informal POs act primarily as intermediaries facilitating farmers access to input and output services, formal organisations can enter into formal contracts, access market opportunities (e.g. procurement policies) and capture financial support (e.g. credit), which can be used to

built their own capabilities, thus reducing the dependency on external support. Homogeneous organisations can more easily focus on core commercial activities, coupled with reduced costs associated with collective decision making. Outsiders can act in favour of POs by providing inputs-related and output-related services or by creating market opportunities (e.g. product acquisition; Figure 6.1b).

6.3 Data and Methods

To explore the relationship between organisation and farm characteristics on one side and PO function and outside support on the other side a multiple case study design was applied. This approach allows the data to be replicated by the different cases, hence providing a more compelling body of evidence for scientific generalisation than single-case design (e.g Ostrom, 1990; Meinzen-Dick, 2007). However, generalisation is restricted to theory building rather than to characterizing a population (Yin, 1989).

In selecting the case studies the objective was to gather information from family farm POs in regions where local governments pursue rural development and implement biodiesel policy. Furthermore, there should be a biodiesel producer to which farmers could potentially supply their feedstock (Figure 6.2). From 2010 to 2013 data was collected from a series of case studies (family farm POs; $n = 14$) in the states of Minas Gerais and Sergipe. The explored case studies are located in the South of Sergipe (Indiaroba, $n = 1$), northern Minas Gerais (Chapada Gaúcha, $n = 1$; São Francisco, $n = 1$; Catuti, $n = 1$; Montes Claros, $n = 4$), and southern Minas Gerais (Viçosa, $n = 4$; Barbacena, $n = 2$). Four biodiesel producers within 300 km from the POs were also identified in Minas Gerais (Montes Claros, Barbacena and Varginha) and Bahia (Candeias) (Figure 6.2).

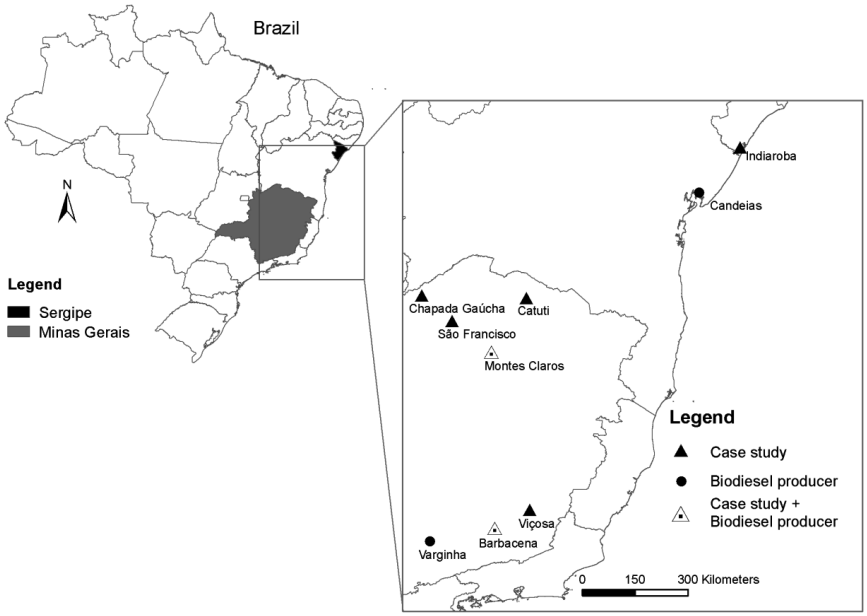

Figure 6.2 Research area (left), case studies and biodiesel producers (right).

The data were collected conducting semi-structured interviews (n = 78) with farmers, village leaders and presidents of local farm associations and technical and administrative staff from cooperatives. Agronomists and technicians from local service providers together with researchers active in the research area were also interviewed. The data was gathered through individual discussions and group meetings. Information was also obtained through direct observation.

The applied questionnaire was designed to capture farm characteristics such as household, location and products, and PO characteristics including group homogeneity, legal structure, function, and type of support from outsiders. Organisations were considered to have a high level of homogeneity if sharing common core agricultural activities (e.g. bulk crops, horticulture). POs in which farmers have two or more agricultural activities were considered to have a low level of homogeneity. Organisations were classified according to the legal structure into formal and informal POs. Product characteristics were used as a proxy for asset specificity, aimed at gaining insights in the level of transaction costs faced by farmers. Farmers were also classified according to their location in high and low potential areas. High potential areas account

for those farmers that have fairly well access to inputs and markets; while low potential areas are associated with limited access due to distance and costs. Farm household characteristics give a general description of scale of production (farm and herd sizes), which affects farmers' production systems (i.e. diversification) and risk aversion.

6.4 Empirical findings

6.4.1 Family farm producer organisations

In the research area, most POs are informal, have low group homogeneity, and are located in low potential areas. In Montes Claros there are about 70 POs of this format, accounting for at least 1,500 small scale (≈ 5 ha) family farmers. These farms are associated with fragile agricultural systems (limited rainfall, poor soils), in which multiple production activities (maize, beans, livestock) are the predominant strategy to cope with climate risk and market price variability. In this study, two POs of this format in Montes Claros are explored (Calhau and Piúma; Table 6.2).These POs help farmers to access micro-credit and training provided by public extension services, but play no role in connecting farmers to the market (Table 6.3). However, in the same area there are also POs that link farmers to markets. In both Montes Claros and Viçosa, farmers formed formal agro-processing POs targeting at added value products (Coop-Riachão, Grande Sertão, Apivicosa; Table 6.2). An important explanation for the success of these POs is the nature of the business which required limited investment in terms of cash and labour from its members. In Montes Claros region, the production of macaúba (*Acrocomia aculeata* Jacq.) oil (Coop-Riachão) and fruit pulp (Grande Sertão) is based on extraction, and hardly conflicts with current farm activities (maize, beans, livestock) due to reduced labour demands during the fruit harvest period (October to March). Similarly, honey producers in Viçosa (Apiviçosa) allocate only a share of their labour to the beehives. These farmers engage in different production activities, but tend to intensify honey production according to market prices, which can vary substantially (more than 100%). These agro-processing POs received financial support from government and donors, thus reducing the need for farmers to mobilize cash, especially in early stages of the business (Table 6.3).

Table 6.2 Description of the case studies.

Case studies	Municipality	Group size	PO characteristics		Farm characteristics		
			Legal structure	Group homogeneity	Potential area	Products	
						Category	Types
Calhau	Montes Claros	53	Informal	Low	Low	Bulk crops, livestock	Maize, beans, livestock
Piúma	Viçosa	20	Informal	Low	Low	Bulk crops, livestock	Coffee, maize, beans, livestock
Coop-Riachão	Montes Claros	48	Formal	Low	Low	Agro-processed	Macaúba oil; soap
Grande Sertão	Montes Claros	176	Formal	Low	Low	Agro-processed	Fruit pulp
Apivicosa	Viçosa	60	Formal	Low	Low	Agro-processed	Honey
Aparecida	Montes Claros	8	Informal	High	Low	Livestock	Milk
Silêncio	Viçosa	5	Informal	High	Low	Livestock	Milk
Várzea	Barbacena	6	Informal	High	Low	Livestock	Milk
ACPG	Barbacena	75	Formal	High	High	Horticulture	Vegetables[1], peach, plum
Assov	Viçosa	20	Formal	High	High	Horticulture	Vegetables[1]
Cooperafir	Indiaroba	468	Formal	High	High	Horticulture	Orange, coconut, pineapple, vegetables[1]
Coopasf	São Francisco	415	Formal	Low	High, low	Horticulture, bulk crops, livestock	Vegetables[1], maize, beans, milk
Coopercat	Catuti	65	Formal	High	High	Bulk crops	Cotton
Cooapi	Chapada Gaúcha	200	Formal	High	High	Bulk crops	Soybean, grass seed

[1] Lettuce, tomato, radish, cucumber, carrots, anion, cabbage, zucchini, squash, pumpkin and spice herbs.

In low potential areas, particularly in the North of Minas Gerais, extensive livestock production is a common activity among farmers better endowed in land (ca. 47 ha; Leite *et al.*, 2013). In this region, milk producers have difficulty in complying with safety and quality standards established by private companies. Limited in cash and production scale (ca. 5 to 10 milking cows), these family farmers are often constrained in participating in modern supply chains. A key problem is the requirement from dairy companies to install a milk cooling tank. In Montes Claros, Viçosa and Barbacena POs have been formed to collectively buy cooling tanks (Aparecida, Silêncio, Várzea; Table 6.2). In Aparecida, the members of the informal PO bought a milk-cooling tank with credit provided by the dairy company (Table 6.3). In this case, group homogeneity is a key element in reducing decision making costs when assets are involved. These groups are often formed by relatives and neighbours with well established social ties, which make contract compliance easier to enforce (e.g. Baland and Platteau, 1996). However, we found in the research area that many attempts fail due to lack of trust resulting from negative earlier experiences. Alternatively, local governments in Viçosa and Barbacena intervened by purchasing milk cooling tanks (state owned) that can be used/operated by farmers, thus reducing farmers' risk of contract default and need for capital contribution (Silêncio, Várzea; Table 6.3). However, this arrangement is appended by poor maintenance of the tanks and conflicts related to selecting farmers who will be granted access to the equipment.

Table 6.3 Case studies and the services provided by producer organisations (POs) and outsiders.

Case studies	Services provided by the PO		Services provided by outsiders
	Related to inputs	Related to outputs	
Calhau	Training, credit	-	Government: training, credit
Piúma	Training, credit	-	Government: training, credit
Coop-Riachão	Training, credit, funding	Oil extraction, packaging, labelling, marketing	Government/donors: training, credit, funding
Grande Sertão	Technical assistance, training, funding, credit	Pulp extraction, packaging, labelling, marketing	Government/donors: training, credit, funding, FAP[1]
Apivicosa	Training, credit, funding	Processing, labelling, packaging, marketing	Government/donors: credit, funding, FAP[1]
Aparecida	Training, credit	Marketing	Private business: training, credit
Silêncio	Training, infrastructure	Marketing	Government: training, milk tank
Várzea	Training, infrastructure	Marketing	Government: training, milk tank
ACPG	Training	Marketing	Government: training, FAP[1]
Assov	Training	Marketing	Government: training, FAP[1]
Cooperafir	Technical assistance, training	Marketing	Government: training, funding, FAP[1]
Coopasf	Technical assistance, training	Packaging, storing, marketing	Government: training, credit, funding, FAP[1]
Coopercat	Technical assistance, training, credit, bargaining	Marketing, storing, bargaining	Government: credit, training
Cooapi	Technical assistance, training, credit, bargaining	Marketing, storing, bargaining	Government: credit, training

[1] FAP: Food Acquisition Programs are policy instruments of food procurement from family farmers. The products are supplied to public institutions such as school and hospitals.

Horticulture POs were formed by groups of farmers with high homogeneity and located in high potential areas (ACPG, Assov, Cooperafir; Table 6.2). For perishable crops like vegetables and fruits a constant flow of products to buyers, good access to information and markets are essential. Despite such conditions being present, all of the explored POs fail to fulfil basic requirements (i.e. volume, timing, consumer standards) of modern supply chains featured by supermarkets. Farmers continue to sell in channels that include middlemen who retain a share of the product value, thus pushing down prices received by farmers. However, through public food acquisition programs (FAP; Table 6.3) POs have been able to bypass the middlemen by directly supplying public institutions (e.g. hospitals, schools, food relief programs), and thus obtaining higher prices. There are also POs, such as Coopasf, which evolve to a more diversified organisation combining different product types (Table 6.2). In this case, the

diversification was followed by the formalisation of the PO, which is an essential step to access government subsidies (Table 6.3).

Despite the low value added of bulk crops, homogeneous POs formed by large (50 to 260 ha) farms in high potential areas (Coopercat, Cooapi; Table 6.2) are able to benefit from economies of scale allowing farmers to reduce costs associated with storage and technical assistance, along with enhanced capacity to negotiate better prices for inputs and outputs. These POs are structured in a more business oriented way, which enables the organisation to invest in assets including facilities, equipment and management skills, thus becoming less dependent on external support (Table 6.3).

6.4.2 Biodiesel market: lessons to be learnt

In the research area, dedicated biodiesel POs were not identified. However, different organisations have been exploring opportunities associated with the biodiesel policy through alternative crops (sunflower, castor bean) and co-products (waste vegetable oil). In addition these cooperatives have received financial support for technical assistance from biodiesel producers. Their formal structure not only facilitates access to inputs, but also allows reduction of transaction costs associated with transport, information, contracting and monitoring contract compliance. These cooperatives are also able to explore synergies between biodiesel crop production and market; and current farm activities. It includes intercropping (fruits and sunflower), crop rotation (maize/beans and castor bean/sunflower), co-products (waste vegetable oil) and bonus prices for current oil crops (soybean).

Crop characteristics also affect the scope for engaging in biodiesel feedstock production. Suggested biodiesel crop options (castor bean and sunflower) are not competitive with high value products such as honey, fruits and vegetables. Furthermore, informal POs in low potential areas rely on external technical support that is challenged by PO's location and farmers' diversified agricultural systems. Under such conditions the identification and development of synergies is difficult. Moreover, in these POs the engagement of farmers in biodiesel crop production is frequently associated with trade-offs with current activities, thus increasing the risk associated with the reduction of farm household food and feed production (Florin *et al.*, 2012; Leite *et al.*, 2013).

6.5 Conclusions

Linking farmers to markets is one of the main goals of rural development policies. In Brazil, a new goal is to connect smallholder farmers to the emerging biodiesel market. POs can play an important role in such linking, by providing farmers with inputs-related and output-related services. However, conditions under which POs can be successful vary greatly, particularly depending on farm, product and organisational characteristics. Outside support is one of the success factors.

Formal POs formed by homogeneous groups and large scale farms can more easily access subsidies and markets, invest in core business activities and develop their own skills, which reduces dependency on external support. However, the majority of POs are informal, formed by very diverse farmers who face high transaction costs. For these POs external support is essential, in the form of providing access to inputs, access to output markets and financial support. Product characteristics determine to a large extent the services of POs as well as the support needed from outsiders. For instance, high value products require identification of niche markets and marketing support. For the farmer, limited competition with current farm activities is important, associated with risk reduction, labour availability, and farm household food and feed self-sufficiency. Outside support can reduce the farmers' need to supply equity capital, and provide technical assistance and market information. Even more important is outside support in the form of public food procurement. Through these procurement programs, paying smallholders a fair price, farmers have an economic incentive to set up a market-oriented PO.

From the case studies we learnt that there is limited scope for POs to fill the gap between small scale farmers and the biodiesel market. While POs can reduce transaction costs in biodiesel supply chains, small scale farmers' payoff from acting collectively is far from evident. Biodiesel crops (castor, sunflower) have low value added and multiple trade-offs with current farm activities.

The contribution of the biodiesel policy to rural development at large still seems to rely on the search for alternative strategies for linking farmers to markets. These might include different feedstock and market options that can reduce competition with staples and enlarge market opportunities for high value added products, thus enhancing farmers' benefits in pursuing collective action. Although food procurement programs

can be seen as a benchmark for market connection, in the case of biodiesel crops additional challenges are related to adverse location and low group homogeneity. While such obstacles can be reduced through the provision of input (credit, technical assistance, fertiliser) and output (market access, bonus prices) services, it is uncertain whether the state will be able to sufficiently compensate supply chain shortcomings. Moreover, farmers' ability to reap the benefits from the biodiesel policy remains a promise, which relies not exclusively but essentially on alternative feedstock that assures added value products, broader market opportunities and a better match with small scale farmers' production systems.

CHAPTER 7

General discussion

7.1 Introduction

Over the past decade, the increasing demand for finite fossil fuels combined with socioeconomic unrest in oil producing regions and concerns about climate change have driven policy and research agendas towards alternative fuel sources. Worldwide, biofuels have become one of the most dynamic and rapidly growing sectors of the global energy economy (Tomes et al., 2010; UN, 2007). The production of liquid biofuels from agricultural feedstocks is acknowledged as one of the most significant agricultural developments of the decade (Elbehri *et al.*, 2013). The surge of biofuels triggered two main scientific and societal debates from the environmental and socioeconomic arena. While the first deals with the impact of biofuels on GHG emissions, production of net energy and resource conservation, the second focuses on the claim that the production of biomass for biofuel by family farms can be a way out of poverty. This thesis aimed at contributing to this second debate.

In Brazil, the government targeted biodiesel as an instrument to combine renewable energy production with rural poverty reduction. Despite the interest of the government to improve family farmers' participation in biodiesel markets, family farmers' uptake of biodiesel crops is still limited especially in poor semi-arid regions of the country. The general objective of this thesis was to perform an integrated assessment of biodiesel crops, farm types, biodiesel policies and producer organisations that could generate useful knowledge on opportunities and limitations of family farmers' engagement in the biodiesel supply chain.

This chapter synthesizes the main findings through the development of an overarching discussion across the presented research chapters. In the discussion, several aspects related to the biodiesel policy and family farms (who benefit?; why(not)?; how to improve?; impacts?) are presented. Moreover, implication for different regions in Brazil, methodological features and shortcomings, final considerations and recommendations are described.

7.2 The biodiesel policy and family farms in Brazil

The relation between family farms and the biodiesel policy was the main topic explored across the chapters of this thesis. In Figure 1 we schematically represent this relationship, in which boxes and arrows indicate a number of fundamental findings as to

the questions addressed by this study. In the next paragraphs we will address these four questions one by one.

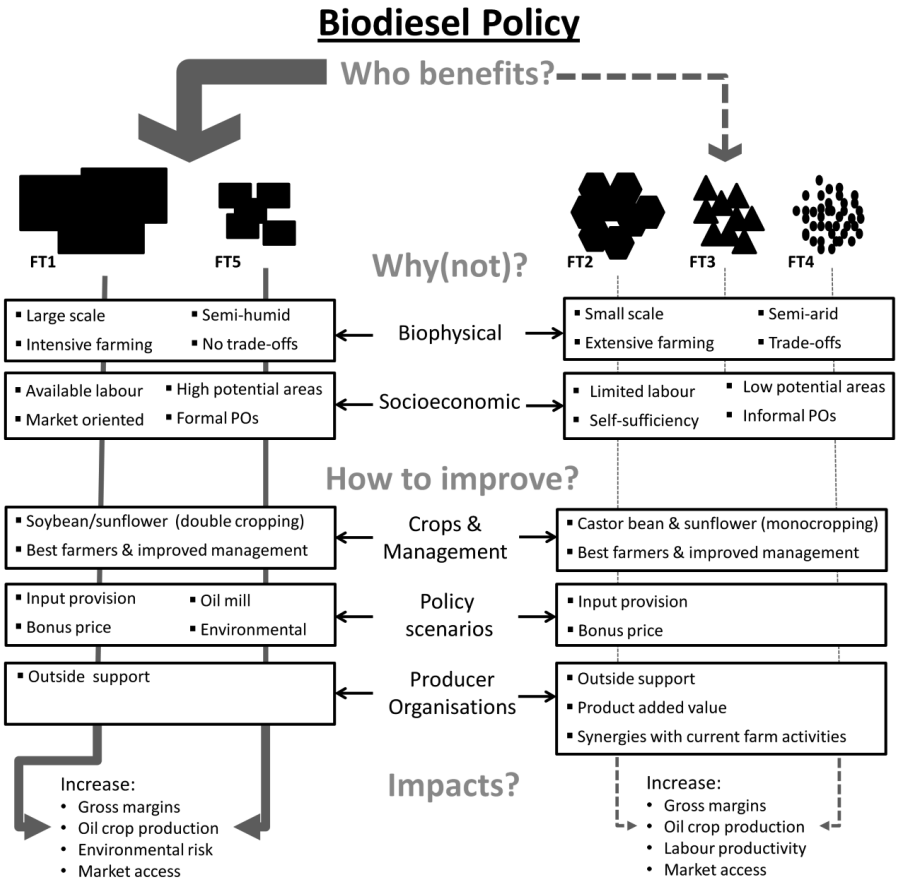

Figure 7.1 Schematic representation of the relationship between family farms (farm types: FT1 to FT5) and the biodiesel policy.

7.2.1 Who benefits?

The distribution of benefits from the biodiesel policy is clearly unbalanced (Figure 7.1). Such disparity is shown by the cash spent on feedstock acquisitions by biodiesel producers. Soybean is the major feedstock, absorbing 95% of the total cash spent on this policy (Figure 7.2). Hence, producers of this crop reap the largest share of the benefits associated with the policy. Only a marginal piece of the pie is allocated to

other crops such as castor bean, sesame, palm, sunflower, rapeseed and groundnut (Figure 7.2). Moreover, we have identified in this thesis (Chapter 2) that soybean producers are substantially different from other family farmers.

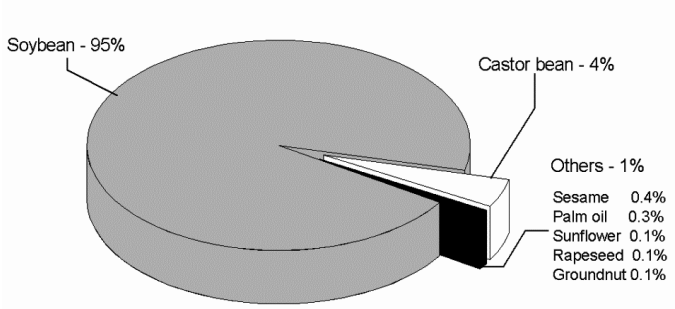

Figure 7.2 Relative economic values of feedstock acquisitions from family farms in 2010. Source: MDA (2011).

In the research area, soybean family farmers form a rather specialized group. These producers are engaged in a double crop rotation (soybean × grass seed). The production is market-oriented and the farming systems require intensive use of production inputs (i.e. fertiliser, biocides and machinery). Such features, combined with the limited use of soybean as a farm household food and feed self-sufficiency crop, restrain its cultivation by small, less endowed farmers as they cannot reach economies of scale. This characteristic can be identified across the country. While maize, which is a common crop among family farmers, is mostly cultivated in small areas (0 – 1 ha; Figure 7.3) soybean production is limited to a smaller group of relatively large farms (Figure 7.3).

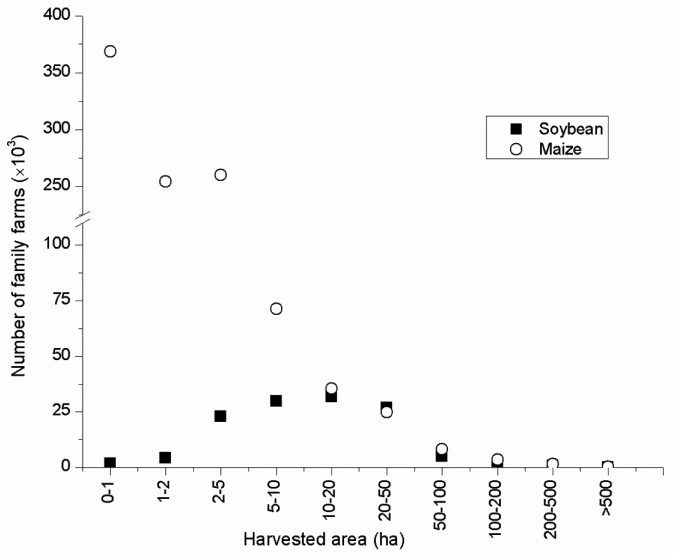

Figure 7.3 Numbers of family farms in Brazil growing different areas of soybean and maize. Source: IBGE (2006).

7.2.2 Why(not)?

In 2012, 2.7 million m^3 of biodiesel were produced in the country, involving more than 100,000 family farmers as feedstock suppliers (MDA, 2011). With as much as 80% of the fuel cost being determined by the feedstock used, biodiesel producers are keen to participate in supply chains in which crop prices, procurement and transportation costs are reduced. For family farms, the biodiesel policy offers opportunities to access a new market, reduce costs of looking for traders and decrease crop price uncertainty (through contract farming).

We have found that matching farmers' and biodiesel producers' interests depends on a number of farm biophysical and socioeconomic characteristics (Figure 7.1). These farm features were identified through the development of a farm typology. To simplify the results of our analysis, the identified farm types were divided in two groups: soybean (FT 1 and 5) and non-soybean (FT 2, 3 and 4) producers. The first group of farmers is located in Chapada Gaúcha, a semi-humid municipality in northwestern Minas Gerais. Farming systems include soybean which is produced under intensive use of inputs (fertiliser, biocides, machinery) in relatively large farms (50 to 117 ha). These farmers are members of a formal producer organisation (i.e. a

cooperative) that plays an essential role in gaining production scale and negotiating better market conditions.

In Minas Gerais non-soybean farmers are mainly concentrated in Montes Claros, a semi-arid municipality in the northern part of the state. In this region, farming systems are characterized by the cultivation of maize and beans, produced with limited use of inputs (fertiliser, biocides and machinery). Apart from maize and beans, relatively large farms (≈ 46 ha) engage in cattle production (farm type 2), while smaller farms (2.4 to 14 ha) have more mixed farming systems including poultry, swine and horticulture production. Sharecropping and off-farm labour are also important activities among farmers less endowed with land (farm type 4). A small, but important group of farmers concentrated close to cities and with access to irrigation engage in horticulture production (Farm type 3). Due to the high value added to vegetables and fruits, these farmers are often neither interested in nor targeted by the biodiesel policy, hence not explored further in this thesis (Figure 7.1). The majority of the farmers is distributed over large areas with poor access to inputs and market information (low potential areas), where producer organisations (POs) are often not registered (informal) and therefore have no legal rights as an organisation. POs are used by farmers to access technical information and micro-credit, but they rarely have a function in linking farmers to markets. Limited market-orientation is associated with fair to high priority for food and feed self-sufficiency of farm households. In this region production surpluses are often commercialized in local (rural) markets, which imply lower logistical costs combined with reduced quality, volume and coordination standards than urban or regional supply chains, such as the biodiesel feedstock chain. Moreover, biodiesel crop production (i.e. sunflower and castor bean) can lead to competition with current farm activities due to farmers' labour and land constraints.

The underlined farm socioeconomic and biophysical characteristics altogether shape the opportunities for farmers to participate in the biodiesel supply chain. Soybean farmers have a clear advantage over other farm types. Their large scale reduces cost of feedstock procurement and transportation. Moreover, these farmers can more easily, through their cooperative, tap into formal contracts with the biodiesel producer and thereby decrease transaction costs. These advantages helped to develop a tight relationship between soybean farmers and biodiesel producers in different regions of the

country (Figure 7.4). There is an almost perfect fit between the soybean production in each Brazilian region and the installed biodiesel industry. The leading regions are the Central-West and South regions which together represent 75% of the biodiesel production capacity and 83% of the country soybean production.

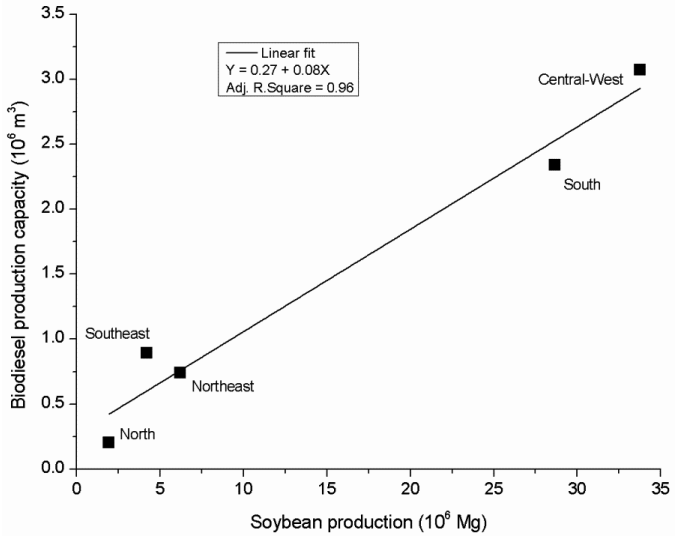

Figure 7.4 Relationship between soybean production and biodiesel production capacity in different regions of Brazil. Source: ANP (2013); IBGE (2011b).

7.2.3 How to improve?

Over the last decade scientists and policy makers in Brazil have been challenged to improve the outcomes of the biodiesel policy in two main aspects. Firstly, there is a need to increase uptake of biodiesel crops by less endowed farmers, especially in poor semi-arid regions of the country where rural development is needed most. Secondly, biodiesel crops with high oil content (≥ 45%; e.g. sunflower, castor bean) are necessary to increase oil productivity and energy efficiency, thus assuring a more diversified and reliable supply of feedstock to satisfy current and future biodiesel demands.

In this thesis opportunities to improve farmers engagement through alternative crop options (i.e. castor bean, sunflower) and production techniques (i.e. best farmers management, improved management, irrigated) were explored in Chapters 3 and 4. Our simulations show that sunflower is only economically competitive with soybean if

cultivated as a second crop in a double cropping system and following short cycle soybean varieties. The feasibility of this cropping system, however, is restricted to best farmers management and the northwestern part of the state (e.g. Chapada Gaúcha) where the rainy season is longer than in the northeastern part (e.g. Montes Claros). Yet, lower yield levels of sunflower (1500 to 2800 kg ha^{-1}) than of soybean (2400 to 2900 kg^{-1}) combined with relatively low crop prices (Chapter 3; Figure 3.7) push sunflower away from a feasible option for farmers.

The ability of biodiesel crops to increase farmers' income when compared to traditional crop activities, such as maize and beans, is often taken for granted among government bodies (e.g. MDA, 2011). However, we have identified that this is not always the case. Beans, which is a common crop among small, less endowed family farmers (e.g. in Montes Claros) is the most profitable (gross margin) of the explored crop options. An indication of the economic gains associated with beans is its high price that varies across years, but is constantly above that for other crops, such as maize (current), sunflower and castor beans (Chapter 3; Figure 3.7). With relatively low yield levels for current and alternative crops (from 500 to 900 kg ha^{-1}) and production costs mainly determined by family labour (under current production technique), crop prices become an important indicator for farmers' decision making. Our calculations have shown that beans also have the highest gross margin ha^{-1} followed by castor, sunflower and maize (Chapter 3). Hence, castor bean and sunflower are viable options *vis-à-vis* maize. For all crops socioeconomic and environmental indicators can be improved through a more intensive and rational use of inputs relative to current farm management.

Despite its low economic gains, maize plays an essential role in furnishing farm household feed requirements, thus integrating crop and animal production. The possibility of using biodiesel feedstock cake (after oil extraction) as a feed source to replace maize exists, however there are limitations. Transportation of the cake from the oil mill to the farm and detoxification in the case of castor bean incur costs which might hamper adoption by farmers.

Yet, another way of improving farmers' engagement as biodiesel crop producers is through different biodiesel policies, particularly in semi-arid regions. Input provision (fertiliser, machinery, oil mill), market oriented (bonus price) and environmental

policies were explored in this thesis with an *ex-ante* integrated assessment approach (Chapter 5; Table 5.4).

The design of new biodiesel policies was based on farmer and other stakeholder consultations taking into account the relationship between current farming systems and socioeconomic and environmental aspects of biodiesel crop production. Among the explored policies in the research area (Chapter 5; Table 5.4), few showed to be effective in improving the engagement of non-soybean producers (Figure 7.1). Farmers' access to small scale oil mills, although regarded as a viable solution for farmers, failed to generate sufficient income when compared with beans (non-soybean producers; Chapter 5). Policies associated with input provision, such as fertiliser, had the most significant effects on all farm types (Section 7.1.4). However, the provision of inputs to farmers is far from being an easy task. Farmers' dispersion over a large area increases logistical costs. Moreover, farmers might be tempted to use the provided inputs in a different way than intended, such as selling to wealthier farmers or applying these in a different crop (maize, beans). Similar drawbacks occur in the current setting, in which the biodiesel producer uses local extension agencies to provide farmers with sunflower and castor bean seeds. Despite service providers' efforts to deliver the seed, it often arrives too late. Consequently, farmers either give up cultivating the biodiesel crop (contract default) or delay their preferably sowing period, thus bearing higher risk of crop losses due to less rain.

Alternatively, output-oriented policies such as bonus prices eliminate the need to provide production inputs, thus reducing implementation cost. The assumption behind this policy is that higher prices would create incentives for farmers to search and invest in inputs themselves. However, as we identified in this thesis (Chapter 5) market-oriented farmers with better access to market channels (soybean farmers) benefit most from bonus price policies. This suggests that policy implementation should be tuned according to farm diversity, thus implying either different policies for different farm types (e.g. input/output oriented) or a certain degree of variation within the same policy. In the case of bonus prices, less market-oriented farmers (farm types 2 and 4) should receive a higher bonus when marketing their feedstock than soybean producers, thus compensating the higher cost of input procurement and market access.

Together with crops and production systems characteristics, limited market access is an important obstacle between farmers and the biodiesel policy. Transaction costs for biodiesel producers and farmers are high (Poulton et al., 2010; Wiggins et al., 2010). Farmers' dispersion over a large area increase costs of providing inputs (e.g. technical assistance, seeds) and collecting outputs (i.e. biodiesel feedstock). Producer organisations (POs) can be an effective way of dealing with high transaction costs. When acting collectively, such as in POs, farmers can benefit from economies of scale, increase bargaining power and reduce information and transportation costs (Dorward, 2001; Ton et al., 2007). Moreover, POs are in a better position to tap into formal contracts reducing costs of feedstock procurement (Figure 7.5) and contract compliance. In the task of linking farmers to markets, POs can be supported by 'outsiders', such as government bodies, donors and NGOs, who provide essential services for market engagement (e.g. technical assistance, market information, credit). The complex relationship between the functioning of a PO and the level and type of support from outsiders was explored in Chapter 6. We found that while formal POs formed by large farmers (soybean farmers) can easily access the biodiesel market with limited external (e.g. financial) support, informal POs formed by small scale farmers (farm types 2 and 4) face great challenges. Support from outsiders is essential in the form of inputs and output services and financial support. Additionally, POs formed by less endowed farmers still rely on the search of products (i.e. biodiesel crops) that assure farmers of added value (e.g. fuel and food/feed market) and low competition with current farm activities (low labour demands).

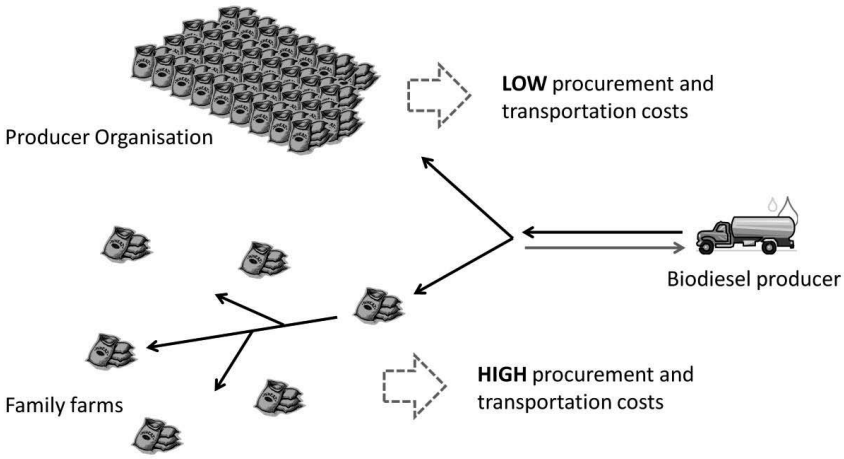

Figure 7.5 Schematic representation of the procurement and transportation costs between the biodiesel producer and individual family farms or a producer organisation.

7.2.4 Impacts?

The impacts of the present biodiesel policy are larger for soybean farmers in Chapada Gaúcha (farm types 1 and 5) than for non-soybean producers in Montes Claros (farm types 2 and 4). Following the analysis presented in this thesis, in the short term (ca. 5 years) there is no evident alternative biodiesel crop to soybean. The cultivation of sunflower seems feasible only in double cropping systems and production techniques associated with high input use. This could be changed by new biodiesel policy scenarios (input provision, bonus price, oil mill), which showed to be effective in increasing farmers' gross margins (up to 40%) and oil crop production (up to 170%) through the combined cultivation of soybean and sunflower. However, sunflower production especially in double cropping systems has shown not to be an appropriate choice when biocide residues are taken into account (environmental policy). Moreover, through their cooperative soybean farmers can easily benefit (participate) from the current biodiesel policy, while the biodiesel producer is able to purchase a large volume of feedstock in a single contract.

In Montes Claros, the challenges faced by non-soybean farmers (farm type 2 and 4) to reap benefits of the biodiesel policy are many. Economically attractive biodiesel crop options that are compatible with farmers' food/feed demands and labour

limitations are yet limited. New policies based on the provision of fertilizer and machinery could be a way of improving farmers' engagement towards sunflower and castor bean production. However, the impact of such policies as to increasing farmers' gross margin is still limited (up to 13%). The main reasons for such minor increase are farmers fair to low market-orientation, diversified production systems (e.g. crop and livestock production; farm type 2) and sources of income (e.g. off farm labour; farm type 4) which dilute the impact of biodiesel crops. Labour productivity, on the other hand, increased significantly allowing the annual cropped area to expand from 42 to 106% when farmers' were provided with land preparation machinery (i.e. input policy). In this policy scenario, farmers are able to cultivate biodiesel crops (0.2 to 2 ha) without compromising food and feed self-sufficiency. Despite the increase of the cropped area, market connection is still a great obstacle for farmers. While maize and beans can easily be commercialized in local (rural) markets, biodiesel crops follow a very different path in which transportation and transaction costs are high. Producer organisations (POs) are acknowledged as a way for small scale farmers to reduce these costs. However, market connection is still poor as current biodiesel crops fail to provide farmers incentives for collective action. Low value added and competition with current farm activities are the main obstacles for POs to evolve into being effective in supporting the proposed biodiesel crops.

7.3 Implications for other regions

The impacts of biodiesel policies and biodiesel crop production explored in this thesis could also be relevant for many of the 4.3 million family farms scattered across Brazil. The implications for other regions of the country are explored in this section based on farm biophysical and socioeconomic similarities.

In Brazil, the majority of the small family farmers is concentrated in the eastern states (Figure 7.6a), particularly in the Northeast where the average farm size varies from 6 to 11 ha (Figure 7.6b). Moreover, maize yields are generally low (Figure 7.6c) in northern states due to the combination of agroecological conditions (e.g. semi-arid) and low use of production inputs. Farmers in this region have a low market orientation (Figure 7.6d), which is an indication of high maize self-sufficiency demands mainly for animal feed.

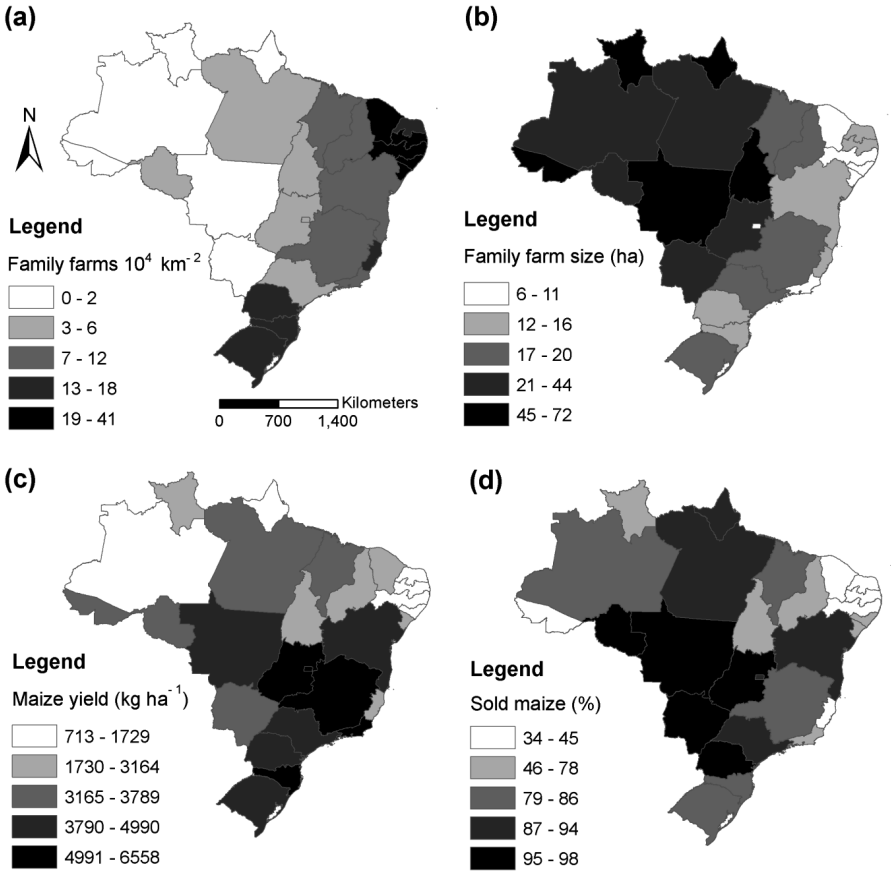

Figure 7.6 The Brazilian map with states (n = 27) featuring the distribution of family farmers per 10,000 km^2 (a), average family farm area (b), average maize yield on family farms (c) and percentage of the produced maize that is sold by family farmers.

Many of the characteristics of northern Brazil, in particularly the Northeast, were also identified among farmers in Montes Claros (farm types 2 and 4). Moreover, both regions have similar agroecological conditions (i.e. semi-arid), along with governments' interest to develop castor bean and sunflower as biodiesel feedstock among family farms (Milani and Severino, 2006; Ribeiro and Carvalho, 2006). These similarities indicate that the knowledge on crop options, production techniques and new biodiesel policies gained from the challenges and opportunities explored for farmers in Montes Claros (farm types 2 and 4) can be useful for northern Brazil.

The Northeast region accommodates the poorest farmers in the country, with an agricultural per capita GDP that is seven times smaller than for farmers in the South and Central-West of Brazil (IBGE, 2006). In this region, any strategy to introduce biodiesel crops needs, more than anywhere else, to assure that farm food and feed self-sufficiency will not be compromised. In addition, with up to 11 dry months, which makes the Northeast the driest region in Brazil, suitable crop options are scarce. Castor bean is adapted to and cultivated in the region, mainly in the state of Bahia that is responsible for 74% of the national production (CONAB, 2013). However, a limited amount of this production is transformed into biodiesel (Kouri et al., 2010). The installed castor mills in the region aim at the transport (e.g. lubrication), cosmetic and pharmaceutical market, which assure high oil prices. For farmers in Montes Claros, our simulations show that economic gains of castor bean production are limited. However, an existing high value oil market can be an opportunity if farmers were able to produce oil as was explored with the oil mill policy scenario (Chapter 5). In this arrangement, the biodiesel industry would be a secondary market for sub-products, such as waste oil. Although opportunities do exist, the identification of viable alternatives for farmers to increase their income remains a great challenge across the region. The identification of best strategies should be combined with a farming systems approach to adapt to the dynamic and heterogenic conditions faced by farmers across regions.

The Central-West, South and Southeast regions, on the other hand, share features with soybean farmers in Chapada Gaúcha (farm types 1 and 5). Common characteristics are the relatively large farms combined with high yield levels and market-orientation. Our study explains that these soybean producers were easily engaged in the biodiesel supply chain because of their skills and capabilities to produce and provide large quantities of feedstock. Furthermore, soybean farmers are often already organized in cooperatives, which reduces procurement, transportation and transaction costs. Cooperatives are eligible to participate as family farm biodiesel suppliers when a minimum of 60% of the members are recognized as family farms (MDA, 2012) as is the case of farmers in Chapada Gaúcha.

In southern Brazil opportunities for double cropping systems, as explored with sunflower following soybean, are limited. Differently from more central areas in the country where cropping systems are mainly defined by the length of the wet season, the

South is characterized by sub-tropical conditions where lower temperatures during the winter also play an important role. The region is the most important producer of winter crops, being responsible for 93 and 99% of the national production of wheat and barley, respectively (CONAB, 2013).

Contrary to sunflower, which is still not a viable option for farmers when compared to soybean (this thesis), winter crops could offer opportunities. Rapeseed cultivation could be a way of improving oil crop production and strengthening family farm participation in the biodiesel supply chain without competing with soybean due to different growing periods. The South is already the most important rapeseed producing region, accounting for 94% of the national production (CONAB, 2013). However, the cultivated area is relatively small (41,500 ha) if compared to soybean (9,876,400 ha; CONAB 2013). Crop management combined with climate conditions are the main shortcomings associated with the low uptake of rapeseed by farmers (Tomm et al., 2010). Similarly to what was suggested for the northeastern part of the country, farmers' access to small scale oil mills could boost family farms' income through their access to food and fuel markets.

The realization of opportunities associated with rapeseed or any other crop, however, relies on a combination of appropriate policies with knowledge of the crop, production systems and farmers objectives. Nevertheless, the large scale of family farms from the South combined with collective action (cooperatives) improves their ability to incorporate innovations; thus it is more likely that they participate and benefit from new market opportunities, such as the biodiesel market

7.4 Methodological approach

The methodological approach used in this thesis is a combination of different methods and tools linked to generate knowledge and address questions at different levels (i.e. field, farm and to some extent region; Figure 7.7). It follows the Integrated Assessment (IA) logic in which the analytical process is based on the combination of interdisciplinary and participatory approaches to allow a better understanding of complex phenomena (Rotmans and Asselt, 1996; van Ittersum et al., 2008). From this approach distinct knowledge can be gained compared to insights derived from disciplinary research. Different from top-down approaches often used in the design of

rural policies, the IA introduces a participatory process in which farmers and other stakeholders are involved not only as questionnaire respondents, but playing an active role in the research, such as in the design of new biodiesel policy scenarios (this thesis). Hence, it allows a more in-depth analysis and assessment of scenarios including their feasibility and sustainability (Rotmans and Asselt, 1996). Moreover, with the support of computerized tools, the impact of new policies and technologies can be assessed *ex-ante*, thus allowing a better informed decision-making for farmers, researchers and policy makers. The approach includes the analysis of socioeconomic and environmental aspects of production systems and their interaction with different policies at field and farm level. It also goes beyond the farm boundaries by exploring market connection opportunities and limitations associated with producer organisations (POs; Figure 7.7).

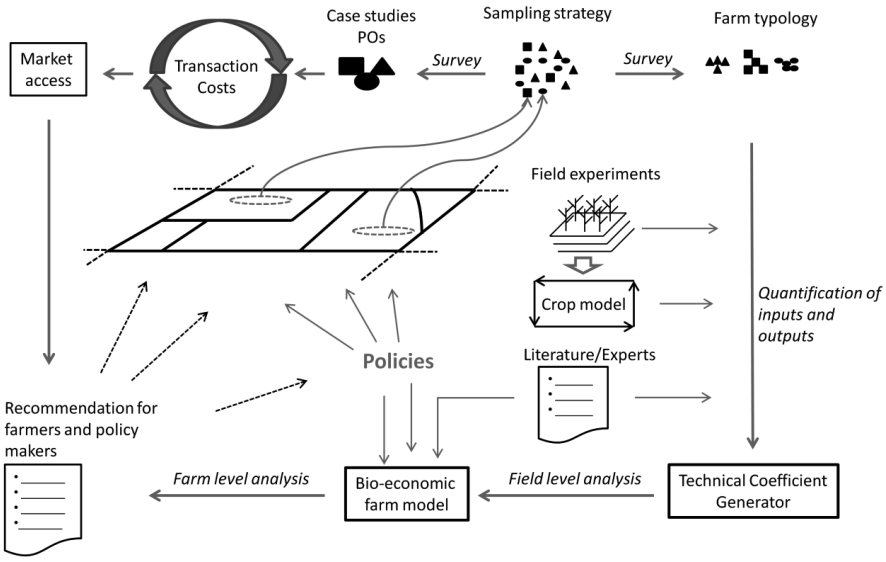

Figure 7.7 The components of the methodological approach.

Although there are a number of strengths associated with IA and its ability to address complex systems in an interdisciplinary way, limitations also exist. Trade-offs might occur between the depth of the analysis and the extent of integration. When different disciplines are combined there is always a risk of being too superficial on the exploration of each discipline or failing to properly integrate the knowledge generated by different disciplines. In this matter, the analysis could also be biased by the

researcher(s) background, thus attributing an unbalanced weight to the explored research topics and findings. Furthermore, the combination of different tools, particularly computer models (crop and bio-economic models) requires extensive compilation of data from farm surveys, field experiments, experts and literature (Figure 7.7). Hence, data availability might be another important limitation to this approach.

For this thesis the available information was one of the main obstacles to the selected IA methodological approach. It not only limited the scope of the research (i.e. number of crop options and production techniques explored) but also required certain levels of adaptation. In this regard, macaúba palm can be mentioned as promising alternatives that could not be addressed by this thesis. The relationships between inputs and outputs are preferably investigated and verified through field/farm trials that reveal crop yields under a given management and environmental condition (climate, soil). Although it increases reliability of data, this approach is expensive and time consuming. The explored alternative crop options (i.e. biodiesel crops) were the most challenging in terms of data availability. An experiment was conducted to calibrate and validate a sunflower crop model aimed at exploring yield levels in different regions and crop growth conditions (Chapter 4). A similar approach was not possible in the case of castor bean due to lack of resources (time, capital, labour) and tested tools (crop models). An alternative strategy based on expert knowledge and literature on experiments in the study region was used. In this case the obtained information is limited to the tested locations and input levels. The use of a crop model would have allowed the extrapolation of experimental knowledge to other locations, input levels and years.

Apart from biophysical, socioeconomic information is also an important database component to bio-economic modelling. Data on costs of production inputs of each crop and animal activity were collected through farm surveys. This information is essential to the calculation of gross margins of current production activities. However, farmers often do not keep track of their expenditures, and some information is poor or absent. To deal with this, costs of all variable inputs such as hired labour and machinery, fertiliser, biocides, seeds and fuel were estimated through “key” farmers combined with experts. Fortunately, there are farmers who have a rather strict discipline in recording yearly costs. Additionally, extension agents also have good knowledge of input costs (i.e. fertiliser, biocides). Although this approach may not give a full

representation of the costs of all interviewed farmers, it provides a fair approximation given the conditions found in the field. Moreover, farmers agreed that the variation in prices due to distance and transportation costs between villages is minor.

Methodological limitations were also found in exploring Producer Organisations (POs) and biodiesel market access by family farms (Chapter 6). Our methodological approach was based on a multiple case study design composed of family farm POs. Ideally, POs involved in the biodiesel supply chain could be used to gain knowledge on the role of collective action in linking farmers to the market. However, dedicated biodiesel POs do not exist in the research area. Instead, we drew a parallel between current POs engaged in different types of products (e.g. horticulture, bulk crops and animal products) and the biodiesel supply chain. PO, farm and product characteristics were used to identify opportunities and shortcomings of biodiesel crops and the necessary support from outsiders (government, donors, NGOs) in the form of input and output services. Although conclusions were not derived from direct observations, this approach allows the identification of important lessons from different experiences in linking farmers to markets, and how these experiences could be translated to the biodiesel supply chain.

7.5 Final considerations

During the past five years I have worked and spent a fair amount of time with family farmers in northern Minas Gerais. During this time I had the opportunity to learn and explore some of the diverse biophysical and socioeconomic characteristics of farming systems in the region. This experience taught me that family farms, due to a myriad of factors, can differ substantially, and that these differences shape opportunities and limitations faced by these farmers. Therefore, rural development policies will not be effective with only one-size-fits-all approaches. Background knowledge on prevailing farming systems is essential to gain insight on farmers' livelihood strategies and resource management regimes. Currently, supportive rural policies seem to be undermined by the lack of farming systems information that would allow to improve both targeting and effectiveness of these policies.

Farm typologies are a simple, but useful tool to gain insight in the diversity of farming systems, generating valuable information for a better policy targeting. The

agricultural census database combined with local expert knowledge are readily available sources of information that could be used to group farms into different types according to resource endowment (land, capital, labour), market- and production-orientation (bulk crops, livestock, horticulture; e.g. Figure 7.6). The combination of biophysical and socioeconomic farm characteristics gives more in-depth information to generate a number of distinct groups or types, which in contrast to the current "family farm" definition (i.e. two groups, family farms and non-family farms) provides richer background information for policy making.

In the research area less endowed farmers face great challenges to participate in the biodiesel policy. Additionally, sustainable biodiesel crop options (i.e. sunflower and castor bean) are scarce. Main shortcomings are low gross margins, high labour demands and limited scope to satisfy farm household food and feed demands. As we explored in this thesis, effective policies as to increasing farmers' gross margin and biodiesel crop production are associated with intensification strategies (i.e. input provision: fertiliser, machinery). Yet, another way of improving policy effectiveness is through novel crops, better matching with farmers' goals and current production activities. In this regard, I believe that macaúba (*Acrocomia aculeata* Mart.) stands out as a promising mid-term (5 to 10 years) potential alternative for farmers. Macaúba or macaw palm is a perennial palm tree with natural occurrence in Brazil, particularly in the cerrado (Motta et al., 2002). Yield assessments indicate that oil productivity can be up to ten times higher than of other crops such as soybean, castor bean and sunflower (Cargnin et al., 2008). It is also suitable for intercropping, has low labour demands and allows the exploration of high value added products. However, it feels rather ambiguous to praise potential crops for which information is still limited; a number of cases teach that promises do not always come true (e.g. jatropha; Kant and Wu, 2011; Sanderson, 2009).

Over the last decade, research on macaúba has gained momentum in Brazil stimulated by the creation of the biodiesel policy. Scientific efforts aim at generating information on crop features such as genetic variability, propagation techniques, optimal growth conditions, productivity and oil quality (Abreu et al., 2012; Ciconini et al., 2013; Manfio et al., 2011; Moura et al., 2009; Nucci et al., 2008; Pires et al., 2013; Ramos et al., 2001; Scariot et al., 1995; Scariot and Lleras, 1991). Some of the findings indicate that productivity can vary substantially between genotypes (Ciconini et al.,

2013), and favourable growth conditions are associated with relatively fertile and wet soils (Motta et al., 2002). Moreover, little is yet known about the palm susceptibility to pests and diseases in a farm environment. Despite these shortcomings, which dismiss the tag of a "miracle crop" that grows well in dry poorly fertile soils, macaúba, in my opinion, still has potential advantages over current biodiesel crop options. Its deep rooting system assures resistance to dry spells that are typical of semi-arid regions such as Montes Claros, where macaúba occurs naturally in the valleys. The palm's perennial life cycle also reduces labour needs for sowing and land preparation. Intercropping with current farm activities is yet another possibility which allows crop management synergies (e.g. weeding). Its feasibility, however, is yet to be proven in the following years.

Although the biodiesel policy was designed to boost rural development through the increase of farmers' income, the evidence presented in this thesis indicates that such development is still limited, especially among less endowed farmers in semi-arid regions. Additionally, there seems to be a conflict between the interests of farmers and biodiesel producers. While farmers need added value crop options, biodiesel producers search for cheap feedstocks that ensure a more competitive production process. Therefore, the integration of food/feed and fuel production among small scale farmers relies essentially on the search of income generating activities, able to accommodate biodiesel production through the generation of co-products (e.g. waste oil) or valuable by-products (seed cake for animal feed). Yet, the search for viable options is less likely to be based on a disciplinary strategy confined to a crop or policy instrument. There is a need for interdisciplinary approaches that vary across regions and account for farmers' heterogeneity, capable to extend beyond the farm boundaries, thus also accommodating aspects related to market connection.

Finally, I hope that by exploring the different nuances of farming systems and their interaction with the biodiesel policy new and useful knowledge to scientists and policy makers can be gained. The findings reported in this thesis appeal to a more farming system-oriented agenda that combines participatory and quantitative approaches, with ample appreciation of the characteristics of the production environment and the objectives of the actors involved.

The research presented in this thesis points at relatively small opportunities for family farms to benefit from biodiesel crops in Brazil, and hence as a way out of poverty for these farms. It, therefore, contributes to one of the two main scientific and societal debates surrounding biomass production for biofuel. Though certain policies may enhance opportunities for family farms, this will require policy investments that need to be assessed against the contribution of biodiesel to reduce GHG emissions, produce net energy and avoid resource degradation (e.g. air and water pollution, soil erosion, biodiversity losses). This last scientific debate has been explored by other scientists (Cook et al., 1991; de Vries et al., 2010; Emmenegger et al., 2012; Hill et al., 2006; Iriarte and Villalobos, 2013; Nogueira, 2011), but also requires attention for the crop and management options analysed in this thesis before comprehensive policy recommendations can be made.

Appendices

Appendix 1

This document provides detailed information on legislation concerning family farms, the methods used to interview farmers in both Montes Claros (North of Minas Gerais) and in Chapada Gaúcha (Northwest of Minas Gerais), and how the farm typology was generated.

1.1 Family farm legislation

In Brazil family farms are defined according to a set of criteria established by national law (Brasil, 2006). According to this legislation family farmers are those family households located in rural areas which comply with all of the following criteria: (i) the farm area should not exceed four fiscal modules – a fiscal module area varies by municipality according to socioeconomic and agroecological features of different regions, in Montes Claros a fiscal module is 40 ha, whereas in Chapada Gaúcha it is 65 ha; (ii) family labour should be predominant over any hired labour regarding the agricultural activities of the farm household; (iii) family income should mainly be provided by farming activities; (iv) the farm should be managed by the family members.

As a result, there is a large range in the size of family farms (up to 160 ha in Montes Claros and 260 ha in Chapada Gaúcha), with various land use and farm management choices contributing to a complex configuration of family farms within and among regions. Such diversity creates challenges for policy makers when trying to design effective policies for family farms across the country.

1.2 Sampling strategy

To capture the variability of family farmers in both municipalities we interviewed farmers from all districts to cover the large area of the municipalities in both research sites (3,568.941 km^2 in Montes Claros and 3,255.187 km^2 in Chapada Gaúcha; Figure 1). In Montes Claros 55% of the family farmers interviewed were connected to Emater and 45% to Banco do Nordeste. The distribution was similar in Chapada Gaúcha with 52% of the family farmers connected to the soybean cooperative and 48% to Banco do Nordeste.

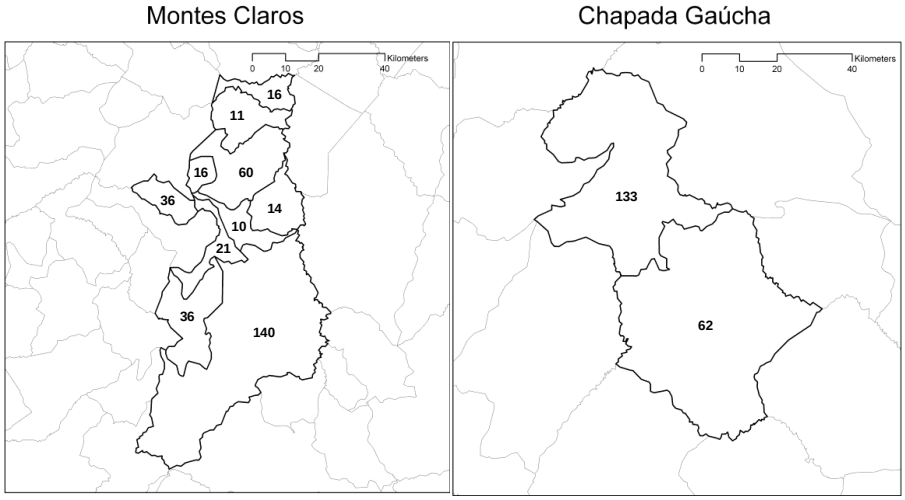

Figure 1 Number of family farms sampled in each district of Montes Claros and Chapada Gaúcha.

Another important issue regarding the sampling strategy is the sampling rate. Small-scale household farming is often characterized by complex interactions of farm activities under the management of family members. It is also common for members of the same family to start a new household but to keep its connection with the farm activities. This means that the same farm establishment can provide for more than one family. When interviewing farmers, especially during group meetings there is always a risk of approaching more than one member of the same extended family farm, thus causing repetitions in the farm database. To address this, the databases were evaluated with the assistance of local experts (extension agents) who helped to identify family members allowing us to derive the degree of overlap in both Montes Claros and Chapada Gaúcha. In both municipalities about a quarter (25%) of the 555 interviewees was estimated to overlap. The sampling rate was then estimated according to the following equation:

$$SR = \frac{ni \times (100 - OR)}{Ni} \quad \text{Eq. 1}$$

where, *SR* is the sample rate (%), *ni* is the number of interviewed farmers in the location *i*; *OR* is the overlapping rate estimated with the assistance of local experts; and *Ni* is the total number of family farmers in the municipality according to national statistics bureaus.

1.3 Farm typology

The ranges of family farm sizes (up to 160 ha in Montes Claros and 260 ha in Chapada Gaúcha), land use and agro-management choices are key issues that contribute to the complex configuration of family farms within and among regions. Although every farm household is different, with its own configuration and facing distinctive decision-making, classification or grouping of the farms is necessary as it is not feasible to analyse all individual farms. A classification should aim to identify maximum heterogeneity between types with great homogeneity within the same type (Köbrich *et al.*, 2003).

PCA was used to transform the selected variables into a smaller, non-correlated group of new variables (the principal components - PCs) which account for the majority of variability among the farms in the database. Following (Jongman et al., 1995) we selected a threshold of 70% of the total database variance and/or with eigenvalues greater than 1 to select PCs for the next step. Five principal components were selected which together account for 80% of the data variability (Table 1.1). The eigenvalues for each PC are given in Table 1.2. Scores were extracted for each observation in the database for the selected PCs (Table 1.3). These scores were then used as variables for cluster analysis.

Table 1.1 Subtracted principal components and their respective eigenvalues and explained variance.

Principal components	Eigenvalues	Explained variance	
		Proportion	Cumulative
PC1	4.23466	0.3529	0.3529
PC2	2.08122	0.1734	0.5263
PC3	1.19589	0.0997	0.6260
PC4	1.08315	0.00903	0.7162
PC5	1.00237	0.0835	0.7998
PC6	0.691254	0.0576	0.8574
PC7	0.618545	0.0515	0.9089
PC8	0.385476	0.0321	0.9410
PC9	0.27677	0.0231	0.9641
PC10	0.182508	0.0152	0.9793
PC11	0.139289	0.0116	0.9909
PC12	0.108858	0.0091	1.0000

Table 1.2 Loading values for the selected PCs in each variable. Higher (correlated) values in bold.

Variables	Loadings (%)				
	PC1	PC2	PC3	PC4	PC5
Area	**38.17**	14.26	-0.15	32.93	-12.30
Annual crops	**37.02**	-24.16	7.61	25.01	-19.26
Horticulture	1.09	17.49	**56.74**	-53.52	18.03
Graze crops	9.74	**59.02**	-13.52	17.49	25.41
Beef/dairy	12.13	**55.23**	1.14	26.75	18.49
Pigs/poultry	4.95	7.89	**74.73**	18.06	-19.61
Infrastructure	**43.03**	-9.61	0.27	-11.58	12.29
Collective action	**40.07**	-26.79	1.55	8.96	-0.08
Access to inputs	**43.22**	-8.75	1.06	-10.46	13.11
Market orientation	**35.72**	13.91	-5.43	-34.81	15.34
Off-farm labour	-17,07	-18.13	30.33	**50.18**	33.72
Off-farm area	-3.54	-30.03	-0.6	4.99	**78.01**

Table 1.3 Principal component scores.

Observations	Predicted PC Scores				
	PC1	PC2	PC3	PC4	PC5
1	3.452251	-1.219786	2.497954	0.4041308	-1.315733
2	4.344707	-1.233388	-0.439733	0.6090482	-0.9117033
3	2.714349	-0.2818776	2.944262	0.1168457	-0.8425839
4	5.640651	-2.047271	-0.1798116	1.490359	-1.579762
5	4.397025	-0.8352897	-0.5172285	0.7232266	-0.8555321
6	5.65293	-1.140796	1.618705	1.990276	-1.745693
7	5.771148	-1.83935	1.790528	1.966466	-2.096832
n^{th} (555)	…	…	…	…	…

1.4 Cluster analysis

Based in similarities or distances (dissimilarities), cluster analysis attempts to group individuals in a way that elements in the same group would share maximum homogeneity in terms of measured variables. Whereas in different groups they would express maximum heterogeneity among the same characteristics. All the observations would be expressed through a similarity matrix, which will be followed by an algorithm aiming to classify or design groups (Johnson and Wichern, 1992). There are many ways of measuring the distances between individuals or observations, although Euclidean (straight-line) distance seems to be one of the most common and used measurements. As a distance measurement, the algorithm would bind individuals with smaller values to form a new group. The Euclidean distance can be algebraically expressed by:

$$D_{AB} = \sqrt{\sum_{i=1}^{m} (X_A - X_B)^2} \qquad \text{Eq. 2}$$

where, D_{AB} is the Euclidean measure between the *A* and *B*, and X_A and X_B represent the observed values of *A* and *B*.

The clustering process begins with all individuals representing one group (number of individual is equal to the number of groups) and finishes with one single group, which contains the whole set of observations. In this paper a non-hierarchical approach (K-means cluster analysis) was used to obtain five clusters or five farm types. The resulting clusters were subsequently refined by reallocating observations which fell

in fuzzy boundaries between groups. The statistical data analysis package Stata™ was used to perform the cluster and PCA analysis.

1.5 Farm Questionnaire

1.5.1 Quantitative information

General farm data

Name:	
Farmer location (Village/Municipality):	
Farm area (ha)	
Agricultural area (ha)	

Crop production

Maize (ha)	
Beans (ha)	
Castor (ha)	
Cassava (ha)	
Horticulture (ha)	
Graze (ha)	
Fodder (ha)	
Soybean (ha)	
Grass seed (ha)	
Others specify (ha)	

Animal production

Dairy cattle (#)	
Beef cattle (#)	
Poultry (#)	
Swine (#)	
Others specify (#)	

1.5.2 Qualitative information

Equipment

	Classes		
Equipment characteristics	(1) Rudimentary equipment to cultivate and/or prepare the land being predominantly manual	(2) Ownership/capacity to hire oxen for plough, small tractor, motor and/or horticulture irrigation equipment	(3) Ownership/capacity to access tractors, combines, sprayers, soil preparation equipment and irrigation systems
N^{th} farmer			

Off-farm labour

Labour characteristics	Classes	
	(1) Occasional labour off-farm	(2) Labour off-farm is frequent: important share of the family revenue
N^{th} farmer		

Off-farm area

Land tenure characteristics	Classes	
	(1) Renting land off the owned farm area is rare	(2) Renting land off the owned farm area is often
N^{th} farmer		

Transaction costs

Collective action characteristics	Classes		
	(1) Incipient forms of collective action (associations) where the main goal is to easily access technical and financial assistance	(2) Farmers use the associations also to buy inputs or sell their production	(3) Highly developed collective action with active role on market information, technical assistance, credit, biophysical inputs, storage and market
N^{th} farmer			
Access to inputs characteristics	Classes		
	(1) Limited access to inputs due to distance and cost	(2) Fair access through association and commercialization of farm products, mainly horticulture and dairy	(3) Unlimited access to private, public or collective forms of information with also unlimited access to inputs
N^{th} farmer			
Market orientation	Classes		
	(1) Self-consumption, farmers' main concern is the household food supply with occasional product sales	(2) Market and self-consumption have equal importance	(3) Market oriented
N^{th} farmer			

Appendix 2

2.1 Calibration and validation of crop model for sunflower

2.1.1 Field experiment and model calibration

An experiment was carried out in Viçosa (20º 44' S, 42° 50' W, 670 m a.s.l.) in the southern region of Minas Gerais in the 2011/2012 growing season on a clay soil to calibrate OILCROP-SUN. Two sunflower genotypes were sown, Embrapa-122 (conventional cultivar) and Helio-358 (hybrid), which represented the experiment treatments. A 50 m^2 (10 × 5 m) plot size was used with four replications for each treatment. A meteorological station located at the experimental site was used to collect weather data used in the simulations (maximum and minimum temperatures, solar radiation, rainfall, relative humidity and wind speed). The two cultivars represent relevant genotypes currently being used for biodiesel feedstock. More detail on the treatments is given in Table 2.1.

Table 2.1 Management description of the two sunflower cultivars in the experiment.

Cultivars	Sowing	Water management	Harvest	Nitrogen fertilization
Embrapa-122	Nov 25th 2011 (Spring)	Rainfed	March 6th 2012	136 kg ha^{-1}
Helio-358	Nov 25th 2011 (Spring)	Rainfed	March 12th 2012	136 kg ha^{-1}

Soil properties, weather data, and experimental information were used as model input. Six cultivar-specific parameters or genetic coefficients (Table 2.2) were estimated, i.e., three related to phenology (P1, P2 and P5) and three related to yield (G2, G3 and O1). The genetic coefficients were obtained through the manual adjustment of the phenological coefficients based mainly on the observations in the experiment and weather data. Yield coefficients were calibrated combining experimental data with literature information (Villalobos *et al.*, 1996; Rolim *et al.*, 2001; Rinaldi *et al.*, 2003).

Table 2.2 Genetic coefficients for the selected sunflower cultivars.

Cultivars	P1	P2	P5	G2	G3	O1
Embrapa-122	260	1.30	715	1500	6.50	75
Helio-358	305	0.90	790	1700	6.50	75

Where P1 = Length of the juvenile phase (°C day) with base temperature of 4 °C. P2 = Photoperiodic coefficient (day h^{-1}). P5 = Duration of the first flowering to the physiological maturity stage (°C day). G2 = Maximum number of grains per head. G3 = Potential kernel growth rate during the filling phase (mg day^{-1}). O1 = Maximum kernel oil content (%).

2.1.2 Model validation

A series of experimental data from the States of Minas Gerais, Goiás, São Paulo and Distrito Federal (Embrapa, 2012a) were used to validate the model's suitability to predict sunflower yields. To evaluate the calibrated model a statistical analysis was performed using two statistical indicators, the Root Mean Square Error (RMSE) and Modelling Efficiency (ME) (Jamieson *et al.*, 1991; Loague and Green, 1991).

$$\text{RMSE} = \sqrt{\frac{\sum_{i=i}^{n}(Pi - Oi)^2}{n}} \cdot \frac{100}{O} \qquad \text{Eq.1}$$

$$\text{ME} = \frac{[\sum_{i=1}^{n}(Oi - O)^2 - \sum_{i=1}^{n}(Pi - Oi)^2]}{\sum_{i=1}^{n}(Oi - O)^2} \qquad \text{Eq.2}$$

where *Pi* = simulated values. *Oi* = observed values. *O* = observed mean values.

RMSE measures the difference between simulated and observed data. Simulations are considered to be excellent with RMSE <10%, good between 10-20%, fair if 20-30%, and poor >30%. The ME, which varies between -1 and 1, compares simulated values (*Pi*) against the observed mean values (*O*). If ME is less than zero the simulated values are worse than simply using the observed mean values. A positive value for ME, on the other hand, indicates that the model performs better than simply applying the observed mean (Loague and Green, 1991).

According to the two statistical indicators the model predicted sunflower yields fairly well for 27 different experiments in several locations (Table 2.3). Furthermore, it proved to have satisfactory results on neighbouring municipalities to the research area, i.e., Jaíba, Janaúba and Leme do Prado, in the northern region of Minas Gerais. As a

consequence the model was considered to be able to simulate sunflower yield levels in both research areas.

Table 2.3 Observed and simulated sunflower yield (kg ha^{-1}) for different locations and the statistical indicators of model performance across all experiments.

Year	Location (State[1])	Genotype	Yield (kg ha^{-1})	
			Simulated	Observed
2004	Londrina (PR)	E-122	964	784
2005	Cravinhos (SP)	E-122	1220	1168
	Londrina (PR)	E-122	1094	931
	Planaltina (DF)	E-122	2061	2485
2006	Cravinhos (SP)	E-122	1230	1077
	Piracicaba (SP)	E-122	1348	1260
	Planaltina (DF)	E-122	2858	3156
2007	Jaíba (MG)	E-122	2548	2206
	Jaíba (MG)	H-358	3137	2835
2008	Londrina (PR)	E-122	1066	1177
	Jaguariúna (SP)	E-122	2189	2197
	Leme do Prado (MG)	H-358	2137	2390
	Londrina (PR)	H-358	1338	1205
	Patos de Minas (MG)	H-358	1950	1796
	Planaltina (DF)	H-358	2859	3184
	Rio Verde (GO)	H-358	1656	1857
	Uberaba (MG)	H-358	2219	1737
2009	Planaltina (DF)	E-122	2315	2062
	Cravinhos (SP)	H-358	3376	3333
	Janaúba (MG)	H-358	2088	1938
	Londrina (PR)	H-358	1184	1304
	Patos de Minas (MG)	H-358	2128	1883
	Patrocínio (MG)	H-358	1994	1561
	Planaltina (DF)	H-358	2888	2858
2010	Leme do Prado (MG)	E-122	1316	1466
	Londrina (PR)	H-358	1073	927
2011	Planaltina (DF)	H-358	3126	2926
Statistics (n = 27)				
RMSE			12.5	
ME			0.9	

[1] PR – Paraná, SP – São Paulo, DF – Distrito Federal, MG – Minas Gerais, GO – Goiás.

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Summary

Over the past ten years, the increasing demand for finite fossil fuels combined with socioeconomic unrest in oil producing regions have driven policy and research agendas towards alternative fuel sources. In addition, the rise of environmental concerns on climate change boosted global interest in renewable sources of energy, especially those made from phytomass. Biomass from energy crops, forestry residues and organic wastes can be used to produce biofuels, which have become one of the most dynamic and rapidly growing sectors of the global energy economy. The production of liquid biofuels (i.e. ethanol, biodiesel) from agricultural feedstocks is acknowledged as one of the most significant agricultural developments in recent years. The surge of biofuels triggered two scientific and societal debates from the environmental and socioeconomic arena. While the first deals with the impact of biofuels on GHG emissions, production of net energy and resource conservation, the second focuses on the claim that the production of biomass for biofuel by family farms can be a way out of poverty. This thesis aims at contributing to this second debate.

In Brazil, the government targeted biodiesel as an instrument to combine renewable energy production with rural poverty reduction. In 2004, a national program for biodiesel production and use (PNPB, in Portuguese) was launched. This program is framed by a set of regulations that aim to develop biodiesel production in a sustainable way throughout the country, with the inclusion of family farmers and rural communities. Currently, federal legislation mandates a blend of 5% of biodiesel into the common fossil diesel. Besides the mandatory blending legislation, the Brazilian government offers tax reductions and selling preferences at biodiesel auctions for biodiesel producers that purchase a minimum amount of their feedstock from family farms, the so-called "social fuel stamp" policy.

Despite government's interest to improve family farmers' participation in biodiesel markets, farmers' uptake of biodiesel crops is still limited especially in poor semi-arid regions of the country. While socioeconomic and biophysical farm characteristics are generally acknowledged as essential in the design of rural policies, little has been done to understand family farms' diversity and its impact on policy targeting. Furthermore, the engagement of farmers in biodiesel crop production will also rely on sustainable biodiesel crop options, able to increase oil production while

complying with socioeconomic and environmental criteria. From a policy and farming perspective, knowledge could be gained from the *ex-ante* assessment of different policies aimed at improving biodiesel feedstock production at family farms. Yet, when transacting with biodiesel producers, farmers' small scale and dispersion over large areas increase transaction costs. Although producer organisations (POs) can be an effective way of dealing with high transaction costs, uncertainty still exists on what functions POs are expected to fulfill and the type and level of support from outsiders that might be needed when organisation and farm-specific characteristics are taken into account.

In this thesis the following questions were addressed: (1) How can the socioeconomic and biophysical diversity of family farms be used to better target the biodiesel policy? (2) How do current and alternative (biodiesel) production activities perform in terms of socioeconomic and environmental sustainability indicators? (2.1) To what extent can knowledge on crop management be gained from a sunflower crop model applied under Brazilian conditions? (3) What are the socioeconomic and environmental impacts of biodiesel policy scenarios on different farm types? (4) What are the opportunities and limitations for producer organisations to facilitate farmers' engagement in the emerging biodiesel market in Brazil?

Family farms' diversity and its implication for the biodiesel policy were assessed in Chapter 2. The study was conducted in a semi-arid (Montes Claros) and a more humid (Chapada Gaúcha) municipality in the state of Minas Gerais, southeast Brazil. In the two research areas, a farm survey was carried out in 2010 among 555 family farmers. From this survey, a combined database of socioeconomic (collective action, access to inputs, market orientation, labour, land tenure) and biophysical (area, crops, livestock, equipment) farm characteristics was formed. A farm typology was developed with the support of principal component and cluster analysis, in which, five farm types were identified. Farm type 1 was formed by relatively large (ca. 117 ha) soybean farmers in Chapada Gaúcha. These farmers are characterized by intensive use of inputs (fertiliser, machinery, biocides), high levels of market orientation and collective action. Similarly to farm type 1, farm type 5 is also formed by soybean farmers, but in this case farms were smaller (ca. 49 ha) and the entire area was farmed under rental contracts. The remaining farm types were identified in both regions,

although the majority of these farmers were found in Montes Claros. Farm type 2 was formed by cattle livestock farmers (ca. 46 ha) with fair levels of market orientation, but low access to inputs and collective action. Farm type 3, apart from being formed by farms (ca. 14 ha) with mixed production systems, in which horticulture features as one of the most important farm activities, shares similar characteristics with farm type 2. Farm type 4 was the less endowed group (ca. 2.4 ha), with low levels of market orientation, access to inputs and collective action. In this group, selling labour and sharecropping were identified as important features. We found that most of the farmers (farm types 2, 3 and 4), particularly those less endowed in land and with low market orientation, face great challenges to participate in the biodiesel market. A better targeting of the biodiesel policy could be achieved through alternative biodiesel crops – more suitable with less endowed farming systems - coupled with input provision (machinery, fertiliser, technical assistance) and bonus prices for biodiesel feedstocks.

Chapter 3 explores the sustainability of different crop production activities through a set of environmental and socioeconomic indicators in northern Minas Gerais. A technical coefficient generator (TechnoGIN) was used to assess current (maize, beans, soybean and grass seed) and alternative (castor bean and sunflower) crop activities managed under different production techniques, that included current management, best farmers' technical means, improved management and irrigation. A detailed survey was carried out among the farm types identified in the previous chapter, covering 80 farmers in Montes Claros (n = 45) and Chapada Gaúcha (n = 35). This survey was used to assess the technical coefficients of each production activity, including the quantification of all inputs required to achieve a certain output under the current production techniques. The design and quantification of alternative production activities was based on the biophysical possibilities, technical feasibility and land use-related objectives, using field experiments, crop growth simulation models, expert knowledge and literature information. Although biodiesel crops are often claimed to increase farmers' income, our results indicated that such economic gains are likely to be overestimated. The gross margins of biodiesel crops (i.e. sunflower and castor bean) were only competitive with a limited number of current crop activities in Montes Claros (i.e. maize) and Chapada Gaúcha (i.e. soybean); and only under specific conditions, which included more intensive use of fertiliser, machinery and biocides.

In Chapter 4 we calibrated and validated the crop growth model OILCROP-SUN to simulate sunflower development and growth, along with yield levels over an array of sowing dates in northern Minas Gerais. For model calibration an experiment was conducted in Viçosa – Minas Gerais, in which two sunflower genotypes (H358 and E122) were cultivated on a clay soil. Growth components (leaf area index, above ground biomass, grain yield) and development stages (crop phenology) were measured. Moreover, a database composed of 27 sunflower experiments from different Brazilian regions was used for model validation. After validation, sunflower yield levels were simulated across 14 different locations in the northern region of Minas Gerais. In this area weather data for a 31 years period (1979 – 2009) was used to explore the inter-annual variability of sunflower water- and nitrogen-limited, water-limited and potential yield levels. The spatial yield distribution of sunflower was mapped using ordinary kriging in ArcGIS. Our simulations indicated that the opportunities for farmers to grow sunflower vary significantly across northern Minas Gerais. Higher crop yield levels were simulated in the northwestern area where the sowing window is wider, when compared with the northeastern part of the region. A relatively large sowing window also enables farmers in the northwestern area to more easily engage in double cropping systems. Moreover, the hybrid genotype (H358) had higher yields for all simulated sowing dates, locations and growth conditions when compared with the conventional cultivar (E122). The results from these simulations were also used as inputs for the modelling studies in Chapters 3 and 5.

Chapter 5 uses an *ex-ante* integrated assessment approach to estimate the socioeconomic and environmental impacts of five biodiesel policy scenarios towards different farm types in Montes Claros and Chapada Gaúcha. The applied modelling framework was a combination of a technical coefficient generator (TechnoGIN; Chapter 3) and a bio-economic farm model (FSSIM). We explored the impact of market-driven (bonus price policy), input provision (fertiliser and land preparation policy), oil production (oil mill policy) and environmental (biocide residues and nitrogen losses) policy scenarios on soybean farmers in Chapada Gaúcha (farm types 1 and 5) and maize/beans/livestock farmers in Montes Claros (farm types 2 and 4). The effects of the different policies on farm gross margins, oil crop production, labour requirements, nitrogen losses and biocide residues were assessed. The impacts of such policies varied

across different farm types and whether the focus is on input provision, feedstock price or environmental criteria. Simulations for soybean farms in Chapada Gaúcha showed a positive response, in terms of oil production and gross margins, to all explored policy scenarios. However, from an environmental perspective the cultivation of sunflower in this region, especially in double cropping systems with soy, should be considered with caution due to unsafe values of biocide residues. In Montes Claros, the scope for biodiesel crops under the explored policy scenarios was limited, when compared to Chapada Gaúcha. In this region, biodiesel crop production coupled with input provision policies had relatively large positive impacts on farmers' socioeconomic indicators.

Opportunities and limitations associated with producer organisations and access to the biodiesel market are explored in Chapter 6. A multiple case study design was applied among 14 producer organisations (POs) in the states of Sergipe and Minas Gerais. The data collection was based on semi-structured interviews (n = 78) with members of the POs including farmers, village leaders, presidents of local farm associations, technical and administrative staff of cooperatives. Agronomists and technicians of service providers together with researchers active in the research area were also interviewed. The applied questionnaire was designed to capture (i) organisation and farm-specific characteristics including group homogeneity, legal structure, farm household, location and product characteristics; and (ii) the function of POs and type of support from outsiders aimed at facilitating farmers' access to input (technical assistance, credit) and output (access to market, storing) services. The explored case studies show the limited scope for POs to fill the gap between most family farmers and the biodiesel market. Such limitation is associated with the low value added to biodiesel crops (castor bean, sunflower) and trade-offs with current farm activities. While POs can reduce the transaction costs in biodiesel supply chains, payoff to farmers from acting collectively is far from evident. Alternative biodiesel feedstocks and market options that can reduce competition with staples and enlarge market opportunities for high value added products show promise. In this process external support will be needed. However, the ability of the state in shaping the economic and political environment, coupled with the provision of the right services to connect smallholder POs to the biodiesel market remains a challenge.

Chapter 7 synthesizes the main findings through the development of an overarching discussion across the presented research chapters. In the discussion main questions regarding the relation between biodiesel policy and family farms are addressed: who benefits?; why(not)?; how to improve?; what are the impacts? The benefits of the biodiesel policy are largely absorbed by soybean farmers (95% market share). Favourable conditions of the soybean producers are their large scale and collective action (cooperative), which reduce the cost of feedstock procurement and transportation. Non-soybean farmers, on the other hand, face many challenges such as the lack of viable biodiesel crop options and high costs to access information and inputs. The engagement of farmers as biodiesel crop producers can be improved through more intensive and rational use of inputs (i.e. new biodiesel policies) than current production systems. However, the resulting increase in non-soybean farmers' gross margins and biodiesel crop production remains limited. In this chapter also biophysical and socioeconomic similarities between farm types in the research area and in other regions of the country are used to assess implications of the work for different regions in Brazil. Our finding as to less endowed farms (farm types 2 and 4) in Montes Claros may thus be applicable to farmers in the Northeast of the country. The castor bean oil market in the Northeast might be an added value opportunity for farmers. Soybean producers in Chapada Gaúcha (farm types 1 and 5) share many characteristics with farmers from the Mid-South of the country, where winter oil crops (e.g. rapeseed) show promise. The methodological approach used follows the integrated assessment logic, which is based on the combination of interdisciplinary and quantitative methods and participatory approaches. From this approach distinct knowledge can be gained compared with disciplinary research, thus allowing a better understanding of complex phenomena. Yet, this approach suffers from a large demand for data, which can be partially reduced through crop simulation models, literature information, farmers and experts knowledge. Finally it is concluded that there is a need for more farming systems research that can offer a new and necessary perspective for farmers, scientists and policymakers on the interaction between different farms and the biodiesel policy. In this approach the characteristics of the production environment and the objectives of the actors involved are emphasized. The research in this thesis indicates that there are only small opportunities for family farms to use biodiesel crops as a way out of poverty. It,

therefore, contributes to one of the two main scientific and societal debates surrounding biomass production for biofuels. Although different policies can be implemented to enhance opportunities for family farms, crop and management options have to be analysed with respect to their environmental consequences (i.e. GHG emissions, net energy production and resource conservation) before comprehensive policy recommendation can be made.

Samenvatting

Door de toenemende vraag naar eindige fossiele brandstoffen, in combinatie met sociaaleconomische onrust in de landen die olie produceren, staan alternatieve brandstoffen de laatste tien jaar hoog op de agenda van wetenschap en beleid. Daarnaast heeft de verhoogde aandacht voor klimaatverandering bijgedragen aan een wereldwijde interesse voor hernieuwbare vormen van brandstof. Biomassa van geteelde gewassen, afvalhout en organisch afval kan gebruikt worden om biobrandstof te produceren. Biobrandstoffen is een van de meest dynamische en snelgroeiende energiesectoren van de wereldeconomie. De productie van vloeibare biobrandstoffen (zoals ethanol en biodiesel) op basis van landbouwproducten wordt gezien als een van de belangrijkste ontwikkelingen in de landbouw van de afgelopen jaren. De opkomst van biobrandstof heeft twee wetenschappelijke en maatschappelijke debatten losgemaakt: ten eerste over de milieueffecten en ten tweede over de sociaaleconomische aspecten. Het eerste debat gaat over het effect van biobrandstoffen op broeikasgasemissies, netto energieproductie en behoud van natuurlijke hulpbronnen. Het tweede debat richt zich op de stelling dat productie van biomassa voor biobrandstof familiebedrijven een uitweg kan geven uit armoede. Dit proefschrift streeft ernaar bij te dragen aan het twee debat.

In Brazilië stimuleert de overheid het gebruik van biodiesel om de productie van hernieuwbare grondstoffen te combineren met het verminderen van armoede op het platteland. In 2004 is een nationaal programma gestart voor het gebruik en de productie van biodiesel (PNPB in het Portugees). Dit programma wordt gevormd door een aantal regelingen die als doel hebben de productie van biodiesel op een duurzame manier te ontwikkelen, met participatie van gezinsbedrijven en lokale gemeenschappen. Momenteel is er voor diesel een nationale bijmengverplichting van 5% biodiesel. Naast deze bijmengverplichting biedt de Braziliaanse overheid ook belastingverlaging en een voorkeur bij verkoop op veilingen voor producenten van biodiesel die een minimum hoeveelheid van hun grondstoffen kopen bij gezinsbedrijven. Dit beleid staat bekend onder de naam “sociale-brandstofstempel”.

Ondanks de doelstelling van de overheid om de participatie van gezinsbedrijven in de biodieselmarkt te verbeteren, is de aanplant van biodieselgewassen nog zeer beperkt, vooral in arme en semi-aride regio’s. Terwijl bekend is dat sociaaleconomische en biofysische bedrijfskarakteristieken belangrijke parameters zijn voor de effectiviteit

van plattelandsbeleid, is er nog weinig aandacht geweest voor de relatie tussen de diversiteit onder gezinsbedrijven en de implementatie van het biodieselbeleid. De medewerking van boeren aan de teelt van biodieselgewassen zal afhangen van duurzame teeltmogelijkheden die enerzijds de productie van olie kunnen vergroten en anderzijds voldoen aan sociaaleconomische en milieu-gerelateerde criteria. Vanuit het perspectief van landbouw en beleid, kan een *ex-ante* analyse van verschillende beleidsopties, bedoeld om de teelt van biodieselgewassen binnen gezinsbedrijven te verbeteren, meer inzicht geven. De kleine schaal en verspreiding over grote gebieden van gezinsbedrijven zorgen voor verhoogde transactiekosten. Producentenorganisaties (POs) kunnen een effectieve manier zijn om de transactiekosten te verlagen. Er is echter onzekerheid over welke functies POs daartoe moeten vervullen, welke ondersteuning van externe partijen daarvoor nodig is, en welke organisatie karakteristieken daarbij horen.

In dit proefschrift werden de volgende vragen beantwoord: (1) Hoe kan de sociaaleconomische en biofysische diversiteit van gezinsbedrijven gebruikt worden om het beleid voor biodiesel te verbeteren? (2) Hoe presteren huidige en alternatieve teeltmogelijkheden van biodieselgewassen op sociaaleconomische en milieu-gerelateerde duurzaamheidsindicatoren? (2.1) In hoeverre kan kennis vergaard worden over teeltmogelijkheden door een gewasgroei-simulatiemodel voor zonnebloemen toe te passen onder Braziliaanse omstandigheden? (3) Wat zijn de sociaaleconomische en milieu-gerelateerde effecten van beleidsscenario's voor biodiesel voor verschillende bedrijfstypen? (4) Wat zijn de kansen en beperkingen van producentenorganisaties om de participatie van boeren in de opkomende biodieselmarkt van Brazilië te faciliteren?

Diversiteit van gezinsbedrijven en de implicaties hiervan voor biodieselbeleid zijn geanalyseerd in Hoofdstuk 2. Deze studie is uitgevoerd in een semi-aride (Montes Claros) en een nattere (Chapada Gaúcha) regio in de staat Minas Gerais. In de twee onderzoeksgebieden is een enquête afgenomen bij 555 gezinsbedrijven. Van deze enquête is een gecombineerde database gemaakt van sociaaleconomische (lidmaatschap van coöperatie, toegang tot productiemiddelen, marktoriëntatie, arbeid, landrechtent) en biofysische (areaal, gewassen, vee, machines) bedrijfskarakteristieken. Een bedrijfstypologie is ontwikkeld met ondersteuning van een *Principal Component Analysis* en een *Cluster Analysis* waarin vijf bedrijfstypen zijn onderscheiden.

Bedrijfstype 1 wordt gevormd door relatief grote (ca. 117 ha) telers van sojabonen in Chapada Gaúcha. Deze boerenbedrijven worden gekenmerkt door intensief gebruik van productiemiddelen (kunstmest, machines, pesticiden), een hoge marktoriëntatie en samenwerking onderling. Net als bedrijfstype 1 bestaat bedrijfstype 5 uit sojaboontelers, maar in dit geval zijn de bedrijven kleiner (ca. 49 ha) en hebben zij pachtcontracten voor het gehele areaal. De sojaboeren zijn allen lid van een coöperatie. De andere bedrijfstypen komen voor in beide regio's, alhoewel de meerderheid in Montes Claros. Bedrijfstype 2 wordt gevormd door veehouderijbedrijven (ca. 46 ha) met een gemiddeld niveau van marktoriëntatie, maar weinig toegang tot productiemiddelen en geen lidmaatschap van een coöperatie. Bedrijfstype 3 heeft dezelfde kenmerken als bedrijfstype 2, met het verschil dat ze bestaat uit bedrijven (met circa 14 ha) met gemengde teeltsystemen waarin tuinbouw de belangrijkste activiteit is. Bedrijfstype 4 is de groep met de laagste marktoriëntatie, geringste bedrijfsomvang (ca. 2.4 ha), nauwelijks toegang tot productiemiddelen en geen formele samenwerking in coöperaties. In deze groep zijn het doen van loonwerk voor andere boeren en het hebben van deelpachtcontracten belangrijke kenmerken. De meeste boeren (bedrijfstypes 2, 3 en 4), en dan vooral diegenen met weinig land en met een lage marktoriëntatie, zijn nauwelijks betrokken bij de biodieselmarkt. Het beleid kan doelgerichter worden gemaakt door alternatieve biodieselgewassen – die beter geschikt zijn voor boerenbedrijven met geringe activa – te koppelen aan het van overheidswege verstrekken van productiemiddelen (machines, kunstmest, technisch advies) en speciale prijzen voor biodieselgewassen.

Hoofdstuk 3 verkent de duurzaamheid van verschillende teeltmogelijkheden in het noordelijke deel van Minas Gerais met een set van sociaaleconomische en milieu-gerelateerde indicatoren. Een technische coëfficiënten generator (TechnoGIN) is gebruikt om huidige teelten (mais, bonen, sojabonen en graszaad) en alternatieve teelten (wonderbonen oftewel *castor beans*) te analyseren met verschillende managementtechnieken. Zowel huidig management als de beste technische opties, verbeterd management en irrigatie zijn onderzocht. Binnen de geïdentificeerde bedrijfstypen van Hoofdstuk 2 is een gedetailleerde enquête gehouden onder 80 boeren in Montes Claros (n = 45) en Chapada Gaúcha (n = 35). Deze enquête is gebruikt om de technische coëfficiënten van elke teeltactiviteit te achterhalen, inclusief kwantificering

van alle middelen die nodig zijn om tot een bepaalde opbrengst te komen. Het ontwerp en de kwantificering van alternatieve teeltactiviteiten is gebaseerd op de biofysische mogelijkheden, de technische haalbaarheid en de landgebruiksdoelen. Hiervoor is gebruik gemaakt van veldexperimenten, gewasgroei-simulatiemodellen, expertkennis en literatuur. Hoewel er vaak beweerd wordt dat biodieselgewassen het inkomen van de boer verhogen, lieten onze resultaten zien dat deze financiële voordelen waarschijnlijk overschat worden. De bruto marge op biodieselgewassen (bijvoorbeeld zonnebloem en wonderbonen) zijn alleen concurrerend met een beperkt aantal huidige teelten in Montes Claros (zoals mais) en Chapada Gaúcha (zoals sojabonen). Dit is alleen het geval onder specifieke omstandigheden met meer gebruik van kunstmest, machines en pesticiden.

In Hoofdstuk 4 is het model OILCROP-SUN gevalideerd en gekalibreerd voor de simulatie van zonnebloemontwikkeling, groei en opbrengst over een range van zaaidata in het noordelijke deel van Minas Gerais. Voor het kalibreren van het model is een experiment uitgevoerd in Viçosa (in de staat Minas Gerais), met een teelt van twee zonnebloem genotypen (H358 en E122) op een kleigrond. Groeicomponenten (bladoppervlakte index, bovengrondse biomassa, opbrengst) en ontwikkelingsfases (gewasfenologie) zijn gemeten. Bovendien is een database met 27 zonnebloem-experimenten uit verschillende Braziliaanse regio's gebruikt voor de validatie van het model. Na validatie zijn zonnebloemopbrengsten gesimuleerd voor 14 locaties in de noordelijke regio van Minas Gerais. Klimaatdata van dit gebied over 31 jaar (1979 – 2009) zijn gebruikt om de variabiliteit tussen jaren van water- en stikstof gelimiteerde, water gelimiteerde en potentiele opbrengstniveaus van zonnebloem te verkennen. De ruimtelijke opbrengstspreiding van zonnebloem is in kaart gebracht met de interpolatiemethode *ordinary kriging* in ArcGIS. Onze simulaties gaven aan dat de mogelijkheden voor boeren om zonnebloem te telen statistisch significant verschillen in delen van het noorden Minas Gerais. Hogere simulatie-opbrengsten werden gevonden in het noordwesten waar het zaaivenster groter is, vergeleken met het noordoosten van de regio. Een relatief groot zaaivenster maakt het ook makkelijker voor boeren in het noordwesten om een dubbel teeltsysteem toe te passen. Bovendien had het hybride ras (H358) hogere opbrengsten voor alle gesimuleerde zaaidata, locaties en groeicondities vergeleken met de conventioneel ras (E122).

In Hoofdstuk 5 is een *ex-ante* geïntegreerde analyse gebruikt om de sociaaleconomische en milieueffecten te schatten van vijf biodieselbeleidscenario's op verschillende bedrijfstypen in Montes Carlos en Chapada Gaúcha. Het toegepaste modelleerkader was een combinatie van een technische coëfficiënten generator (TechnoGIN, zie Hoofdstuk 3) en een bio-economisch bedrijfsmodel (FSSIM). Wij hebben de effecten van de volgende beleidsscenario's op sojaboontelers in Chapada Gaúcha (bedrijfstypen 1 en 5) en mais/bonen/veehouderijbedrijven in Montes Claros (bedrijfstypen 2 en 4) verkend: marktgericht (bonusprijs), verstrekking van productiemiddelen (kunstmest- en landbewerking), olieproductie (oliepers) en milieu (pesticideresten en stikstofverliezen). De effecten van de verschillende beleidsmogelijkheden op de bruto marge, olieproductie, arbeidsvraag, stikstofverliezen en pesticideresten zijn geanalyseerd. De effecten van deze beleidsmogelijkheden varieerden tussen bedrijfstypen en hingen samen met het feit of de focus was op het verstrekken van productiemiddelen, de prijs van gewassen of milieucriteria. Simulaties voor sojaboontelers in Chapada Gaúcha toonden een positief effect op olieproductie en bruto marge voor alle beleidsscenario's. Vanwege de onveilige waarden van pesticideresten moet de teelt van zonnebloem in dit gebied vanuit milieuperspectief echter met voorzichtigheid worden overwogen. Vergeleken met Chapada Gaúcha zijn de mogelijkheden voor biodieselgewassen in Montes Claros onder de verkende beleidsscenario's beperkt. In dit gebied had de combinatie van biodieselgewassen en beleid gericht op het verstrekken van productiemiddelen wel een groot positief effect op de sociaaleconomische indicatoren.

Mogelijkheden en beperkingen die samenhangen met producentenorganisaties en toegang tot de biodieselmarkt zijn verkend in Hoofdstuk 6. Een onderzoekontwerp bestaande uit een meervoudige casestudie is toegepast onder 14 producentenorganisaties in de staten Sergipe en Minas Gerais. De dataverzameling is gebaseerd op semigestructureerde interviews (n=78) met vertegenwoordigers van de producentenorganisaties, waaronder boeren, dorpshoofden, voorzitters van lokale boerenverenigingen, en technisch en administratief personeel van coöperaties. Agronomen en technici van dienstenverleners en onderzoekers actief in het onderzoeksveld zijn ook geïnterviewd. De gebruikte vragenlijst was ontworpen om de volgende zaken te achterhalen: (i) organisatorische en bedrijfsspecifieke kenmerken,

waaronder homogeniteit van het ledenbestand, de omvang, locatie en producten van de ledenbedrijven; (ii) de functie van producentenorganisaties, en (iii) het soort ondersteuning van buitenstaanders bedoeld om de toegang tot productiemiddelen (technische hulp, krediet, kunstmest) en verkoop (markttoegang, opslag) te faciliteren. De casestudies tonen beperkte mogelijkheid voor producentenorganisaties om het gat te vullen tussen de meeste gezinsbedrijven en de biodieselmarkt. Deze beperkingen hangen samen met de lage toegevoegde waarde van biodieselgewassen (wonderbonen, zonnebloem) en de concurrentie met huidige teeltactiviteiten. Alhoewel producenten organisaties de transactiekosten in de biodieselketen kunnen verlagen, is voor de meeste boeren het voordeel van collectieve actie niet evident. Alternatieve biodieselgewassen die niet concurreren met voedsel- en voedergewassen en marktmogelijkheden voor producten met grotere toegevoegde waarde zijn veelbelovend. Voor dit proces is externe ondersteuning nodig. Het vermogen van de overheid om de economische en politieke omgeving vorm te geven, in relatie tot de verstrekking van de juiste diensten om kleine producentenorganisaties te koppelen aan de biodieselmarkt, blijft een uitdaging.

Hoofdstuk 7 geeft een synthese van de belangrijkste bevindingen door middel van een discussie die de individuele hoofdstukken overstijgt. In deze discussie worden de belangrijkste vragen over de relatie tussen biodieselbeleid en gezinsbedrijven behandeld: Wie profiteert? Waarom wel of waarom niet? Hoe kan verbetering bereikt worden? Wat zijn de effecten? De voordelen van het biodieselbeleid vallen voornamelijk toe aan sojaboontelers (marktaandeel van 95%). Gunstige condities van de sojaboontelers zijn hun grote schaal en hun samenwerking (in coöperaties), waarmee ze de kosten van aankoop en transport kunnen beperken. Boeren die geen sojabonen verbouwen hebben daarentegen te maken met veel uitdagingen zoals het gebrek aan levensvatbare biodieselgewassen en hoge kosten voor het verkrijgen van informatie en productiemiddelen. De participatie van boeren als producenten van biodieselgewassen kan verbeterd worden door intensiever en rationeler gebruik van productiemiddelen, bijvoorbeeld als onderdeel van nieuw biodieselbeleid. De verhoging van de opbrengst en de bruto marge van boeren die geen sojabonen verbouwen zal echter beperkt zijn. In dit hoofdstuk worden ook de biofysische en sociaaleconomische overeenkomsten tussen bedrijfstypen in het onderzoeksgebied en andere regio's van Brazilië besproken, om de implicaties van dit werk voor verschillende Braziliaanse regio's te beoordelen. Onze

bevindingen over de bedrijven met geringe productiemiddelen (bedrijfstypen 2 en 4) in Montes Claros zijn van toepassing op boeren in het Noordoosten van het land. De markt, in het Noordoosten, voor olie van wonderbonen kan een kans voor toegevoegde waarde-activiteiten zijn voor de boeren aldaar. Sojaboontelers in Chapada Gaúcha (bedrijfstypen 1 en 5) delen veel kenmerken met boeren uit het Midden-Zuiden van het land, waar oliegewassen die in de winter worden geteeld veelbelovend zijn (bijvoorbeeld koolzaad).

De methodologisch aanpak die gebruikt is volgt de logica van de geïntegreerde analyse, welke gebaseerd is op de combinatie van interdisciplinariteit, kwantitatieve methode en participatieve aanpak. Met deze benadering wordt andere kennis verkregen dan met disciplinair onderzoek, wat een beter begrip van complexe fenomenen mogelijk maakt. Tegelijkertijd leidt deze aanpak tot een grote vraag naar data, die enigszins verminderd kan worden met gewassimulatiemodellen, informatie uit de literatuur en boeren- en expertkennis. Er is behoefte aan meer onderzoek naar bedrijfssystemen om boeren, wetenschappers en beleidsmakers een nieuw perspectief te geven op de interactie tussen boerenbedrijven en biodieselbeleid. Hierin staan het productie-milieu en de doelen van de actoren centraal. Dit proefschrift laat zien dat er voor familiebedrijven maar geringe mogelijkheden zijn om biodieselgewassen te gebruiken als uitweg uit armoede. Het draagt hiermee bij aan een van de twee wetenschappelijke en maatschappelijke debatten omtrent biomassa productie voor biobrandstof. Er kunnen beleidsmaatregelen worden genomen om de mogelijkheden voor familiebedrijven te verbeteren. Voordat integrale beleidsaanbevelingen kunnen worden gedaan, zullen ook de milieueffecten (bijvoorbeeld broeikasgasemissies, netto energieproductie en behoud van natuurlijke hulpbronnen) van de verschillende gewas- en managementopties moeten worden onderzocht.

Acknowledgements

In my study area 'sharecropping' is a common agreement among farmers. In it, farmers that have available land but not sufficient labour welcome other farmers for whom land is a major constraint. By exchanging these assets, after some time has passed, both labour and land abundant farmers become better-off through the division of the harvested products. I think writing a thesis is a bit of a 'sharecropping' arrangement. It requires the compromise, time and toil of many who look forward to a rewarding harvest. Differently from crops that can be literally divided among the contributors, a thesis cannot. What I can do, however, is to dedicate this section of the thesis to acknowledge the support received from different people, which was essential in building productive conditions throughout the PhD.

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Curriculum vitae

João Guilherme Dal Belo Leite was born in Passo Fundo/RS, Brazil on April 23, 1981. He is the son of Célda Dal Belo Leite and João Batista Leite. During his first years João lived in Machadinho/RS, a small (5,510 inhabitants) agricultural municipality in the northeast of the state. In 1998 he obtained his high school diploma at the Federal Agricultural School of Sertão/RS, which inspired and provided him a solid first contact with the agronomic discipline. He graduated in 2006 at the Federal University of Rio Grande do Sul (UFRGS), with a BSc in Agronomic Engineering. During the five years required to finish his BSc, João's scientific experience was initiated at the Soil Science Department of the university. From 2002 to 2006 he worked with Prof. Dr. Ibanor Anghinoni on soil fertility and integrated crop and animal production systems. In 2008 he completed his Masters degree in Agribusiness at UFRGS with a scholarship granted by the Brazilian government (CAPES). The MSc thesis was entitled *'Technological innovation in agriculture as a strategy to cope with climate change'* which resulted in one peer reviewed journal article. Intrigued by the complex relationship between agriculture and energy production, in December 2008 he applied for a PhD to explore opportunities and limitations of biomass for biodiesel production in Brazil at Wageningen University. In February 2009 he was accepted as a (sandwich) PhD candidate in the Plant Production Systems Group of that university. After finishing his doctorate, João plans to extend his work with farming systems and the challenges on sustainable agricultural production in Brazil. João is married to Elizandra and they are currently living in Viçosa/MG, Brazil.

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List of Publications

Published papers

Leite, J.G.D.B., Bijman, J., Giller, K., Slingerland, M. Biodiesel policy for family farms in Brazil: One-size-fits-all? Environmental Science & Policy, v.27, p.195 - 205, 2013.

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Leite, J.G.D.B., Justino, F.B., Silva, J.V., Florin, M.J., van Ittersum, M.K. Exploring sustainable biodiesel crop options for smallholder farming in Brazil.

Leite, J.G.D.B., Silva, J.V., Justino, F.B., van Ittersum, M.K. Exploring sunflower (Helianthus annuus L.) yields in northern Minas Gerais: a crop model based approach.

Leite, J.G.D.B., Silva, J.V., van Ittersum, M.K. Integrated assessment of biodiesel policies aimed at family farms in Brazil.

Leite, J.G.D.B., Bijman, J., Slingerland, M., van Ittersum, M. K. Ling family farmers to biodiesel markets in Brazil: can producer organisations make a difference?

PE&RC PhD Training Certificate

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

Review of literature (5.6 ECTS)

- Biomass for biodiesel production on family farms in Brazil: promise or failure?; integrated assessment of sustainability, farm configurations and responses of farmers to policies

Writing of project proposal (4.5 ECTS)

- Biomass for biodiesel production on family farms in Brazil: promise or failure?; integrated assessment of sustainability, farm configurations and responses of farmers to policies

Post-graduate courses (7.5 ECTS)

- Multivariate analysis; PE&RC (2009)
- Multivariate analysis applied to economics; UFV (2010)
- Logic of collective action; UFV (2010)
- Agroenergy; UFV (2011)

Invited review of (unpublished) journal manuscript (1 ECTS)

- African Journal of Plant Science: crops growth components and livestock management (2011)

Deficiency, refresh, brush-up courses (3 ECTS)

- System analysis, simulation and systems management (2009)
- Quantitative analysis of land use systems (QUALUS) (2010)
- Training in modelling (FSSIM) (2010)

Competence strengthening / skills courses (1.6 ECTS)

- Information literacy, including Endnote; WGS (2009)
- Effective behaviour in your professional surroundings; WGS (2013)
- Career assessment; WGS (2013)

PE&RC Annual meetings, seminars and the PE&RC weekend (1.5 ECTS)

- PE&RC Weekend (2009)
- CERES Summer School; Nijmegen, the Netherlands (2009)
- PE&RC Day (2010)

Discussion groups / local seminars / other scientific meetings (4.8 ECTS)

- Mathematics, statistics and modelling (Maths & Stats); PE&RC (2009)
- Biofuels: an interdisciplinary approach; PE&RC (2009/2010)
- Sustainable intensification of agricultural systems (SIAS); PE&RC (2013)

International symposia, workshops and conferences (5.1 ECTS)

- PENSA Conference; São Paulo, Brazil (2009)
- African Crop Science Society Conference; Maputo, Mozambique (2011)
- WOTRO Workshop: biofuels – opportunity or threat?; Wageningen, the Netherlands (2013)

Supervision of a MSc student (3 ECTS)

- João Vasco Silva: Farming systems; experiments and crops growth model; bio-economic farm model

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