Socio-economic benefits and limitations of irrigated family farming in Brazil's semi-arid region

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Dissertation

Submitted in fulfillment of the requirements for the degree

"Doktor der Agrarwissenschaften"

(Dr.sc.agr./Ph.D. in Agricultural Sciences)

to the

Faculty of Agricultural Sciences

presented by

Heinrich Karl Hagel

Stuttgart, Germany, 2016

This thesis was accepted as a doctoral thesis (dissertation) in fulfillment of the requirements for the degree “Doktor der Agrarwissenschaften” (Dr. sc. agr./PhD in Agricultural Sciences) by the Faculty of Agricultural Sciences at the University of Hohenheim, Stuttgart, Germany, on January 20, 2016.

Date of the oral examination: May 10, 2016

Examination Committee

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Acknowledgements

One single student can hardly handle the whole workload of a dissertation and relies on the support from many sides. Thus, I would like to express my gratitude to everyone who supported me on my way to submit this dissertation.

First, I would like to thank Prof. Dr. Reiner Doluschitz for accepting me as his PhD student and therewith giving me the opportunity to participate in such an interesting research project. I am very grateful for all the support, advice, and faith during my doctoral phase, and, especially, for the enduring patience during various field trips. I would like to express my gratefulness to the whole research group of the Institute 410c for the great working environment and countless entertaining coffee breaks. In this context, I especially thank Dr. Christa Hoffmann for the nice introduction into the research group and all the support a new PhD candidate could ask for; and Dr. Til Feike for the great cooperation in the office and on the pitch. Thanks also to Renate Bayer for the support with countless administrative issues. Thanks to Prof. Dr. Joachim Müller and Prof. Dr. Christian Lippert for their kind willingness to be co-examiner of this dissertation.

Irrespective of the previous days, the workload, the mood, or the weather, Friday afternoons constituted a small highlight of every week in Hohenheim. Thanks a lot to the team of Real Hohenheim for every single minute on the pitch. In this context I would also like to thank my friends and neighbors in Recife – especially the ones from Vila Tamandaré – for the joint stadium visits and every football match we played together in Brazil.

For funding the studies forming this dissertation in the framework of the INNOVATE project (01LL0904C) within the Sustainable Land Management Program, I would like to express my gratitude to the Bundesministerium für Bildung und Forschung (BMBF).

For every unforgettable moment in Germany and Brazil, I would like to thank the whole team of the INNOVATE project. Thanks to Prof. Dr. José Ferreira Irmão for the great support during every visit. A special thanks to my house- and flat mates in Brazil, Jan Mertens and Andre Ferreira. For their hospitality, I would like to thank my landlord and friend Jair Ferraz and his caring wife Ceiça.

I would further like to thank my BSc and MSc students, Anja Lienert, Lucy Zavaleta Huerta, and Thomas Boos, for doing great jobs in the field. Thanks also to all interviewers who supported me in the field, especially to Walterny Fonseca Dantas and José Francisco De Souza Germino for various trips into the irrigation schemes, countless interview hours, and several interesting, entertaining, and encouraging conversations. I can hardly express my gratitude to all the farmers who patiently participated in the interviews and granted me insight into the local agricultural production, but also shared very personal details which enabled me to do the analyses for this dissertation. In particular, I would like to say thank you to Joana, Ricardo, and Rodrigo Nogueira, and Ze Naldo for unforgettable moments in Apolônio Sales, and to Ze do Aio and his family for their extraordinary hospitality on their lot during the project's evaluation. I further thank all CODEVASF, HIDROSONDAS, and PLANTEC officials who supported me in planning and conducting the field work, especially Marcelo Mergulhão for his support and his honest interest in this study.

I would also like to thank to my dear housemates Krittiya Tongkoom and Patrick Artur Grötz for always creating a warm atmosphere back in Hohenheim; to Thomas Ennulath for spending countless hours with me on the construction site to make the warm atmosphere possible. Special thanks to all my old friends from Dietzenbach for enriching every return to my home town.

Last but not least, I would like to thank my whole family in Germany and Vietnam for all the support and encouragements during the last years; representatively to mẹ Tám and bố Dũng for every warm welcome in Vietnam, to Dr. Eberhard Hagel and his family and Reto, Barbara and Gian Gantenbein for every nice moment after project meetings in Berlin, to Elisabeth Hagel and her family for great times in Laupheim. A special thanks to my parents Irmgard Barbara Hagel and Dr. Karl Grobe-Hagel and to my sister Hildegard Friederike Hagel for always being there and supporting me in a wonderful way on my whole path from birth (respectively Kindergarden) until now. I dedicate this dissertation to my grandmothers Friedl Hagel and Hilde Grobe.

Words can hardly express my gratefulness to my wife Nguyen Thi Thanh and our daughter Barbara Nguyen Hagel. Thanh supported me from the first moment, encouraged me to do my PhD, and showed me how fascinating science can be. Thank you for being patient and even-tempered during the whole period of dissertation, for wonderfully taking care of Barbara while I was working on this dissertation, and for just being there. Finally, I thank our daughter Barbara for making me smile (almost) every single morning, for the additional motivation to finish my PhD, and for always cheering me up while I am sitting in front of the computer.

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List of abbreviations

ANA	Agência Nacional de Águas
ANOVA	Analysis of variance
BMBF	Bundesministerium für Bildung und Forschung
BSh	Abbreviation for hot semi-arid climate by the Köppen climate classification
CHESF	Companhia Hidro Elétrica do São Francisco
CM	Contribution margin
CNPq	Conselho Nacional de Desenvolvimento Científico
CODEVASF	Companhia de Desenvolvimento dos Vales do São Francisco e do Parnaíba
DNOCS	Departamento Nacional de Obras Contra as Secas
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
GDP	Gross Domestic Product
GDPagri	Agricultural Gross Domestic Product
GEIDA	Grupo Executivo de Irrigação para o Desenvolvimento Agrícola
IBGE	Instituto Brasileiro de Geografia e Estatística
IDHM	Índice de Desenvolvimento Humano Municipal
MCTI	Ministério da Ciêncía, Tecnologia e Inovação
LP	Linear Programming
NLP	Non-Linear Programming
OCEPAR	Organização do sistema sindical cooperativo
PAA	Programa de Aquisição de Alimentos
PLANTEC	Agricultural extension agency in the Itaparica irrigation schemes
PNAE	Programa Nacional de Alimentação Escolar
PPI	Programa Pluriannual de Irrigação
PRONAF	Programa Nacional de Fortalecimento da Agricultura Familiar
PV	Present value
RM	Research module
R$	Brazilian Real
SESCOOP	Serviço Nacional de Aprendizagem do Cooperativismo
SP	Sub-project

TLU	Tropical Livestock Unit
UFPE	Universidade Federal de Pernambuco
US$	U.S. Dollar
VMT	Verba de Manutenção Temporária

Chapter 1. General Introduction

The studies presented in this dissertation were conducted in the framework of the Brazilian-German collaborative research project INNOVATE (Interplay among multiple uses of water reservoirs via innovative coupling of substance cycles in aquatic and terrestrial ecosystems). The German part was funded by the German Federal Ministry of Education and Research (BMBF) within the research program "Sustainable Land Management". The overall objective of the project was to contribute to sustainable land and water use in the São Francisco River catchment, with a focus on the Itaparica Reservoir at the lower-middle São Francisco in Brazil's semi-arid region as illustrated in Fig. 1. The research was conducted by an interdisciplinary team of over 100 participants. Professors, postdocs, PhD, postgraduate, and graduate students were organized into 22 research modules (RM) belonging to seven thematic sub-projects (SP). The studies forming this dissertation were conducted within the SP6-RM2 "Socio-economic analysis of agricultural production systems" aiming a contribution to increase the agricultural productivity at farm level along the lower-middle São Francisco River considering the sustainable development of the whole river catchment.

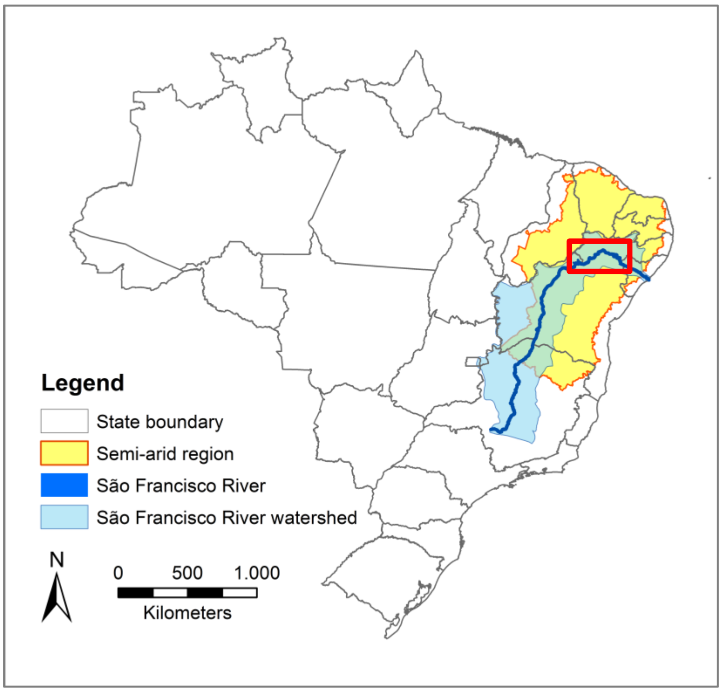

Fig. 1: The study region in the content of the Rio São Francisco Watershed and the semi-arid region.
Source: Own figure after IBGE, 2013a

1.1 Problem statement

Since the 1960s, Brazil's government intensified the promotion of irrigated agriculture to foster rural development and counteract frequently occurring severe droughts in the country's semi-arid northeast (Damiani, 1999). Severe droughts in this so-called drought-polygon have been described since the country's colonization in the early 17th century (Brooks, 1971; Hall, 1978). Rural smallholders, who were already facing unequal distribution of land, capital, and access to infrastructure, were most vulnerable to these droughts (Andrade, 2011; Finan and Nelson, 2001). Due to impact of affiliation to specific social classes on drought vulnerability, several authors indicate the droughts in the semi-arid region as a climate as well as a socio-economic phenomenon (Finan and Nelson, 2001; Hall, 1978). Under such conditions, migration is considered a common strategy to escape droughts in semi-arid and arid environments worldwide (IIED, 2008). In Brazil, forms of migration have been described since the country's colonization, starting with enslavement of indigenous population and the import of slaves from Africa followed by the recruitment of European peasants and refugees (Wagner and Ward, 1980). Consequently, migration to urban centers was one of the main livelihood strategies of the rural population in the semi-arid region (Brooks, 1971; Finan and Nelson, 2001; Fischlowitz and Engel, 1969; Kenny, 2010). Irrigated agriculture to reduce the effects of droughts and counteract the rural exodus has its origin in the construction of the first large reservoir in Ceará state – the *Açude Quixadá* – triggered by the drought of 1890 (Hall, 1978). Since then, the role of irrigated agriculture in the semi-arid region increased slowly (França, 2001; Hall, 1978).

However, irrigated agriculture gained importance as anti-drought strategy only from the 1960s (Hall, 1978). In this period, Brazil's military regime strongly promoted the construction of large dams and reservoir for hydropower generation to satisfy the country's increasing demand for electricity and to increase energy affordability, reducing the energy use inequalities within the population (Da Costa et al., 2007; Da Costa, 2010). Due to their strong impact on concerned ecosystems and forced resettlements of the local population, large dams have been controversially discussed ever since (Da Costa, 2010) – a discussion that lasts until today (Ansar et al., 2014; Fearnside, 2006; Imhof and Lanza, 2010; Soito and Freitas, 2011; WCD, 2000). Despite the controversies, the number of large dams constantly increased after the military dictatorship period. Nowadays there are 1,335 large dams[1] in Brazil (ANA, 2015) with 198 hydropower plants and a total capacity of 85.28 Mio. kilowatt (kW). In addition to these, eleven hydropower plants are currently under construction with a capacity of over 15 Mio. kW and the construction of four more hydropower plants is planned in the near future. In total, hydropower contributes almost two thirds (65.2% or 90.5 Mio. kW) of the total domestic electricity supply (ANEEL, 2015; EPE, 2015). Eight of those hydropower plants are located

[1] Dams with a height of at least 15 m or a reservoir volume of more than three million m³ are defined as large dams (ANA, 2015)

at the São Francisco River, where three reservoirs for hydropower generation have been constructed by the governmental São Francisco's Hydroelectric Company (CHESF) (CHESF, 2015). Consequent constant water availability enabled the governmental company for the development of the valleys of the São Francisco and Parnaíba rivers (CODEVASF) to implement 34 irrigation schemes with a total irrigable area of 135,500 hectares (ha), providing employment to over 250,000 people. Further irrigation schemes with a total irrigable area of 255,000 ha were planned to be implemented in the following years (CODEVASF, 2014; CODEVASF, 2015a).

1.2 Historical and agricultural background of the study region

Due to the cumulative character of this dissertation, the most relevant aspects of the study region are described in the articles in the following chapters. However, aspects that did not fit into these publications, but are relevant for context of this dissertation, are briefly presented in this section. A profound understanding of the region is crucial to determine the driving and limiting forces of rural development and to identify the potentials of irrigated agriculture. The studies forming this dissertation were conducted along the lower-middle São Francisco River in Pernambuco state. The region, which reaches from the Sobradinho dam nearby the city Petrolina until the end of the Itaparica Reservoir, consists of the two micro-regions Petrolina and Itaparica, as shown in Fig. 2.

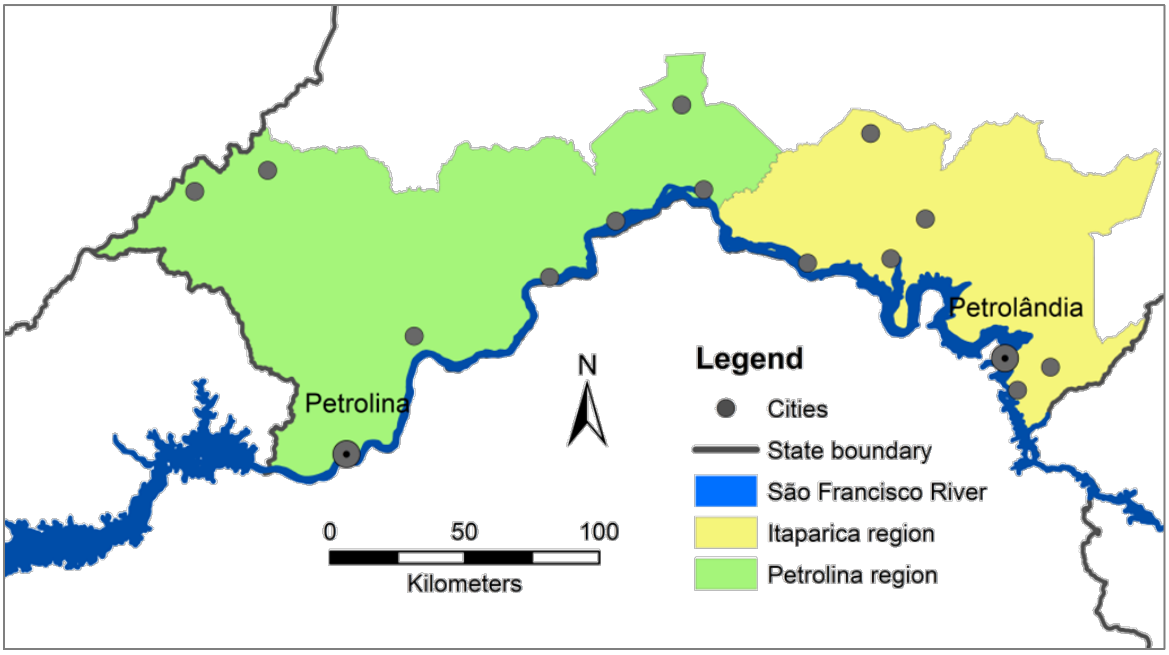

Fig. 2: The Petrolina and Itaparica micro-regions at the lower-middle São Francisco River. Source: Own figure after IBGE, 2013a

The study area is characterized by relatively constant temperatures of around 25 °C (Parahyba et al., 2004) and yearly average rainfall of 340 mm (APAC, 2015). Irregularly occurring severe droughts are mostly caused by the El Niño and the La Niña phenomena (Hastenrath and Heller, 1977; Nobre and Shukla, 1996; Rodrigues and McPhaden, 2014). Natural vegetation is the tropical scrub forest *Caatinga*. It is well adapted to the dry climate, as, due to its deciduous character, most species lose their leaves during the dry season and reduce their metabolism (Parahyba et al. 2004).

In the 17th century owners of large parcels of land – so-called *fazendeiros* – began to raise cattle on large natural pastures (Damiani 1999; Untied 2005). Since the 18th century, smallholders started with subsistence agriculture in rainfed and extensive irrigation systems (Andrade 2011; Antonino et al., 2005; Untied 2005). The growing period in the riverbeds was traditionally during the season of low tide. Additionally, small reservoirs, so called açudes, were constructed for more constant water supply (Saito and Yagasaki, 1995). The first cash crop was cotton, often produced by sharecroppers with corn and beans as intercrops. Sharecroppers, who were mainly landless former slaves, paid around 50% of their yields to the landowners (Damiani 1999). From the 19th century, farmers extensively cultivated onions, tomatoes, melons, watermelons, and beans as cash crops, whereas onion was the main cash crop (Marsden et al. 1996; Saito and Yagasaki, 1995).

As highlighted previously, the plans of using irrigated agriculture to reduce the impacts of droughts date back to the severe drought of 1890 (Hall, 1978), when the region was one of the most remote regions in Brazil (CONDEPE, 1998). Although projects to promote irrigated agriculture had started in several states, its implementation was promoted slowly and in 1941 only an area of 500 ha was irrigated (Hall, 1978). However, promotion of irrigated agriculture came along with massive investments in basic infrastructure such as roads, airports, and supply of electricity and water (Damiani, 1999). Still, governmental institutions, especially the National Department for Fighting the Droughts (DNOCS), were criticized due to their inefficiency and favoritism towards larger landowners (Hall, 1978; Untied, 2005). The foundation of the Executive Group of Irrigation and Agricultural Development (GEIDA) in 1968 and the formulation of the first long-term irrigation plan as part of the national strategy (PPI), built the basis for the implementation of large public irrigation schemes. Constant availability of irrigation water due to the construction of large reservoirs favored the rapid increase of irrigable areas (Hall, 1978).

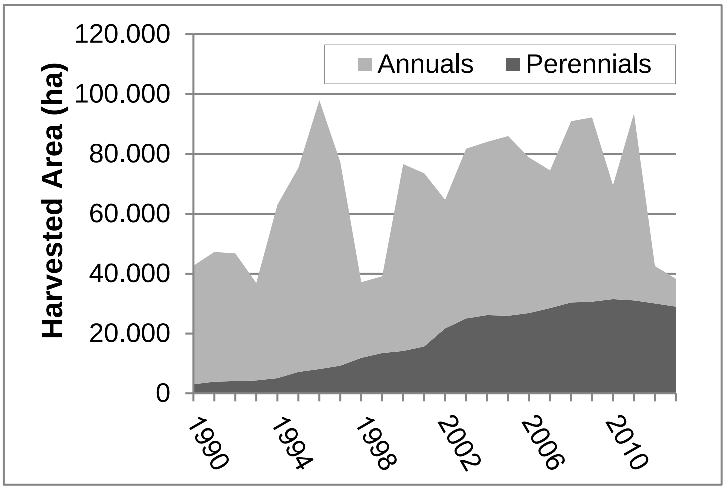

Fig. 3: Harvested area of annual and perennial crops in the São Francisco Pernambucano meso-region 1990-2013. Source: Own figure after IBGE, 2013b.

Since the year 1970, CODEVASF was liable for the development of irrigated agriculture along the São Francisco River (Hall, 1978; CODEVASF, 2010). Since the 1990s, the cultivation of perennial high value fruits and vegetables was promoted in the public irrigation schemes. The consequent increase of perennials in the São Francisco Pernambucano meso-region, which consists of the Petrolina and Itaparica micro-regions, is shown in Fig. 3. Whereas annuals are often cultivated in rainfed systems outside the irrigation schemes and their production is heavily affected by droughts, constant water availability in the irrigation schemes enables stable harvested areas of perennials (IBGE, 2013b).

Since the 1990s, the development of the semi-arid region went along with the economic development of the overall country, as estimated by the Brazilian Municipal Human Development Indicator (IDHM)[2] in the period from 1991 to 2010 (Table 1). However, the gap between the Brazilian average and the semi-arid region remained obvious (PNUD Brasil, 2015). A positive effect of irrigated agriculture can be assumed by the relatively higher IDHM in the municipalities of Petrolândia and Petrolina, where CODEVASF implemented several irrigation schemes (CODEVASF, 2015a). Ferreira

Table 1: Regional Development of the Brazilian Municipal Human Development Index 1991-2010

	1991	2000	2010
Brazil	0.493	0.612	0.727
Semi-arid region	0.324	0.456	0.617
Petrolina/PE	0.471	0.580	0.697
Petrolândia/PE	0.401	0.527	0.623

Source: Own calculations after PNUD Brasil, 2015

[2] The calculation of the Human Development Index on Municipality Level (IDHM - Índice de Desenvolvimento Humano Municipal) is based on the HDI (Human Development Index) summarizing the indicators “life expectancy at birth”, “mean years of schooling”, and “income per capita” to an index between 1 and 0, whereas proximity to 1 indicates high development (PNUD, 2015).

Irmão et al. (2013) confirm strong economic growth in the Petrolina and Itaparica regions. However, smallholders in the semi-arid region in general, and in both study regions in particular, are still facing poverty aggravated by insufficient infrastructure and clientelism (Andrade, 2011; Finan and Nelson, 2001; Untied, 2005; World Bank, 1998).

Despite regional proximity, the implementation of the irrigation schemes in the Petrolina and Itaparica regions presents two contrary cases (Ferreira Irmão et al., 2013; Untied, 2005). The reservoirs which formed the base for the irrigation schemes were already built under different preconditions. The Sobradinho dam in the Petrolina region was constructed during the military dictatorship period and followed by strongly enforced resettlements without appropriate compensations for the affected population.

As a consequence of the "*painful rural resettlement experience*" (World Bank, 1998), the dam operator CHESF, strongly influenced by worker unions, farmers, and even worldwide protests, intended to compensate the affected population adequately (Beck, 1994; Scott, 2006). Besides the different political background, the economic approach differed strongly, as outlined in the following paragraphs.

On the one hand, large irrigation schemes in the Petrolina region were planned to foster social and economic development. In 1984, CODEVASF implemented the first sectors of the Nilo Coelho irrigation scheme (DINC, 2015). Agricultural production concentrated on high value perennials for exportation (Andrade, 2011; Possídio, 1999). To attract private investors, around 50% of the irrigable areas were made available for agricultural enterprises with farm sizes from 50 – 100 ha, whereas the other 50% were reserved for smallholders with farm sizes from 6 – 12 ha (Damiani, 1999). Despite the economic success and provision of livelihood for almost 2,000 rural families in the Nilo Coelho irrigation scheme (Calvacanti, 2004; Damiani, 2003; DNIC, 2015; Lima and Miranda, 2001; Possídio, 1999), land allocation and working conditions for day laborers are criticized (Collins, 1993; De Sousa Sobrinho, 2009; Untied, 2005).

On the other hand, the irrigation schemes in the surroundings of Petrolândia were implemented to compensate the local population for flooded land in the course of the Itaparica reservoir construction (CODEVASF, 2015b; Untied, 2005; World Bank, 1998). The Itaparica dam and reservoir were constructed to supply the economically growing northeastern region with electricity during a period of high oil prices (CODEVASF, 2015b; Da Costa, 2010). For the construction of the 149 km long reservoir, 30,000 ha of arable land were flooded. Five towns were directly affected by the reservoir construction and had to be rebuilt. Two of them were located in Pernambuco state (Itacuruba and

Petrolândia) and three of them in Bahia state (Barra do Tarrachil, Glória, and Rodelas) (CODEVASF, 2015b). Around 9,400 of the 10,400 affected households were resettled into one of the new towns or into one of the 126 so-called agrovilas – small rural villages built near the newly introduced irrigation schemes (World Bank, 1998). In Pernambuco state, three major irrigation schemes were constructed to sustain the resettled people's livelihoods as required by the worker's union *Pólo Sindical* (Scott, 2006). Despite positive economic development, favorable production conditions, and access to irrigated land for resettled people, several problems persist in the region (Bartolomé, 1999; Untied, 2005). Scott (2006) describes pollution with agrochemicals, alcoholism and unemployment, HIV rates, and gender inequality as severe problems in the irrigation schemes. Besides social constraints, several studies report difficulties with commercialization of agricultural goods and consequent low profitability (Bartolomé, 1999; Untied, 2005; World Bank, 1998).

1.3 Justification, objectives and hypotheses of this research

This study aims at scientifically contributing towards a sustainable land and water use in the surroundings of the Itaparica Reservoir by providing a scientific background for policy guidelines to increase the efficiency of agricultural production methods. Consequently, this study focuses on the social and the economic pillars of sustainability in agricultural production but also considers social and ecological aspects.

Several studies (Burney et al., 2014; Hall, 1978; Untied, 2005) identify a strong correlation of droughts to agricultural performance in the study region. The role and efficiency of irrigated agriculture as drought adaptation strategy in the case of the Itaparica and Petrolina regions has been well analyzed and major constraints within the irrigation schemes have been identified (Scott, 2006; Untied, 2005; World Bank, 1998). However, there was lack of detailed quantitative socio-economic analysis within the irrigation schemes as well as a profound identification of the capability of small scale irrigated family farming under limited infrastructure in the study region. Considering the importance of family farming for the Brazilian agricultural production (Paulino, 2014) underlines the importance of this study. The following research objectives were investigated:

- Identification of the impact of rainfall variability on agricultural performance grouped into perennial and annual crops, and livestock production.
- Analysis of the socio-economic key indicators of income distribution under

the current agricultural production systems.

- Analysis of the potentials of structural changes within the irrigation schemes, such as the implementation of agricultural cooperatives or associations for bundling the supply of agricultural commodities and to improve the market conditions in favor of small family farmers
- Determination of optimized resource allocation at farm level by farm household optimization models considering farmers' preferences.
- Examination of the impact of changing production conditions, such as changing input costs or producer prices, on farm household productivity.

The objectives can be summarized into the following general hypotheses:

- **Farm income is affected by the socio-economic status of the household head;**
- **Irrigated family farming is highly vulnerable to changing production conditions;**
- **Irrigated family farming has the potential to provide an appropriate livelihood for rural families.**

1.4 Overview on the research methodology

To investigate the research objectives and answer the formulated hypotheses, an interdisciplinary approach combining qualitative and quantitative methods was used. As each research methodology is described in detail in the corresponding article in their particular chapters, at this point a brief overview on the overall methodological approach and therewith the chronological progress of the research is given.

In general in liberal market economies, decision making on resource allocation takes place at farm level. However, during two field trips in 2012 to prepare the data collection, agricultural extension, which had been funded by CODEVASF until 2012, was identified as main driver of farmers' decisions (see also Murphy and Sprey, 1983; Untied, 2005). Consequently, data collection concentrated on farm level in close cooperation with the main stakeholders of agricultural extension service and CODEVASF as the irrigation schemes' operator.

In preparation for the first field visits, publically accessible secondary data sources, such as the demographic and agricultural census (IBGE, 2006; IBGE, 2010; IBGE, 2013), annual reports of public agencies (ANA, 2013; APAC, 2013; EMBRAPA, 2013), and previous studies on the region (CONDEPE, 1998; Da Costa, 2010; Saito and Yagasaki, 1995; Untied, 2005; World Bank, 1998) were analyzed. Based on the retrieved information, sixteen qualitative in-depth expert interviews were conducted. Findings from the first interviews underlined the need for two further studies, which were conducted in the framework of one Master (M.Sc.) and one Bachelor (B.Sc.) thesis. Qualitative and quantitative questionnaires were designed in close cooperation with the Brazilian counterparts and adjusted to local production conditions using site specific expressions supported by local extension service. In the study region, farmers measured their yields in more practically applicable units, such as boxes, bags, or number of fruits. Producer prices were calculated in price per on-site sales units (Brazilian Reais per fruit, box, or bag). In the same way, application of fertilizer and agrochemicals was measured in bags, bottles, and number of filled knapsack sprayers; lot size and seedling costs could be calculated by the number of plants and the distance between plants and plant rows. Labor demand per production step was counted in workers per day. Considering these circumstances, even very detailed interviews could be finished successfully in a short time. Design of the questionnaires and conduction of the interviews followed the established guidelines as described in the corresponding chapters. As shown in Table 2, in total 253 interviews were conducted, of which 193 projected the agricultural production methods in the irrigation schemes in the Itaparica and Petrolina regions as well as the agricultural production outside the irrigation schemes.

Table 2: Summary of conducted interviews within the dissertation

Purpose of interview	Interview type	Data type	Location	Year	Quantity
Assessment of socio-economic key indicators	Expert interview	Qualitative	Itaparica region, Petrolina region, Recife	2012	16
Analysis of agricultural cooperatives*	Expert interview	Qualitative	Itaparica region, Recife, Curitiba/PN	2013	24
Examination of farmers' preferences°	On-farm interview	Qualitative and quantitative	Itaparica region	2013	20
Detailed analysis of agricultural production within and outside public irrigation schemes	On-farm interview	Quantitative	Itaparica region, Petrolina region	2013	193

* Conducted by Lucy Zavaleta Huerta within her master thesis

° Conducted by Anja Lienert within her bachelor thesis

Data analyses are only presented shortly, as they are described in detail in the particular chapters of this dissertation. Qualitative data were analyzed by methods of the content analysis (Huberman and Miles, 1983; Hycner, 1985; Mayring, 2010). The impact of rainfall variability on agricultural production was analyzed by linear regression. Socio-economic analysis was conducted by analysis of variance (ANOVA) and regression analysis, and farm optimization models were created using Linear Programming (LP) (Berbel and Gómez-Limón, 2010; Kaiser and Messer, 2011; Das et al., 2015). Linear and Non-Linear Programming (NLP) models can be applied with free accessible spreadsheets including solvers. LP models were used due to the relatively easy applicability in comparison to Non-Linear Programming (NLP) models (Singh, 2015).

1.5 Content of the dissertation

In this chapter, the peer-reviewed publications that form this dissertation are linked and therewith the structure of this dissertation is presented. After that, all additional reviewed contributions published in the content of this dissertation are presented. As they are thematically closely linked to the topic of this dissertation, but not fundamental to realize its main objectives, only their original abstracts are presented.

Chapter 2, titled *"Annual Rainfall Variability and Economical Dependency of Smallholder Agriculture in the semi-arid Northeast Brazil"*, deals with the effects of severe droughts on agricultural and livestock production in the Pajeú River watershed. In this study, publically accessible secondary data sources were used. The Pajeú, the river with the largest watershed in Pernambuco state, flows into the São Francisco River at the Icó-Mandantes irrigation scheme. First, trends in rainfall variation considering climate change were examined to identify the risk of increasing vulnerability of the region in the future. Subsequently, regional impacts of severe droughts on agricultural and livestock production were analyzed. Adaptation strategies of smallholders and livestock farmers to mitigate income losses were identified to get a profound understanding of the regional trends in agricultural and livestock production. Due to the trend towards perennial crops in the study region, as illustrated in Fig. 3, the differences of annuals and perennials to drought susceptibility were observed separately. From this study, the importance of constant water availability for the rural population's livelihood could be underlined.

In Chapter 3, *"Factors of success and limitations of irrigated family farming in semi-arid Northeast Brazil"*, the socio-economic situation in the Apolônio Sales, Barreiras, and Icó-Mandantes irrigation schemes and its impact on farm income is analyzed. Socio-economic key indicators and the main strengths and constraints of agricultural production in the irrigation schemes were identified by expert interviews. The impact of socio-economic characteristics of small family farmers was investigated using data retrieved from the 120 on-farm household interviews conducted in the irrigation schemes in the surroundings of the Itaparica Reservoir. Findings were compared to previous reports and studies on the irrigation schemes. Differences in farm income between the irrigation schemes were identified, emphasizing the importance of access to sufficient irrigable land and appropriate infrastructure. The study also explored the extreme volatility of producer prices in the study region. Due to its interdisciplinary character by the combination of qualitative and quantitative methods, the study contributed towards a holistic understanding of the situation of smallholders in the irrigation schemes and formed the base for further purely economic research on agricultural production.

The study presented in Chapter 4, *“The situation and perspectives of agricultural cooperatives in the surrounding of the Itaparica Reservoir in Northeast Brazil”*, is based on observations during the second field visit in 2012 to pre-test the quantitative questionnaire. Agricultural production on small areas in the irrigation schemes appeared to be predestined for farmers’ unions such as associations or cooperatives, especially considering the economic success of agricultural cooperatives in the south of the country. However, during the field trip no successfully operating cooperatives could be identified in the irrigation schemes. Consequently, 24 experts, farmers and members of inactive cooperatives and associations, agricultural consultants, local authorities, and scientists, were interviewed to assess the potentials and limitations of agricultural cooperatives and associations in the study region. On the one hand, experts mentioned several benefits of cooperatives; on the other hand structural obstacles for the successful implementation and operation as well as reasons for failure of farmer unions became clear. However, promising examples of small associations indicate the capability of farmer unions.

In Chapter 5, *“Mathematical Programming Models to Increase Land and Water Use Efficiency in semi-arid NE-Brazil”*, based on the socio-economic analysis, the economic performance and optimal resource allocation of fruit tree plantations in the Apolônio Sales irrigation scheme is analyzed. The impact of changing production conditions – an increase in wages of day laborers and the implementation of moderate volumetric water prices – on the production systems is used as an economic indicator of the robustness of fruit cultivation as stable income opportunity for the local population. An LP farm optimization model for optimal resource allocation considering the main perennials in the irrigation scheme, banana, coconut, and mango, was developed and fit well to the actual production conditions identified in Chapter 3. This study intentionally concentrated on the wealthiest of the three major irrigation schemes in the Itaparica region considering the current producer prices of agricultural commodities during the study period. By this method, the vulnerability of the farm income of relatively wealthier farmers, who are equipped with larger irrigable areas than the ones in the Barreiras and Icó-Mandantes irrigation schemes, could be underlined. On increasing daily wages, the high share of day laborers on the required workload in irrigated fruit production in the irrigation scheme increased the susceptibility of farm income. However, income derived by off-farm activities, which were only marginally investigated in this study, may exceed farm income and therewith compensate the effects of increasing expenses for hired labor in fruit production.

The LP farm optimization models presented in Chapter 6, *"Optimal resource allocation in irrigated family agriculture in Northeast Brazil"*, are based on the model presented in Chapter 5 but include all three major irrigation schemes of the Itaparica region as well as all cultivated crops identified during the interviews. Orange cultivation, which had been investigated by the Brazilian Agricultural Research Corporation (EMBRAPA) and mentioned during a personal interview in the research center in the semi-arid region, was added as production alternative. To adapt the LP model to local production conditions, farmers' preferences were determined by qualitative in-depth interviews. Farmers' risk aversion, as well as their tendency to maximize profits was considered in the model. With the extended LP model, the economic attractiveness of all cultivated and alternative crops could be investigated. Another focus of this chapter is on the impact of moderate and high volumetric water pricing on farm income and the identification of a recommendable water price to induce the implementation of water efficient irrigation technologies. Evaluation of the situation of producer prices for agricultural commodities and the comparison of local prices with Brazilian and regional average prices underlined the potentials of agricultural cooperatives and associations, which were identified in Chapter 4.

During the field survey in the Petrolina region, the high level of adoption of modern agricultural production methods, such as efficient irrigation, fertigation, ground cover to reduce evapotranspiration and increase organic matter content in the soils, became clear. In addition, the structures for commercialization appeared to be significantly better developed than those found in the Itaparica region. Combined with detailed analyses of agricultural production on farm level, high education level of the interviewed farmers, and personal correspondence with the schemes operator of both regions (CODEVASF), extended need for research was identified in the irrigation schemes in the Itaparica region. However, to get a deeper insight in the agricultural production systems along the lower-middle São Francisco River and to grasp the potentials of irrigated agriculture in the region, a random sample of 22 farmers was interviewed in the Nilo Coelho irrigation scheme. The main part of agricultural production appeared to take place inside the public irrigation schemes. However, outside the irrigation schemes peasants earned their livelihood by subsistence rainfed farming or by independently irrigation along the São Francisco River.

To get an overview on the agricultural production in this irrigation scheme and determine the differences between the agricultural production of the Petrolina and the Itaparica regions, in Chapter 7, *“Characteristics of agricultural production systems outside the irrigation schemes of the Itaparica region”*, the retrieved data are presented by descriptive statistics comparing both regions. To complete the overview on agriculture in the study region, production outside the three major irrigation schemes, as well as in the small Manga de Baixo scheme, is also presented in this chapter. The inclusion of the sample of Manga de Baixo in the overall context had been originally planned. However, agricultural production in this irrigation scheme had nearly stopped during the study period. While conducting the survey, few smallholders cultivating onion seeds and coriander could be identified. Nevertheless, the sample is also presented in this chapter to complete the overview on irrigated agriculture in the Itaparica region.

Finally, to complete the compilation of conducted studies within this cumulative dissertation, all additional scientific contributions, book chapters, and contributions to international conferences, are presented in the annex.

Chapter 2. Annual rainfall variability and economical dependency of smallholder agriculture in the semi-arid Northeast Brazil[3]

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Abstract

In the semi-arid region of Northeast Brazil, water resources are scarce and rainfall often has high temporal and spatial variability. Despite regional climate trends, no significant rainfall change could be detected by linear regressions in the Pajeú River watershed between 1912 and 2013. This study focused on the identification of regional impacts on agriculture in form of crop yields, livestock, and animal products through the annual rainfall departure, whereas permanent crops were less susceptible to droughts, bad had a negative effect on the memory after the dry years. In the livestock sector, farmers reacted to the consequences of droughts and increased stocks of smaller animals with faster recovery rates, and also implemented apiculture. The results show a high vulnerability of agricultural production and regional income due to the low adaptation to local climate conditions. Hence, agricultural practices and water management should be further improved to fight against crucial economic depressions during droughts.

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[3] **A version of this chapter has been published as:**

Selge, F., Hagel, H., Gunkel, G., Doluschitz, R.. Annual Rainfall Variability and Economical Dependency of Smallholder Agriculture in the semi-arid Northeast Brazil. In: Revista Brasileira de Ciências Ambientais – RBCIAMB 36, 2015, 143-154. doi: 10.5327/Z2176-947820151009

Keywords

Agricultural production, livestock, Pajéu River watershed, rainfall, water scarcity

Resumo

A região semiárida do Nordeste do Brasil apresenta escassez de recursos hídricos e grande variação temporal e espacial da precipitação. Entretanto, apesar da tendência climatica regional, não foi detectada variação significativa de precipitações na bacia hidrográfica do Rio Pajeu entre 1912 e 2013. Este estudo tem como foco a identificação de impactos regionais na produção agropecuária provocados pela variação anual da precipitação. A produção de lavouras temporárias apresentou forte relação com a precipitação anual. A produção de lavouras permanentes apresentou um efeito negativo após anos secos. Os criadores de animais se adaptaram aos efeitos da seca através do aumento da criação de animais de menor porte e da implementação da apicultura. Os resultados demonstraram alta vulnerabilidade da produção em razão ao baixo grau de adaptação às condições climáticas. As práticas agrícolas e o manejo da água devem ser melhorados no intuito de combater os efeitos econômicos negativos da seca.

Palavras-chave

Agricultura, pecuária, bacia hidrográfica do Rio Pajeú, chuva, escassez de água

2.1 Introduction

Semiarid regions are characterized by low annual rainfall and suffer under severe droughts which occur rather frequently and where water is really scarce (Montenegro and Ragab, 2012). The high climate variability and extreme weather events enhance the vulnerability of natural resources, threatening world populations with an increasing trend of decreasing water availability (Gutiérrez et al., 2014).

Societies, especially in semi-arid and developing regions, are specifically vulnerable to limitation of water resources and therefore, to changes of climate conditions. In addition, a dense population depending on few short-term options to earn their livelihood increases the anthropogenic pressure on water availability (Krol & Bronstert, 2007; Montenegro & Ragab, 2012; Simões et al., 2010).

Although climate conditions are harsh in the semi-arid northeastern region of Brazil, agriculture has an important role for the local economy and society. In Brazil, family farming accounts for about 70% of the food consumed throughout the country (Burney et al., 2014; Sietz et al., 2006). Given that water storage in soils as ground or interflow water is limited in this region due to wide distributed crystalline rock formations and shallow soils, water availability is mainly provided by spatial and temporal distributed annual rainfall. However, other measures of water storage such as subsurface dams, small reservoirs, and cisterns are widespread in the region (Cirilo, 2008).

Traditional agriculture consists of extensive livestock breeding and (partly irrigated) cultivation of subsistence crops along the river margins or in form of recession agriculture on the borders of temporary reservoirs (Antonino et al., 2005; Sietz et al., 2006). Furthermore, for life quality maintenance, agricultural expansion into less favorable areas and livestock grazing in natural areas are a common practice. This livelihood increased the pressure on natural resources and led to overgrazing, loss of natural vegetation, soil erosion, and landscape degradation with decline of crop yields (Leal et al., 2005; Sietz et al., 2006). More recently, large irrigation projects are developed along the perennial São Francisco River and around larger reservoirs.

The strong negative economic and social impacts were recently observed in the most severe drought conditions since several decades from 2010 until 2013 in entire Brazil, but extremely in the semi-arid northeastern region of Brazil (Gutiérrez et al., 2014). Especially in a scenario of global warming and changing rainfall patterns, agricultural production in semi-arid regions is at high risk (Toni & Holanda, 2008). As climate variability and future changes affect especially non-irrigated agriculture, small subsistence farmers highly depend on water availability and are prone to economic depression during the years of drought, or else the death of their livestock due to thirst (Krol et al. 2006; Lindoso et al. 2014). Due to the severity of the problem, a profound analysis of the local impact of rainfall to agricultural production and the livelihood of the subsistence farmers should be carried out and the results used for other semi-arid regions.

2.2 Material and Methods

The study is conducted for the watershed of the Pajeú River in the semi-arid region of northeastern Brazil. It is the largest watershed in Pernambuco state and is located between 7°16’20” S to 8° 56’01” S and 36°59’00” W to 38°57’45” W. Its northern boundaries are identical to state borders of Paraiba and Ceará, and it belongs to the lower-central watershed of the São Francisco River (Fig. 4).

The hydrological basin of the Pajéu River with 22 municipalities covers an area of 16,686 km², about 2.4% of the total Caatinga biome or 17% of the state territory. The watershed has a mean altitude between 300 and 500 m above sea level, whereas mountain ranges in the north reach up to 1,100 m above sea level.

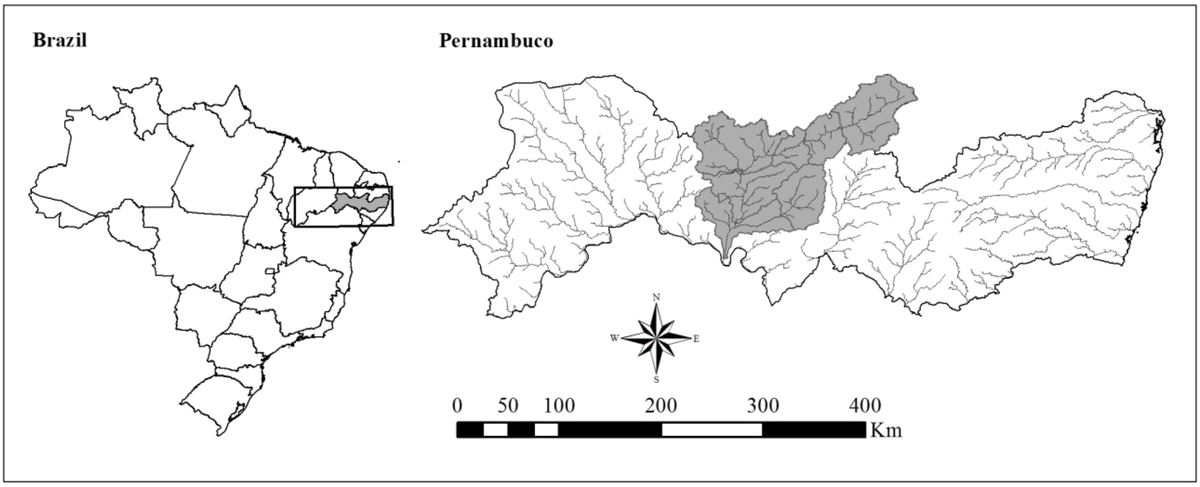

Fig. 4: Brazil and the study area in Pernambuco state located in the semi-arid of Northeast Brazil, marked is Pernambuco state (Brazil map) and the Pajeú River watershed (Pernambuco map). Source: Own map after ANA, 2014

This region is part of the drought polygon and is characterized by annual mean temperatures above 20 °C, annual rainfall less than 1,000 mm $year^{-1}$, and high evaporation rates ranging between 1,500 and 2,500 mm $year^{-1}$ (Sampaio, 1995). Most of the annual rainfall occurs from January to May; the rest of the year remains dry and receives only little amounts of rainfall. Frequently occurring one year droughts are strongly related to the Southern Oscillation phenomenon El Niño (Rodrigues & McPhaden, 2014), but reasons for multi-year droughts are not yet well understood. The region is characterized mainly by the Caatinga biome – adeciduous xeric shrubland typically on relatively shallow soils (Sampaio, 1995). In the study area, three soil types - luvisol, regosol, and arenosol, cover more than 50% of the watershed with low water retention capacities. Groundwater is limited to areas of the sedimentary basin, but often tends to be saline (Cirilo, 2008; Voerkelius et al., 2003).

This integrated study is based on data from publicly available data sources in Brazil. Historical rainfall data were obtained from the national water agency of Brazil (ANA 2014) for six active weather stations located along the Pajeú River course. Data resolution is carried out on a daily basis, but partly with large gaps of data records. Daily data were screened for false data, and corrected by linear interpolation of surrounding data, depending on the availability.

For this study, the data at municipality level regarding land use and demographic development were collected for all municipalities of the Pajeú River watershed from the Brazilian Institute of Geography and Statistics (IBGE, 2014). Additionally, the IBGE offers historical data about annual agricultural and livestock production with the datasets *Produção Agrícola Municipal* (IBGE, 2013b) for the period 1990 to 2013 and *Produção da Pecuária Municipal* (IBGE, 2014) from 1973 to 2013.

Daily rainfall data were summarized to annual totals of the respective stations and standardized as per the the annual rainfall departure, with the following equation:

$$X_{ij} = \frac{(r_{ij} - \bar{r}_i)}{\sigma_i} \quad (1)$$

where X_{ij} is the annual rainfall departure, r_{ij} is the annual total for station *i*, and year *j*, $\bar{r}_i$ is the annual mean rainfall at station *i* averaged over the study period, and σ_i is the standard deviation of the annual totals. The new time series are characterized by a mean equal to 0 and a variance equal to 1. The regionally integrated rainfall departure is calculated as the means for all stations. The annual rainfall departure is defined into three categories: $z < -0.5$ refer to dry years; $z > 0.5$ refer to wet years; $-0.5 < z < 0.5$ define normal years; where the z-score indicates how many standard deviations an element is from the mean; analog to Kutiel et al. (2014). For the categorization of the entire domain, the integrated standardized rainfall departure is calculated as mean across all stations.

Linear regression models are used for trend removing of analyzed time series and correlation of crop yields with annual rainfall departure and agricultural gross domestic product (aGDP) according to equation 2:

$$Y_{ij} = a \cdot x_j + b + E_{ij} \quad (2)$$

where Y_{ij} is the standardized crop yield for crop *i* and, year *j* or the annual aGDP, a and b are the regression factors for slope and intercept and E_{ij} is the residual error for crop *i* and year *j*. The coefficient of determination (R^2) larger than 0.75 describes a strong relationship, and a coefficient below 0.25 describes a weak relationship.

2.3 Results

In the semi-arid area of northeastern Brazil, rainfall has a high spatial and temporal variability. In the Pajeú River watershed, more than 90% of the total rainfall occurs mostly in the rainy season from January until May, while the rest of the year is dry. The temperature is characterized by small annual amplitude between 23.3 °C and 27.9 °C, but relatively large daily fluctuations between 20.0 °C and 33.7 °C as monthly means and all-the-year high evaporation rates.

Over the past century, between 1912 and 2013, no significant trend of rainfall could be detected in the watershed by linear regression analysis (Fig. 5). However, 20-30-year periods of linear regressions show variable but non-significant tendencies. Particularly, the severe long drought period in the 1950s is strongly affecting regressions between 1930 and 1990. In contrast, rainfall is more expressed by high annual variability between 300 mm and 1,500 mm with a mean of 585 mm year^{-1} at the stations within the Pajeú River watershed (Fig. 5).

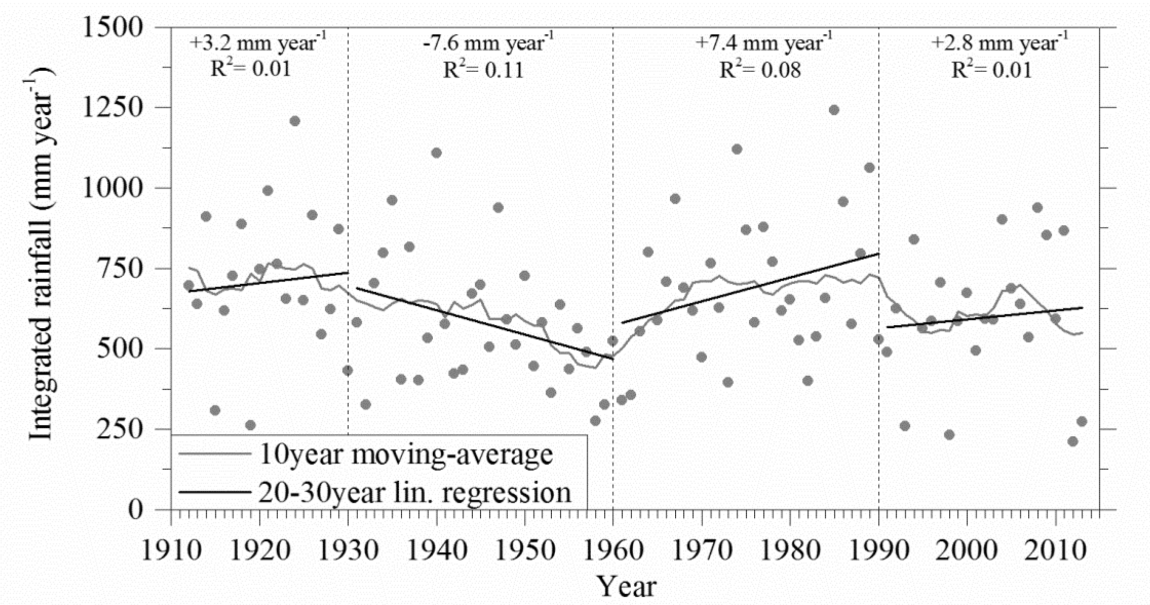

Fig. 5: Annual integrated rainfall (dots) in the Pajeú River watershed with 10-year moving-average (red line) from 1911 until 2013. Solid lines (black) represent linear regressions for 20-30-year periods with embodied annual slopes and R^2. For the total period a non-significant annual rainfall change of -0.42 mm year^{-1}, R^2 = 0.003, was detected. Source: Own figure after ANA, 2014.

Within the period from 1912 to 2013, 9 severe droughts with z < -1.0 or less than 305 mm year^{-1} occurred. The frequency of severe or multi-year droughts is irregularly distributed. In the period of 30 years (from 1930 until 1959), 16 years were classified as dry (z < -0.5) including 2 severe drought years; however, from 1960 until 1989, 4 years were dry including 1 severe drought year. From 1990 to 2013, 5 dry years including 4 severe drought years were registered. But, the longest time period between two dry years was maximal 10 years with an average occurrence of every 3.4 years, whereas the time period between severe droughts was between 2 and 31 years with an average occurrence of every 12.9 years.

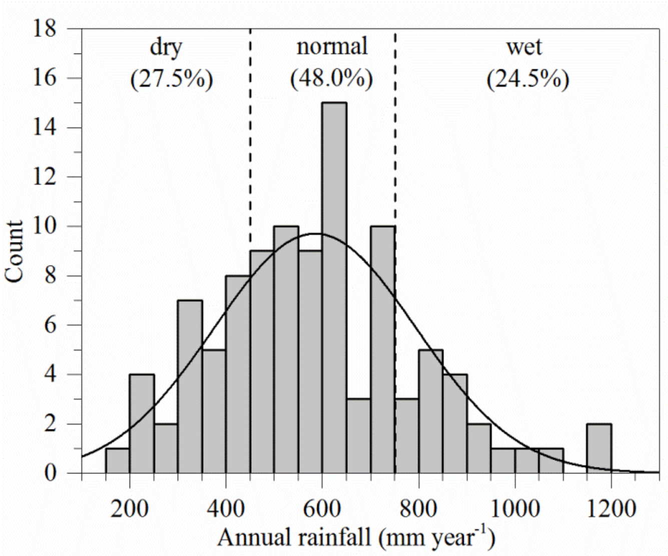

Fig. 6: Histogram of regional integrated annual rainfall in the Pajeú River watershed for the period 1912 to 2013; with a normal distribution around the mean of 585 mm $year^{-1}$. Source: Own figure after ANA, 2014.

Agricultural production in the Caatinga is widely practiced in a land tenure system. In the Pajeú River watershed, average farm size varied between 3.3 and 6.0 ha with an area-weighted mean of 4.9 ± 1.2 ha $farm^{-1}$, but landownership is unevenly distributed. For easier water access and all-the-year water supply, most farms are allocated along a riverbed or close to larger reservoirs.

Crop production in the Pajeú River watershed is dominated by typical temporary subsistence crops, mostly beans, corn, and tapioca, which cover a cumulative area of 173,067 ha (average from 1990 to 2012) representing 97% of the total temporary agricultural land use. The main important permanent crops regarding the total planted area (8,083 ha, average from 1990 to 2012) for the entire Pajeú River watershed are cashew nut (57%), banana (16%), guava (12%), mango (5%), and coconut (4%), with banana and coconut recently becoming more important.

Crop yields depend on various factors; main drivers are water availability, temperature, solar radiation, soil characteristics, nutrients, fertilization and irrigation practice, and pest control among others.

The calculated crop yields, by division of harvested weight through planted area, show a strong variability. For example, corn as temporary crop varies between 0 and almost 1,000 kg ha^{-1}. These strong variations of crop yields suggest varying management practices and, that other environmental conditions besides rainfall may play an important role within the study area.

The trend-adjusted time series of crop yields, especially of major temporary crops show a linked pattern to annual rainfall (Fig. 6). Correlating annual crop yields with the annual rainfall departure shows the dependency of temporary crops on annual rainfall (Table 3). In contrast, the maximum length of consecutive dry days do not show any influence on crop yields in the study region.

Table 3: Average crop yields with standard deviation and trend adjusted linear regression equation in relationship to the annual rainfall departure. Pearson coefficients presenting correlations between crop yield and annual rainfall departure of the same year (n) and included weighted previous year ($n_i + n_{i-1}$)

Crops	Mean ± SD (kg ha^{-1})	Trend adjusted		p-value (Pearson)	
		Equation	R^2	n	$n_i + n_{i-1}$
Temporary crops					
Beans	171 ± 101	y = 86.04x + 6.17	0.38	< 0.001	0.024
Corn	433 ± 296	y = 229.9x - 26.38	0.27	0.006	0.045
Manioc	6,815 ± 2,257	y = 1,370x + 98.4	0.18	0.022	0.006
Sugarcane	28,182 ± 12,044	y = 8,472x + 608	0.26	0.006	< 0.001
Permanent crops					
Cashew nut	500 ± 178	y = 154.3x + 11.08	0.40	< 0.001	0.005
Banana	8,058 ± 6,287	y = 1,748x + 126	0.08	0.100	0.023
Guava	52,678 ± 47,845	y = -907x - 65.1	-0.05	0.898	0.972
Mango	19,571 ± 17,520	y = -2,410x - 173	0.02	0.250	0.177
Coconut	8,165 ± 4,141	y = 1,514x + 108	0.08	0.102	0.043

Permanent crop yields are less significant when correlated to annual rainfall departure, but including the previous year annual rainfall departure by adding the annual rainfall departure of the respective two years ($n_i + n_{i-1}$), correlations become more significant for some permanent crops (Table 3). However, the cash crop cashew nut is highly correlated to the actual annual rainfall ($p < 0.001$), which covers 57% of the area for permanent crops and has a major contribution to income production.

Livestock in the region is dominated by chicken (62%), goat (18%), cattle (9%), and sheep (6%), which cover summarized 95% of livestock in this region with increasing trends of stocks. In 1993, a sharp decrease in number of animals occurred due to the severe drought. More than 55% of the cattle and pig stock died because of water and food scarcity, whereas chicken and goats had a higher survival rate.

Recovery of stocks, especially for larger animals such as cattle and horses, needs several years. In contrast, the chicken stock is recovered within one year after the drought in 1993. Since this drought, apiculture was introduced with an increase of about 11% and production of quail eggs started in the region. In addition, chicken farming was extended and goat and sheep farming increased slightly, while pork production currently plays a minor role.

Animal husbandry is also undertaken for products derived from animals. Here, milk and eggs are the main products for the region. From 1974 until 2012, the production of milk and eggs increased by 1.8% and 3.8%, respectively. In the drought of 1993, the amount of milked cows declined to 60% of the previous year's stock; as also shown for Bahia by Burney et al. (2014). Not only did the total number of milk cows decline drastically but the average daily milk production per cow also decreased from 1.9 to 0.6 L. Although the number of milked cows recovered relatively fast within a few years, the average yield recovered more slowly (Fig. 7).

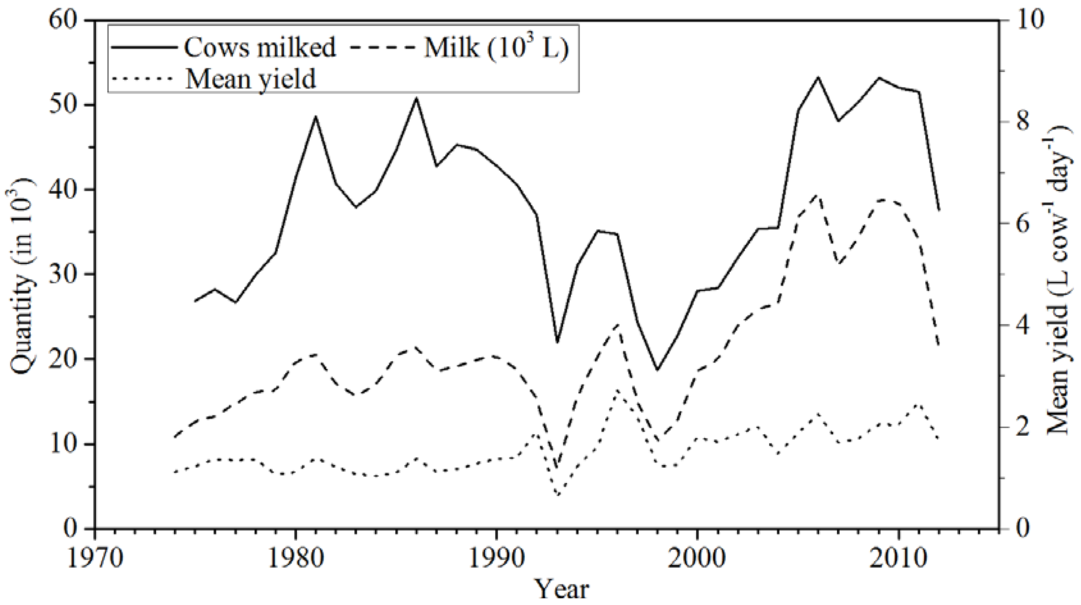

Fig. 7: Development of milk production in the Pajeú River watershed with number of cows, milk (in 1000 L) and the mean milk yield in L per cow and day. Source: Own figure after IBGE, 2013b

The aGDP of the Pajeú River watershed varied on both temporal and spatial scales for the period 1999 to 2013. The aGDP shows a significant trend of a yearly growth rate of 8.8% for the entire watershed, but due to the severe multiyear drought from 2010 to 2013, the aGDP declined about 40% from 182.2 Mio R$ in 2009 to 109.8 Mio R$ in 2012 (Fig. 8). The partial contribution of the selected agricultural sectors temporary and permanent crops as well as livestock is temporally relative constant, and account for 45.6, 7.0, and 26.1% of the total aGDP. However, during the drought, the temporary crop income had for the most part decreased significantly.

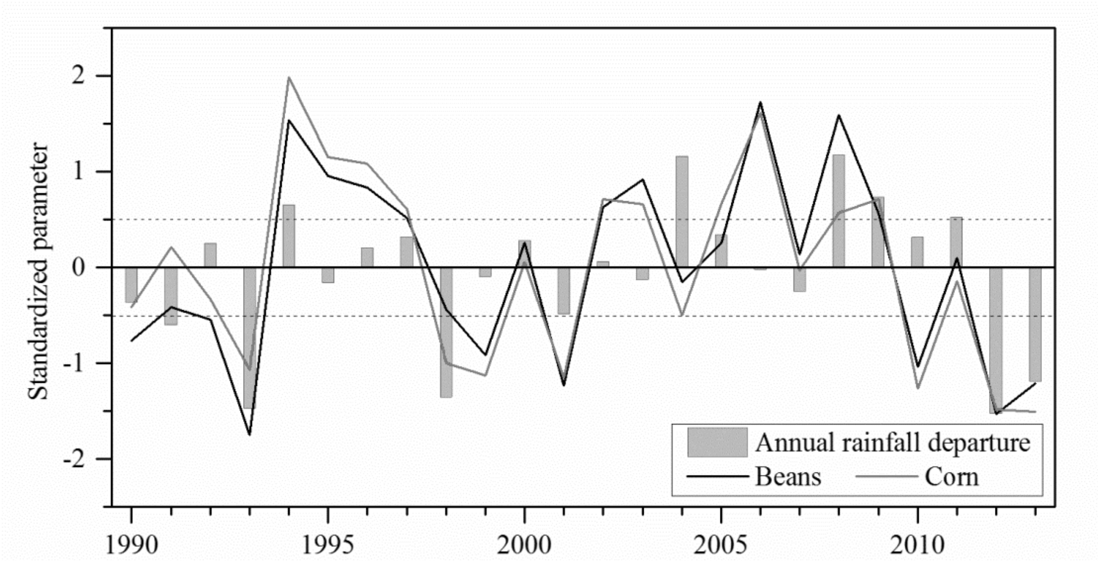

Fig. 8: Time series of annual rainfall departure and standardized trend adjusted crop yields for beans and corn. Source: Own figure after ANA (2014) and PAM (2014)

As presented in the aGDP, low annual rainfalls favored reduced crop yields, led to death of livestock and decrease in animal produce. Due to these facts, the entire watershed shows in the period between 1999 and 2012 an existing relationship and a significant correlation between the aGDP and annual rainfall. As a result, the local economy was under stress during these periods and had a major negative impact on the livelihood of the people.

Although permanent crop yields and milk yield are affected by the previous year's conditions, the annual rainfall departure of the same year has the highest correlation with the trend-adjusted aGDP of the entire watershed (Pearson: p = 0.01). According to the modeled relationship between aGDP and annual rainfall departure by linear regression, a drought year with an annual rainfall departure of -1.5 reduces the aGDP by 33% (41 Mio. R$). A wet year with an annual rainfall departure of 1.5 increases the aGDP by approximately 34 Mio. R$ or 28%. This reflects the strength of drought

Table 4: Factors of linear regression between regional annual rainfall departure and trend adjusted aGDP in R$ per ha of agricultural land use including tillage, pasture and forestry

Region	a	B	R^2
Total watershed	28.31	-4.09	0.39
Upstream	40.11	-14.62	0.41
Downstream	23.57	-2.35	0.62

years for the local agricultural economy, as losses by dry years cannot be compensated by wet years. In Table 4, the sensitivity of agricultural production to annual rainfall variability is expressed by the slope of the linear regression function. The downstream area shows on the one hand, a lower dependency on annual rainfall with more stable income generation, but generates on the other hand a lower aGDP in wet years than the upstream region. The residual distances between predicted and observed aGDP are mainly explained by livestock practices. In the upstream region, the number of milk cows ($p = 0.03$) and pigs ($p = 0.04$) and downstream milk production per cow ($p = 0.03$) describe the major variance of the model.

2.4 Discussion

Global climate models mostly agree in the prediction of higher rainfall variability and longer droughts in semi-arid regions (Burney et al., 2014; IPCC, 2014). However, regional climate models show changes in precipitation trends for northeast Brazil (Krol & Bronstert, 2007; Marengo et al., 2009). Several authors state that the semi-arid region is the most vulnerable area of Brazil regarding climate change impacts, amplified by the high population density, reduced productivity, livestock deaths, and out-migration of labor (Lobell et al., 2011; Simões et al., 2010).

Da Silva (2004) performed a trend analysis of climate parameters for the northeastern region and identified an increasing trend towards climate variability, whereas the two considered stations within the Pajeú River watershed showed no significant trends, which is consistent with the findings of this study. This may be due to the mitigation measures of large reservoirs, rainwater harvesting such as small reservoirs, subsurface dams, cisterns, and increased areas of irrigation agriculture in the region having an effect on local climate conditions (Da Silva, 2004). Still, vegetation change towards strongly reduced ground covering can reverse this effect and negatively influence local climate (Burney et al., 2014; Oyama & Nobre, 2004).

Although rainfall and related water availability in the studied watershed does not underlie any observable trend, stress on water resources is increasing in drought periods due to the population growth and increasing land degradation. Migration, especially from the countryside into cities, enhances local water stress by concentrated water consumption and point-release of mostly inappropriate purified wastewater, therefore resulting in the decrease of the quality of the water and its effects on irrigation agriculture.

Despite the semi-arid climate and frequent occurrence of droughts, agriculture is the main economic pillar in northeast Brazil. Although Brazil has begun to face water scarcity since 1877, after a severe drought followed by an emergency response and large water infrastructure, such as the construction of reservoirs and more recently water transposition channels, significant impacts from limited water resources in drought years persisted (Cirilo, 2008; Gutiérrez et al., 2014).

Agricultural production is inseparably linked to water availability, which is the main driving factor for crop yield (Steduto et al., 2012). In the semi-arid northeastern region and for the Pajeú River watershed, temporary crops are the most abundant crops in more than 95% of agricultural area. In general, the observed temporary crop yields for the total watershed have a high year-to-year variance, which is strongly related to annual rainfall.

Achieved crop yields are comparably low as compared to Brazilian or global averages (Sampaio, 1995; Steduto et al., 2012), as for instance, maize which is generally cultivated in an extensive subsistence system. In the downstream region, especially in the municipality of Floresta, water availability is increased due to the reservoir Açude Serrinha II, which retains water during the rainy season and releases increased amounts in the dry season. Relatively secured all-the-year water resources motivate farmers to invest in irrigation technique (up to 22% of agricultural land area in Floresta), and the cultivation of permanent or more cost intensive crops such as coconut or onions. This explains the lower sensitivity of the local aGDP in the downstream region to annual rainfall, too.

Overall, agricultural extension is important to improve agricultural productivity and also to promote water saving irrigation technologies for an increased resilience against droughts. Permanent crops especially require advanced agricultural and business skills (Hagel et al. 2014). Sietz et al. (2006) discuss persistent negative effects of droughts to agricultural production systems, which underlines the importance of smallholders' drought resilience.

Livestock and animal products have an important economic contribution and are less susceptible to droughts (Coutinho et al., 2013). Despite the relatively higher drought tolerance when compared to crops in dry years, animal productivity and survival are crucial factors that bring a decrease in the economic income (Burney et al., 2014; Lindoso et al., 2014). In years of severe droughts, animal survival is reduced due to restricted water availability, limited forage production on pasture land, and overgrazing effects in the natural vegetation (Leal et al., 2005).

The data point out that recovery time for large animals is much longer than for smaller animals such as chicken, quails, or goats. For this reason, there is a shift of livestock practice to increased numbers of chicken and quails, whereas importance of pig and other large livestock declined after the drought years in 1993 and 1998. However, milk production is an important means of income generation and shows increasing yields, probably because of better feeding conditions. However, the high death rates of livestock during droughts still threaten small farmers’ livelihoods as recently reported for the drought from 2010 to 2013 (Gutiérrez et al., 2014).

Since the 1993 drought, apiculture was introduced in the region as a less cost-intensive agricultural alternative with rapid recovery time, probably mainly for subsistence economy. Until now, no sufficient studies about the local apicultural activity and production have been carried out which could enhance market expansion and value by knowledge of pollen components (Santos de Novais et al., 2010).

Despite widely applied water storage measures and changes in agricultural practice since decades, heavy economical impacts are still observed in the recent drought from 2010 until 2013. Although relatively high temporary crop yields are stabilized with irrigation measures in the downstream region, water resources are made available round the year by the perennial water reservoirs. In areas without access to perennial water, subsistence agriculture, economical problems, and devastation are still occurring during drought periods as they are not adapting the improved agricultural practices.

The introduction of apiculture and the shift to more drought resilient animals or those with faster recovery time are innovative practices to create a more drought resilient agricultural business. A shift towards integrated water management including supplemental irrigation in rainfed production systems, instead of strictly separating irrigated and non-irrigated agriculture may dampen the effects of droughts and even increase the overall agricultural production (Rockström et al., 2010). The income alternatives outside the agricultural sector should be promoted to reduce the pressure on land and water (Hagel et al., 2014).

For an improved adaptation of agricultural practices there are several institutions working in this field in the semi-arid northeastern region; this study should strengthen the discussion about more water saving techniques and adapted agricultural practices. Furthermore, climate change models have to be refined and locally adopted for an improved simulation of future trends for an appropriate land and water management.

2.5 Conclusions

Despite the regional climate trends, the annual rainfall does not show significant trends in the Pajeú River watershed, probably due to small and large-scale water storages and irrigation schemes. The occurrence of droughts is irregular, but average intervals are between 3.4 and 12.5 years for dry and severe drought years, respectively. Although agricultural and livestock production show an increasing tendency in the studied region, the agricultural income in dry years and especially in severe drought years is reduced by about 30% and economic welfare reverts. Agricultural production, especially for temporary subsistence crops, highly correlates to regional annual rainfall, which affects the small-scale or subsistence farmers who have more difficulties to recover from droughts. Therefore, the high climate variability has strong effects on the regional economic development in all agricultural practices, which is observable in the agricultural gross domestic product. As a local adaptation strategy for higher drought tolerance, farmers increased the small animal stock with higher recovery rates and implemented apiculture in the region. However, in the recent drought between 2010 and 2013 economic devastation occurred at the subsistence farm level due to low drought adaptation. In contrast, irrigation schemes with perennial water supply achieved constant high crop yields independent from local rainfall with high income generation due to increased market prices.

Acknowledgements

This study is performed within the bi-national (Brazil and Germany) research project INNOVATE (INterplay among multiple uses of water reservoirs via inNOvate coupling aquatic and Terrestrial Ecosystems) funded by the German Ministry of Education and Research (BMBF) and the Brazilian Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Ministério da Ciência, Tecnologia e Inovação (MCTI) and the Universidade Federal de Pernambuco (UFPE). The authors are thankful to IBGE (Instituto Brasileiro de Geografia e Estatística) and ANA (Agência Nacional de Águas) for several open available statistical and rainfall data.

Chapter 3. Socio-economic analysis of irrigated family farming in Brazil's semi-arid northeast[4]

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Abstract

Along the lower-middle São Francisco River, in the semi-arid region of northeast Brazil, irrigated agriculture contributed to reduce rural poverty. In the framework of the Itaparica Reservoir construction, three irrigation schemes were implemented in the Pernambuco state to compensate the local population for flooded land. Despite favorable production conditions for irrigated agriculture, many smallholders in the irrigation schemes are facing poverty. To identify socio-economic key indicators on farm income, sixteen expert interviews were conducted, and a random sample of 120 households were interviewed. The effect of socio-economic factors and crop choice on farm income was investigated by analysis of variance. Insufficient infrastructure, limited market access and low market power, volatility of producer prices, lack of credit availability, unequal distribution of irrigable land, and insufficient social capital and knowledge about irrigated fruit production threatened the smallholders' livelihoods. Crop choice and availability of irrigable areas were the main characteristics of prosperous smallholders, whereas knowledge and capital intensive perennials as well as high value annual cash crops with high risks of yield losses were the most profitable crops. Thus, wealthier farmers were more likely to generate high farm income. Agricultural extension, invest-

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[4] **A version of this chapter has been submitted as:**

Hagel, H., Hoffmann, C., Ferreira Irmão, J., Doluschitz, R. Socio-economic analysis of irrigated family farming in Brazil's semi-arid northeast.

ments in infrastructure, especially in improved market access and value-adding facilities, and off-farm income alternatives are recommended to provide adequate income to the local population and prevent rural exodus.

Keywords

Socio-economic analysis, irrigated agriculture, Itaparica reservoir, ANOVA

3.1 Introduction

Migration is a commonly used livelihood strategy of rural population in drylands (IIED, 2008). The history of migration in Brazil dates back until its colonization as summarized by Wagner and Ward (1980). Fischlowitz and Engel (1969) explain the continuous internal migration with periodic droughts in the country's semi-arid Northeast and several booms in agricultural production and mining. Internal urban migration began with the crash of coffee prices in 1929 and continued with the economic depression in the 1930's. In the following decades, rapid industrialization accelerated this process (Wagner and Ward, 1980). Economic crises in the 1980s and 1990s finally led to a rural exodus, mainly affecting the semi-arid Northeast (Perz, 2000). As discussed in several studies, main drivers for rural-urban migration was rural poverty caused by low returns from agriculture, income insecurity aggravated by droughts, and lack of income alternatives, forcing numerous smallholders to migrate to the metropolises in the center and the south of the country. Although rural exodus had its peak in the period from the 1980s until the late 1990s, it still continues until today (Alves et al., 1999; Finan and Nelson, 2001; Sieber et al., 2011). It is estimated that since the 1960s, around eight million people emigrated from Brazil's northeast (Reuveny, 2007). A well-known result of this rural exodus is the development of shanty towns (favelas) in the metropolises such as Rio de Janeiro (O'Hare and Barke, 2002) and São Paolo, with a high share of inhabitants descending from the Northeast (Lloyd-Sherlock, 1998). Despite several drought adaptation strategies, such as small-scale irrigated agriculture (Burney et al., 2014), migration remains the main strategy of many smallholders to escape from poverty (Lindoso et al., 2014). Climate and environmental change may worsen this situation (Barbieri et al., 2010; Krol et al., 2006; Vieira et al., 2015).

Since the 1980s, Brazil's government intensified the promotion of irrigated agriculture which had started in the 1960s, to stimulate rural development and to reduce rural poverty in the semi-arid Northeast. The construction of several large dams for hydropower generation favored the implementation of irrigation schemes along the lower-middle

São Francisco River. In the case of the Itaparica Reservoir, irrigation schemes were implemented to compensate the affected population from land losses (Andrade, 2011; Camelo Filho, 2011). While irrigated agriculture enabled welfare in some regions (Possídio, 1997), and despite constant development in the whole semi-arid region, many smallholders are still facing lack of access to land, infrastructure, markets, and income alternatives (Sietz et al. 2006). Although smallholders without access to irrigable land are considered most vulnerable population in the semi-arid region (Lindoso et al., 2014), resettled smallholders in the irrigation schemes in the surrounding of the Itaparica Reservoir are facing income security. Supported by the World Bank, the Brazilian government had intended to organize a socially acceptable resettlement process, especially against the background of forced resettlements around 400 km upstream within the Sobradinho dam construction during the military dictatorship. Still, problems mentioned in earlier studies appeared to be persistent (Hagel et al., 2014; Untied, 2005; World Bank, 1998). Detailed analyses on the small scale may help to identify key indicators which are also of use on larger scales or in comparable regions (Birkmann, 2007).

This paper analyses the income situation of smallholders at the Itaparica Reservoir and its interaction with the socio-economic environment at farm level. The first aim was to identify socio-economic key indicators for the situation of smallholders using a qualitative approach. Despite the increasing importance of off-farm activities for income generation, similar to other rural areas in Brazil (Diniz et al., 2013; VanWay and Vithayathil, 2012), farm income still forms the base of most rural households' income in the semi-arid region (Gutiérrez et al., 2014; Sietz, 2014; Untied, 2005). Thus, the second aim was the detailed statistical analysis of the impact of socio-economic and infrastructural indicators on farm income.

3.2 Material and methods

3.2.1 Study site description

The study area is located in Petrolândia municipality, and includes the surrounding irrigation schemes which were built in the context of the Itaparica Reservoir construction at the lower-middle São Francisco river basin in Pernambuco state/Northeast Brazil (Fig. 9, right).

The area is part of the so-called drought polygon (Fig. 9, left). Climate is semi-arid and characterized by a constant average temperature of around 25 °C (Parahyba et al., 2004). Infrequent rainfall and irregularly occurring droughts are influenced by the El Niño

Southern Oscillation (ENSO) phenomenon and the La Niña phenomenon (Hastenrath and Heller, 1977; Nobre and Shukla, 1996). El Niño seasons are characterized by decreased precipitation in the Northeast and consequent reduced yields in agriculture whereas precipitation in Brazil's south tends to increase at the same time. In La Niña seasons, the opposite can be observed (Toni and Holanda Jr., 2008). However, severe drought conditions in the period from 2011 until 2012 occurred during a La Niña season (Rodrigues and McPhaden, 2014). In the last decades, yearly average precipitation was around 340 mm, but during droughts extreme values fall below 100 mm; for instance 55 mm in 1993 and 80 mm in 1998. Years with rainfall significantly more than 500 mm are the exception (930 mm in 1985) (APAC, 2013). Variations in rainfall occur mainly during the rainy season from January to April, whereas in the period from June to October there is almost no rainfall in both, rainy and dry years (Parahyba et al., 2004). Potential annual evapotranspiration of up to 2000 mm intensifies the negative impacts of the aridity (Maneta et al., 2009; Untied, 2005). Teixeira and Bassoi (2009) observed actual evapotranspiration rates of around 1400 mm in areas with regionally relevant fruit crops (banana, grape, mango, and guava). Therewith the study area is located in one of the driest regions of Brazil's semi-arid Northeast (CONDEPE, 1998).

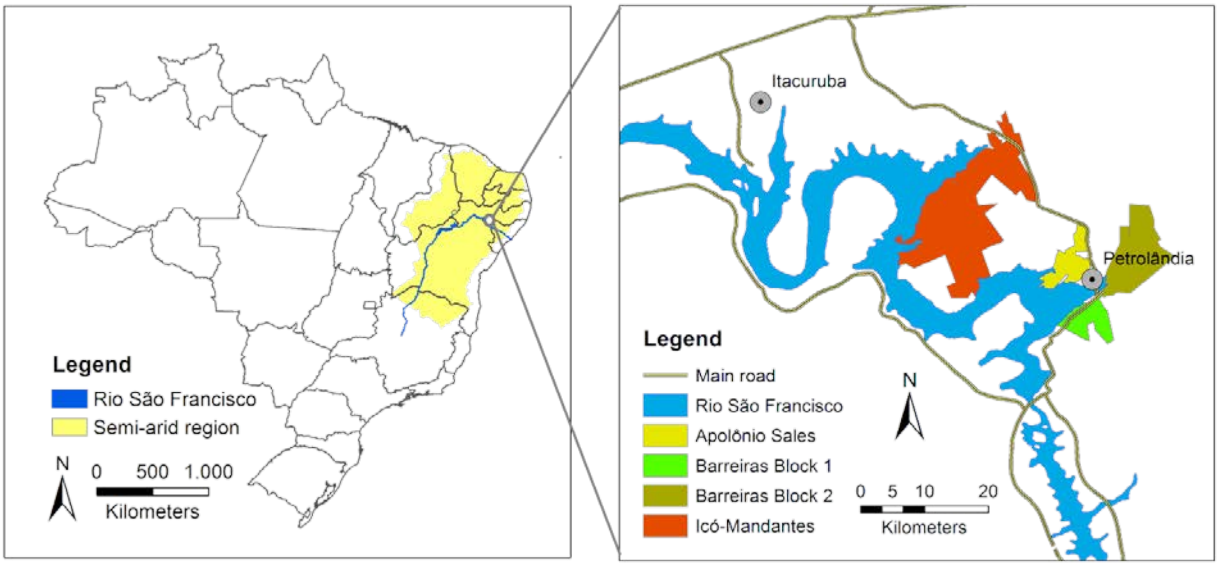

Fig. 9: Location of the investigated irrigation schemes. Source: Own figures after IBGE, 2013a.

Most of the soils in the study region are Arenosols (IUSS Working Group WRB, 2007) derived from sediments of the Jatobá Basin which are characterized by low nutrient availability. Thus, soils in the study region have a naturally low fertility and high water permeability. Other soil types in the region are Ferralsols, Cambisols, and Lixisols derived from fine sediments (Araújo Filho et al., 2013; Parahyba et al., 2004). Even in the irrigation schemes, most of the soils are rather not suitable for agriculture and susceptible to salinization and erosion (Corrêa et al., 2010; Parahyba et al., 2004; World Bank, 1998). Although soils along the lower-middle São Francisco River are rather less fertile than in the rest of the whole river catchment, the main areas of irrigated fruit production are located there. Presence of reservoirs, quite constant temperatures, and additional governmental support favored the implementation of irrigation schemes (Untied, 2005). Natural vegetation of the region is the tropical deciduous scrub forest Caatinga, which is the dominant biome in the semi-arid region of northeast Brazil (Parahyba et al., 2004; Rada, 2013).

Traditional land use consisted of extensive livestock farming, recession agriculture, and marginal rainfed crop production in the hinterlands supported by extensive irrigation systems along the river flood plains (varzea) (Andrade, 2011; Antonino et al., 2005; Damiani, 2003; Sietz et al., 2006). Typical subsistence crops were beans, corn, and cassava (World Bank, 1998). To stimulate development in the Northeast, investments in basic infrastructure such as roads, railways, schools, or wells, had started at the beginning of the 20th century but were slowly intensified from the 1940s (Albuquerque and Cândido, 2011). With the formation of the São Francisco and Parnaíba Valleys Development Company (CODEVASF: Companhia de Desenvolvimento dos Vales do São Francisco e do Parnaíba) in 1973, the state intensified its promotion of irrigated agriculture along the São Francisco River (Camelo Filho, 2011). As mentioned before, the irrigation schemes in the surrounding of the Itaparica Reservoir were built in the framework of the Itaparica Reservoir construction, which was finished in 1988 and affected approximately 10,400 households of which 9,400 were resettled (World Bank, 1998). Dislocated people were resettled into four newly built towns or in one of the 126 so-called "agrovilas" (World Bank, 1998). Agrovilas are small rural villages which are located close to the planned irrigation schemes and equipped with basic infrastructure such as schools, retail trade, health care, and water and electricity (Untied, 2005). To compensate the local population for their flooded land, three big schemes were planned around the newly built Petrolândia: Icó-Mandantes (Block 3 and 4), Barreiras (Block 1 and 2), and Apolônio Sales (Fig. 9, right). A planned area of 5,190 ha irrigated land should provide income for 1,452 families of which 1,099 were resettled into agrovilas (World Bank, 1998). In addition to new dwellings, CHESF promised resettled households irrigated lots between 1.5 ha and 6 ha per family. Assigned lot sizes depended on former land ownership status as well as on number and age of family workers. Households were also promised land for dry farming, consultancy, monthly compensation payments until the first harvest (VMT: “*verba de manutenção temporária*”), and guaranteed commercialization of their yields in the first five years of production. An exception was the scheme Apolônio Sales, where experienced farmers of the former irrigation project Barreiras were resettled. These farmers received lots of 8 ha per household and dwellings directly on their lots instead of in the agrovilas (Untied, 2005; World Bank, 1998).

Due to increased construction costs and because soils in some areas turned out to be not suitable for agriculture, completion of the schemes was delayed. The first scheme, Apolônio Sales, entered production in 1993, Block 3 of Icó-Mandantes in 1994 and Block 4 in 1997. Block 1 of Barreiras had entered production during the study of The World Bank (1998), while Block 2 was still under study (World Bank, 1998). As a consequence of the delayed provision of irrigation water, the VMT was extended (Galvão, 1999). Even 10 years after the resettlement process there were still families receiving VMT (Untied, 2005).

3.2.2 Methods

Secondary data were collected from publicly accessible sources and internal data of local authorities as described in the following. Primary data collection consisted of key informant interviews, field observations, and a household survey with smallholders in the irrigation schemes in the surrounding of Petrolândia. Data were collected during three field trips from 2012 to 2013.

A socio-economic and agricultural profile of Petrolândia municipality was created analyzing demographic and agricultural censuses (IBGE, CONDEPE/FIDEM). Literature review (e. g. Untied, 2005; World Bank, 1998) and reports about agricultural production received from local authorities (CODEVASF) and agricultural consultants (PLANTEC) completed this analysis. Based on this analysis, a guideline for semi-structured key informant interviews was created following established guidelines (Atteslander, 2010; Bernard, 2006; Kumar, 1986; Schnell et al., 2011). The main tasks were to assess the historical and current situation of agriculture in the Itaparica region and to determine the region’s main strengths and weaknesses. During field visits in April and September 2012 and from February until June 2013, sixteen key informants were interviewed on irrigated agriculture and its history in the regions of Itaparica and Petrolina. Selection of key informants considered experts from policy, science, consultancy, and farmers themselves. During first interviews, further key informants were selected by snowball sampling

(Biernacki and Waldorf, 1981; Kumar, 1986). The last interviews provided no additional information, so the sixteen interviews appeared sufficient (Guest et al., 2006). Results were analyzed using content analysis (Mayring, 2010).

According to the interviewed experts most irrigation farming in the study region takes place within irrigation schemes. Few smallholders irrigate with own pumps along the river. Recession farming nearly disappeared since the construction of the reservoir. Rainfed agriculture is practiced extensively on subsistence level, providing only marginal extra income. Thus, the survey focused on production within irrigation schemes. After the first field visit a structured and standardized questionnaire was developed to collect socio-economic, demographic, and agricultural data on farm level. The questionnaire was pre-tested and adjusted with the support of local agricultural consultants during the second field visit in September 2012. Final adjustments and sampling were made in February 2013, supported by local agricultural consultants. For the interviews inside the irrigation schemes, a stratified random sample of 110 of the total 914 households was selected. This sample aimed to cover at least more than 10 % of total households with at least 30 interviews per irrigation scheme. Field survey was conducted by a team of three interviewers consisting of one researcher and two former agricultural consultants with long-time professional experience in the region. Whenever a selected household head was not available for any reason, the next available neighbor was interviewed. In some cases interviews could be completed faster than expected so ten additional were held (n=120). Forty-seven of the interviews were conducted in Icó-Mandantes, 35 in Barreiras, and 32 in Apolônio Sales. Collected data included demographic and socio-economic data as well as details on agricultural production. To acquire reliable information questions on farm production were asked like “How many boxes of coconuts did you harvest on this field?”, “How often do you harvest per week?”, or “How many men do you need for weeding of this lot?”.

The main difficulties during the interviews were disturbances in and limited access to the irrigation schemes. Both problems occurred mainly in Icó-Mandantes and Barreiras. During the study, farmers in the irrigation schemes did not receive any consultancy as the contract between CODEVASF and the consultants of PLANTEC had expired. Farmers were not informed about the bureaucratic process of a contract extension and, understandably, often refused to share detailed information on their production and income with strangers. A shortfall of irrigation water for few days in March 2013 complicated the situation. The bad condition of dirt roads inside the schemes Icó-Mandantes and Barreiras impeded the access to both lots and agrovilas. Due to the increased risk of armed robberies, though not as high as compared to the difficulties described in World Bank (1998) and Untied (2005), interviews were limited to end before dusk, as advised by the local interviewers. Thus, in relation to the statistical population, we conducted more interviews in the safer irrigation scheme Apolônio Sales and less in the scheme Icó-Mandantes.

The farm income was calculated by summing up the contribution margins (CM, revenue less variable costs) per cultivated crop and field in Brazilian Reais (R$) (2013: 1 R$ ≈ 0.5 US$). In the case of perennial crops, only farms with already producing areas were considered. To estimate the present value (PV) of the investments in perennial crops, implementation costs and inputs during the non-productive period of the plantation were summed up. All farmers mentioned that they could not receive credits to implement perennial crop plantations. Limited capital sources for investments were own savings, family members, or a mutual aid system within the neighborhood. Due to the fact that farmers neither did pay nor receive credits for capital, there was no interest rate included in the calculation. As this study aims at analyzing the determinants of various factors on farm income that has already been generated, possible time preferences are not considered. Finally, the PV of the investments was divided by the plantation's useful lifetime and subtracted from the contribution margin.

In the scheme Barreiras, twelve newly established farms were identified. Those farms had recently planted permanent crops which did not yet provide income but required inputs. Earnings from annual intercrops could not compensate the investments and resulted in negative agricultural income. To provide a comparable base of productive farms in this study, these farms were excluded from the statistical analysis. However, data of those farms were useful to check the implementation costs of fruit plantations.

Descriptive and statistical data analyses were conducted using the software Statistical Package for Social Science (IBM SPSS Statistics) version 22. Differences of farm income between the irrigation schemes were tested by analysis of variance (ANOVA) and the more robust Tamhane-T2 test (Tamhane, 1977). It was estimated that farm income depended on crop choice and main socio-economic factors of the interviewed households. Thus, the impact of the following explanatory variables on farm income was tested using ANOVA:

a) Age – Age of the household head in years;

b) Lab_Av – Available family labor in hours per year;

c) TLU – Tropical Livestock Units. All recorded animals were summarized in Tropical Livestock Units as defined in Chilonda and Otte (2006) and Jahnke (1982);

d) Irr_Sch – Location of the household in one of the three irrigation schemes, Apolônio Sales = 1, Barreiras = 2, Icó-Mandantes = 3;

e) Gender – 0 if the household head was male, 1 if female;

f) Job – 0, if agricultural activities were the main profession of the household head, otherwise 1;

g) EduClass – Education based on graduation or visited school years classified in four groups;

h) Ar_*C* – Area of crop $C_{1\text{-}22}$ (includes all recorded crops and fallow areas).

A regression analysis was conducted as well, considering the same variables. As both results were similar, the following chapter solely contains the results of the ANOVA.

3.3 Results

In the first three sections the socio-economic and agricultural situation of Petrolândia and the adjacent irrigation schemes is analyzed based on expert interviews supported by secondary data. In the two following sections, basic information about the interviewed households and the impact of socio-economic and crop choice factors on farm income are presented.

3.3.1 Socio-economic frame conditions

According to the interviewed experts, Petrolândia is relatively wealthy compared to the average of Brazil's semi-arid region - aside from economic centers such as Petrolina/Juazeiro. Socio-economic indicators presented in Table 5 confirm this valuation but also show the gap to Brazil's average which can be seen at the Human Development Index or the illiteracy rate. The low homicide rate for 2011 seems to be below the city's average. In 2011, four homicides were recorded; in 2010 there were eleven homicides and eight in 2009, which would lead to a rate close to semi-arid and Brazilian average (Waiselfisz, 2012). Experts explained the high gross value added per capita with electricity generation in the hydropower plant Luiz Gonzaga. They regarded the hydropower plant to be the main factor for the city's prosperity, confirmed by the 69% share of industry on the gross value added. Still, the agricultural sector is the most relevant one for employment. Modern production methods in irrigated agriculture are reflected in the relatively high rural income. Furthermore, farmers' demand for means of production also influences the urban economy. Retail of fertilizer, agrochemicals, and construction and irrigation material forms a high share of the service sector. Despite the relatively wealthy situation, rural income remains clearly below the legal minimum wage of 510 R$ in 2010 (Presidência da República 2010).

Table 5: Socio-economic profile of Petrolândia (2010)

	Petrolândia	Semi-arid region	Brazil
Area [km²]	1,056.6	979,876.1	8,502,728.3
Population	32,492	22,598,318	190,755,799
Urban	23,621	14003118	160,925,792
Rural	8,871	8595200	29,830,007
Human Development Index	0.623	0.617	0.727
Life expectancy at birth	70.30	71.16	73.94
Homicide rate [a] (2011)	12.16	24.36	27.13
Illiteracy [% adults]	19.57	26.28	10.19
Gini index of income distribution	0.55	0.53	0.6
Gross value added per capita [current R$]	19,500	6,015	16,918
Share agriculture [%]	2.8	9.9	5.3
Share industry [%]	69.3	20.5	28.1
Share services [%]	27.9	69.6	66.6
Share of most relevant economic sectors on employment [%] [b]			
Agriculture	39.53	36.17	14.20
Industry	14.18	15.85	20.49
Services	44.27	44.55	59.12
Per capita income [R$]	419.89	322.78	1,327.91
Urban	464.18	397.88	1,451.34
Rural	296.73	237.71	563.58

[a] Homicide rate = quotient of homicides and population multiplied by 100,000 (Source: Waiselfisz 2012)

[b] Excluded sectors “non-specified activities” and “international organizations”

Data source: IBGE 2010

3.3.2 Agricultural production systems

Similar to the whole semi-arid region, agricultural production outside the irrigation schemes is characterized by subsistence rainfed or irrigated crop production on a small scale, and extensive livestock on large areas. There are 1,006 farms in Petrolândia of which 125 farms operate 5,054 ha ranchland in total. Altogether, 747 farms practice irrigated agriculture on a total area of 3,179 ha. A total of 714 small farms with less than 10 ha irrigated land per farm possess 2,629 ha irrigated land, which equals 80% of the total 3,179 ha irrigated area. Main irrigation technology is sprinkler irrigation (66.78%) with a range of 15 meters, but the use of micro-sprinkler and drip irrigation is increasing. The few farms outside the irrigation schemes usually irrigate by furrow irrigation and mainly cultivate subsistence crops such as beans, maize, and cassava. These crops are also cultivated in a rainfed system on a small scale. Farmers conduct most farm work manually in large part supported by day laborers. Tractors are used for soil preparation and in few cases to support the application of agrochemicals.

After the completion of the irrigation schemes in the mid 90's, irrigated fruit production and therewith harvested area of perennials increased strongly in 1998, as illustrated in Fig. 10 (IBGE, 2013b). On recently planted fruit plantations, farmers cultivate annuals in an intercropping system to generate income until the plantations provide stable yields.

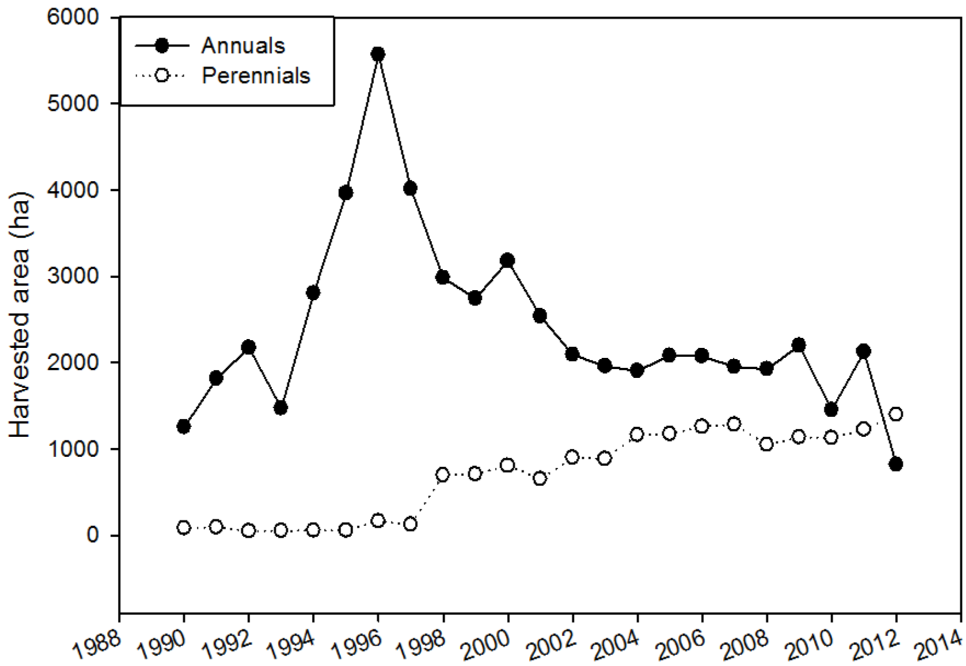

Fig. 10: Development of harvested area of annual and perennial crops.
Source: Own figure after IBGE (2013)

Besides the previously mentioned subsistence crops, watermelon and beans are the main annual cash crops. Perennial crop production concentrates on coconut cultivation, whereas banana and mango are cultivated on smaller scales. Guava production declined heavily because of nematodes but is continued on new lots in Barreiras Block 2.

Agricultural production differs significantly between the irrigation schemes. In Apolônio Sales, most of the irrigable area is used for cultivation (83.24%). The average lot size per household including areas for dwellings is 8 ha as shown in Table 6 (HIDROSONDAS, 2012a-b and 213a-c). Agricultural production concentrates on perennial fruit trees, of which coconut cultivation has the highest share covering more than 80% of the area (Table 7). Farmers grow annuals mainly for own consumption (beans, maize, and cassava) and fodder (maize and forage grass).

Table 6: Situation of the irrigation schemes in 2012

	Icó-Mandantes	Barreiras	Apolônio Sales
Farms	650	163	101
No. of lots	749	188	107
Lot size [ha]	1.5 - 6	1.5 - 6	8 [a]
Irrigable area [ha]	2,187 (100%)	1,154.5 (100%)	825.5 (100%)
Irrigated area [ha]	1,077.15 (49.25%)	483.22 (41.86%)	687.11 (83.24%)
Originally planned area [ha] [b]	2,230	2,366	594

[a] Six of the total lots ranged from 2-4 ha in size.
[b] Source: World Bank (1998)

Source: CODEVASF (2013c), HIDROSONDAS (2012a-b), (2013a-c)

In Icó-Mandantes (49.25%) and Barreiras (41.86%) farmers irrigate less than half of the potential area (Table 6) (HIDROSONDAS, 2012a-b and 213a-c). As illustrated in Table 7, in both irrigation schemes annual crop production dominates. Most relevant cash crops are watermelon and pumpkin (CODEVASF, 2013c). High value crops such as peanut, tomato, and onion, are grown on smaller scales. Maize and beans are typical intercrops on recently planted fruit tree plantations or cultivated for own consumption. The high share of annuals in Barreiras and the low usage of irrigable area are also due to the recent implementation of Barreiras Block 2. For instance farmers had planted perennials on 224.61 ha of which in 2012, only 41.87 ha were producing (CODEVASF, 2013c). Thus, experts assumed that the importance of perennials in Barreiras will increase within the next years. In both schemes the main perennial is coconut complemented by banana and mango cultivation. Agricultural production is characterized by coconut plantations which cover more than 70% of the irrigated area, followed by banana (13.33%), and mango (4.39%).

Table 7: Harvested area of the main crops in the irrigation schemes

	Apolônio Sales		Barreiras		Icó-Mandantes	
Perennials	602.80	(100.00%)	203.86	(100.00%)	457.84	(100%)
Banana	80.36	(13.33%)	30.73	(15.07%)	59.26	(12.45%)
Coconut	491.70	(81.57%)	146.16	(71.70%)	308.19	(64.77%)
Mango	26.44	(4.39%)	3.45	(1.69%)	64.10	(13.47%)
Others	4.30	(0.71%)	23.52	(11.54%)	44.29	(9.31%)
Annuals	47.65	(100.00%)	770.33	(100.00%)	1,611.80	(100.00%)
Beans	9.30	(19.52%)	353.76	(45.92%)	190.55	(11.82%)
Corn	18.70	(39.24%)	79.85	(10.37%)	31.97	(1.98%)
Peanuts	10.05	(21.09%)	6.64	(0.86%)	112.33	(6.97%)
Pumpkin	1.50	(3.15%)	35.90	(4.66%)	523.25	(32.46%)
Watermelon	7.00	(14.69%)	226.78	(29.44%)	573.90	(35.61%)
Others	1.10	(2.31%)	67.40	(8.75%)	179.80	(11.16%)

Source: CODEVASF (2013c)

The drought of 2012 caused high producer prices of annuals leading to high values of production in the schemes Icó-Mandantes and Barreiras. As shown in Fig. 11, prices of the main annuals increased heavily, whereas coconut prices declined (CODEVASF, 2013c). Interviewed experts held yield losses due to the drought in the North and heavy rainfalls in the South at the same time responsible for the increase. For that reason, cultivation of perennials was less profitable compared to annual crop production during the study period. However, in the experts' opinion cultivation of perennial fruit trees is the most profitable alternative in the long term. Main limitation was the high demand for investments until first income is generated.

Reported higher harvested area than the officially indicated irrigated area was due to several possible harvests per year, intercropping, and illegal plantations. One expert, whose father also possessed a lot in Icó-Mandantes, estimated an illegal irrigated area of nearly 1,000 ha solely in Icó-Mandantes. Data of CODEVASF (2013a) seem to be more detailed as most farmers in the irrigation schemes were in close exchange with consultants who conducted the interviews.

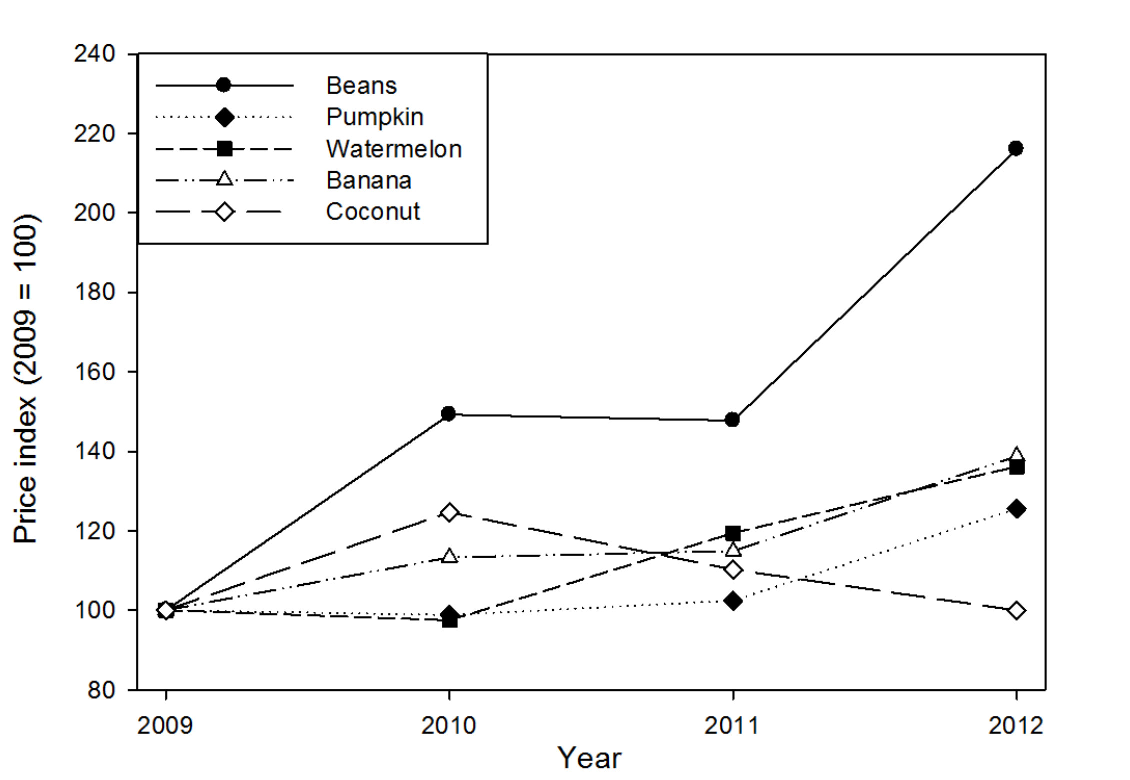

Fig. 11: Price development of the main crops in the irrigation schemes
Source: Own figure after CODEVASF (2013c)

3.3.3 Major problems in the irrigation schemes

Similar to earlier studies of World Bank (1998) and Untied (2005), interviewed experts identified low fertility of the sandy soils and lack of infrastructure with its consequences as the main problems in the irrigation schemes. Sandy soils in the irrigation schemes do not provide high natural fertility and were described as restrictedly suitable for irrigated agriculture. Salinization occurred mainly in the early years favored by high salinity of irrigation water and high evaporation rate. Although installation of drainages reduced this problem, it was still present on a few lots. Besides the permanent lack of fertile soils, lack of infrastructure was the major constraint in the study region. Although experts classified social infrastructure as adequate, they mentioned that infrastructure for agricultural activities was insufficient. Even under good conditions, small lots in the Icó-Mandantes and Barreiras schemes were too small to provide sufficient income to subsist a family. To avoid farmers selling their lots, they did not receive definite land titles. As a consequence, they had little incentive to apply techniques which improve soil fertility. Lack of collateral downgraded the already insufficient access to credits for inputs. Farmers without additional off-farm income or land titles have practically no access to micro-credits. Consequently they rarely invested in their farm, for instance in modern irrigation technologies or crop and site specific fertilizer. The poorer farmers had no capital to invest in perennial fruit trees which would improve income security in the medium and long term. Furthermore they were more vulnerable to volatile yields and producer's prices.

Lack of access to markets hindered the successful commercialization of agricultural products. The closest big producer market is located in Paulo Afonso and around 60 kilometers distant from Petrolândia. Few smallholders possessed sufficient means of transportation and the market was too distant for them to sell their products. National roads were the only transport routes and generally in bad condition. Rides after dawn are considered very dangerous. On national roads as well as inside the irrigation schemes, armed robberies on motorbikes, cars, and trucks happened regularly even though the frequency decreased in the last years. Mobile middlemen were well networked, whereas smallholders hardly cooperated. Thus, the middlemen created a kind of syndicate and dictated producer prices, took over the harvest, and bought agricultural products at farmgate. Thus, they had the opportunity to select parts of the production and even decreased yields by manipulated weights. As farmers had no stocks, they depended on these direct sales for the main part of their yields. Alternatives like selling to governmental programs and small local markets covered only a small share of their production, except in Apolônio Sales where a factory to extract coconut water exists, thus giving marginal additional value apart from the primary production. However, the operator pays the same price or less than the middlemen so there is no major effect on prices. The lack of infrastructure also led to relative high input costs whereby it affected the smallholders on both, production and sale of their yields. Despite the unbalanced market power, there are no well-organized agricultural cooperatives in the study region. Hagel et al. (2015b) analyzed the specific reasons for the failure of agricultural cooperatives and associations in the study region.

Consequences of the delayed provision of irrigation infrastructure were still visible during the study period – 26 years after the planned launch of irrigated crop production. Whereas the Apolônio Sales, Icó-Mandantes, and Barreiras (Block 1) schemes were operating, in Barreiras Block 2 most areas had started producing within the last 1-2 years. In addition farmers in the irrigation schemes were not familiar with new cash crops and irrigation techniques. Especially in Icó-Mandantes and Barreiras, most smallholders were resettled subsistence farmers or former landless day laborers who were not experienced in irrigated cash crop production. Consultancy was generally insufficient and in 2013 even not available.

To avoid disturbances within the schemes and to relieve resettled farmers economically, there was no water pricing system implemented in the irrigation schemes. Water flow meters with detailed information of consumption by lot or farm did not exist. Practically unlimited and uncontrolled water availability created incentives to illegal extension of the irrigated area, especially considering the small lot sizes of most farmers. Delayed availability of irrigation water, infrequent consultancy, lack of land titles, and the overall feeling of injustice during the whole resettlement process provided justification to the illegally expanding farmers. Soils in these areas have not been studied and are often less suitable for irrigation than soils of the officially irrigated areas. Furthermore, there was no drainage for these areas. Soil degradation and salinization were the consequence.

3.3.4 Basic household information of the interviewed households

The main socio-economic indicators of the analyzed 107 established farms, categorized by irrigation scheme, are illustrated in Table 8. Twenty of the 107 considered household heads were females; ten had their main occupation outside of agriculture. Farmers in Apolônio Sales had the largest irrigated areas and generated the highest income, whereas farmers in Icó-Mandantes had the smallest irrigable areas and earned in average less than half of the farmers in Apolônio Sales. High standard deviations indicate high economic inequality within the sample. Farmers with less irrigable areas generated a slightly higher income by area than farmers with more land available. Educational level of the household heads in Apolônio Sales was higher than in the other two schemes which may be due to the historical background of the former landless farmers in the schemes Barreiras and Icó-Mandantes. Livestock played a minor role and was mainly kept for own consumption. It consisted mainly of small ruminants, but also cattle, chicken, pork, quails, and draft animals. The high standard deviation was due to few farmers keeping big herds of small ruminants (0.1 TLU per sheep or goat) or some cattle (0.7 TLU per animal). The recently established farms, which were excluded from this analysis, had planted on an average area of 5.25 ha and cultivated between two and five crops. Main perennial cash crops were coconut and banana. Water melon, beans, and cassava were the main annual crops. Earnings from annual intercrops could not compensate the investments in perennial plantations, what led to negative agricultural income.

Table 8: Income and socio-economic variables of the interviewed households by irrigation scheme

	Apolônio Sales		Barreiras		Icó-Mandantes	
	Mean	SD	Mean	SD	Mean	SD
Profit (R$)	19,848.10	12,924.14	11,759.69	12,045.63	8,033.50	9,388.63
Profit by area (R$/ha)	3,374.25	1,871.29	3,188.27	2,553.29	3,645.75	3,834.67
Irrigable area (ha)	6.97	2.13	4.11	1.48	2.84	1.25
Fallow irr. area (ha)	1.08	1.36	0.56	0.67	0.52	0.84
Age of head (yrs)	52.00	11.63	53.00	10.74	50.00	14.21
Education of head (yrs)	11.00	1.48	7.00	3.24	8.00	3.33
Family labor (hrs/year)	6,731.00	2,660.41	4,946.00	3,952.72	3,249.00	2,931.55
Livestock (TLU) [1]	6.29	13.27	3.23	7.39	2.12	4.72

[1] TLU calculated according to Jahnke (1982) and Chilonda and Otte (2006)

The income distribution shown in Fig. 12 illustrates not only the different economic situation between the irrigation schemes but also the variance within the whole sample. Despite the income gap, with highest incomes in Apolônio Sales and lowest incomes in Icó-Mandantes, the minimum and maximum values as well as the median do not differ strongly between the irrigation schemes. In all schemes, the sample included farmers with practically no profits as well as farmers earning over 50,000 R$ from agricultural activities.

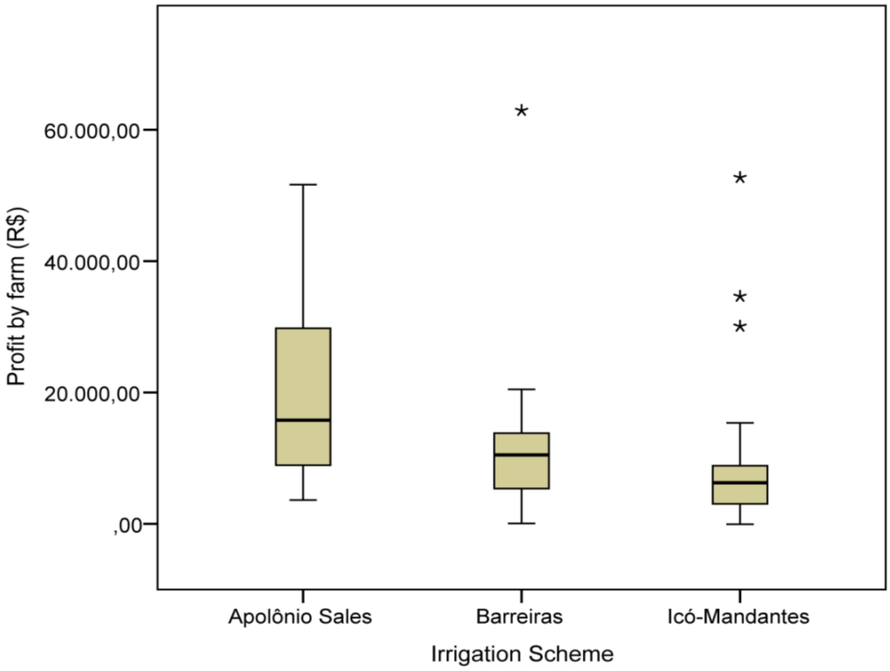

Fig. 12: Distribution of farm income (R$/farm) by irrigation scheme

However, the farmers with high income in Barreiras and Icó-Mandantes were outliers. In Barreiras, the only outlier cultivated mango and guava as high value fruits and achieved high yields at his coconut plantation (27 t/ha). The three outliers in Icó-Mandantes were specialists in high-value, but also high risk, vegetable production (tomato and onion). They belong to a small group of wealthy farmers in the scheme, who could handle the economic risk (especially in tomato cultivation) and the high implementation costs (in onion production). In addition, they benefited from the high prices during the study period.

In line with the descriptive analysis, the mean difference of income in Apolônio Sales in comparison to that in Barreiras and Icó-Mandantes was significant at the 0.05 level, whereas there was no significant difference between Barreiras and Icó-Mandantes as shown in Table 9. The significant difference between Apolônio Sales and the other schemes reflected the available irrigable areas per farm and confirmed the expert's opinion about the situation in the irrigation schemes. Although the difference between Barreiras and Icó-Mandantes was not significant, the higher income in Barreiras was apparent.

Table 9: Differences of the mean income between the irrigation schemes (Tamhane-T2)

(I) Irr Scheme	(J) Irr Scheme	Mean Diff. (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Apolônio Sales	Barreiras	8,088.41*	3,154.75	0.038	331.93	15,844.90
	Icó-Mandantes	11,814.60*	2,615.65	0.000	5,381.99	18,247.21
Barreiras	Apolônio Sales	-8,088.41*	3,154.75	0.038	-15,844.90	-331.93
	Icó-Mandantes	3,726.19	2,639.81	0.417	-2,815.63	10,268.00
Icó-Mandantes	Apolônio Sales	-11,814.60*	2,615.65	0.000	-18,247.21	-5,381.99
	Barreiras	-3,726.19	2,639.81	0.417	-10,268.00	2,815.63

* The mean difference is significant at the 0.05 level.

Interviewed farmers cultivated 21 different crops which are illustrated in Table 10. New plantations, which did not provide yields, were excluded from the calculation.

Table 10: Distribution and economic performance of the assessed crops [1]

Crop	Variable	No. of farms	Total area (ha)	Mean area (ha)	SD	Mean Profit (R$/ha)	SD
Banana	Ar_Ban	33	47.9	1.452	0.8570	3,775.34	1,976.26
Beans	Ar_Bean	22	44.5	2.023	1.2486	2,492.11	1,246.06
Capim	Ar_Cap	3	6.7	2.233	0.6807	1.269,10	927.06
Cashew	Ar_Cash	1	0.8	0.800	-	691.05	-
Coconut	Ar_Coco	62	197.2	3.232	2.0128	1,970.96	2,028.64
Corn	Ar_Corn	20	27.2	1.360	0.5789	905.41	552.55
Grape	Ar_Grape	1	3.5	3.500	-	12,645.12	-
Guava	Ar_Guava	13	16.2	1.242	0.4291	5,536.02	5,040.15
Mango	Ar_Mango	10	11.6	1.160	0.4624	3,954.25	3,433.25
Manioc	Ar_Manioc	6	5.3	0.875	0.4937	4,002.72	2,430.24
Melon	Ar_Melon	2	3.5	1.750	0.3536	4,974.49	438.38
Onion	Ar_Onion	4	5.5	1.375	0.7500	10,278.33	5,443.05
Papaya	Ar_Papa	4	4.6	1.138	0.1601	1,823.89	2,090.67
Paprika	Ar_Papr	3	1.8	0.600	0.3606	-169.31	726.11
Passion Fruit	Ar_PFruit	1	1.0	1.000	-	9,596.49	-
Peanuts	Ar_Pean	3	2.5	0.833	0.2887	1,806.15	923.27
Pumpkin	Ar_Pump	8	10.6	1.319	0.2902	2,369.25	1,806.33
Tomato	Ar_Toma	2	2.3	1.150	1.2021	26,604.43	6,246.55
Water melon	Ar_WMel	21	46.3	2.204	1.3314	3,099.44	1,545.30
Zucchini	Ar_Zucc	1	1.5	1.500	-	6,92 9.19	-
Fallow	Ar_Fallow	50	75.9	1.520	1.0374	-	-

[1] Lots with ongoing production were considered

Similar to the irrigation schemes, coconut cultivation dominated but appeared to be overrepresented in the sample. It was followed by banana, beans, water melon, and corn. Thirteen farmers cultivated the high value annuals mango and guava. The gap between profits of the main annuals, banana, and coconut were due to the price situation (Fig. 11). Profits of the high-value fruits mango and papaya were unequally distributed in favor of the Apolônio Sales and Barreiras irrigation schemes.

Despite high prices during the study period, only a few farmers cultivated the high value vegetables onion and tomato. High risks, caused by high implementation costs and high risk of crop failure, and attractive production alternatives for wealthy farmers (mango, guava, papaya, and grapes) discouraged farmers to cultivate these crops.

3.3.5 Factors influencing farm income

The influence of the main socio-economic factors and crop area on the farm income tested by ANOVA is presented in Table 11. Considering all integrated factors, 77.1 % of the total variance could be explained (R^2 0.771, adjusted R^2 0.632). As expected, variables related to cultivated area had the highest impact on farm profits. High value cash crops, especially tomato, onion, and grape, had the highest impact on farm income. Beans seem to have a high impact in relation to profits and area but were often cultivated as intercrop and therewith added value to already planted areas. The low impact of coconut, despite its cultivation on large areas, may be due to the relatively low price during the study period and the high variance of its profits. Contrary to the results from expert interviews and the descriptive statistics as shown in Fig. 12, the irrigation scheme had no significant impact on farm income but, due to the high education level in Apolônio Sales, an interaction with education class effect could be observed. However, removing the outliers may increase the effect of irrigation scheme. The socio-economic factors age, gender, job alternative, and available family labor had no significant impact on the farm income.

Table 11: Test of Between-Subject Effects, dependent variable profit by farm

Source	Type III SSQ	df	Mean Square	F	Sig.	ETA-squ.
Corrected Model	12184843825,055[a]	40	304621095,626	5,553	,000	,771
Intercept	6489909,275	1	6489909,275	,118	,732	,002
Age	349239,698	1	349239,698	,006	,937	,000
Lab_Av	23812489,196	1	23812489,196	,434	,512	,007
TLU	65421174,699	1	65421174,699	1,193	,279	,018
Ar_Fallow	13920110,083	1	13920110,083	,254	,616	,004
Ar_Ban	221553980,614	1	221553980,614	4,039	,049	,058
Ar_Bean	712451599,533	1	712451599,533	12,987	,001	,164
Ar_Cap	474171,976	1	474171,976	,009	,926	,000
Ar_Cash	259408,704	1	259408,704	,005	,945	,000

Table 11: Continued

Ar_Coco	142664766,726	1	142664766,726	2,601	,112	,038
Ar_Corn	195810067,321	1	195810067,321	3,569	,063	,051
Ar_Grape	933379976,431	1	933379976,431	17,014	,000	,205
Ar_Guava	21512464,565	1	21512464,565	,392	,533	,006
Ar_Mango	239192173,655	1	239192173,655	4,360	,041	,062
Ar_Manioc	84381842,731	1	84381842,731	1,538	,219	,023
Ar_Melon	151340434,498	1	151340434,498	2,759	,101	,040
Ar_Onion	1515193018,649	1	1515193018,649	27,620	,000	,295
Ar_Papa	13180956,916	1	13180956,916	,240	,626	,004
Ar_Papr	158075818,969	1	158075818,969	2,882	,094	,042
Ar_PFruit	413322873,103	1	413322873,103	7,534	,008	,102
Ar_Pean	42775676,925	1	42775676,925	,780	,380	,012
Ar_Pump	18348503,789	1	18348503,789	,334	,565	,005
Ar_Toma	1736609800,703	1	1736609800,703	31,656	,000	,324
Ar_WMel	360892450,860	1	360892450,860	6,579	,013	,091
Ar_Zucc	71616137,006	1	71616137,006	1,305	,257	,019
Irr_Sch	26575879,338	2	13287939,669	,242	,786	,007
Gender	22353750,512	1	22353750,512	,407	,525	,006
Job	3045763,614	1	3045763,614	,056	,814	,001
EduClass	112209757,004	2	56104878,502	1,023	,365	,030
Irr_Sch*Gender	218325181,855	2	109162590,928	1,990	,145	,057
Irr_Sch*EduClass	600966874,486	3	200322291,495	3,652	,017	,142
Gender*Job	186490,265	1	186490,265	,003	,954	,000
Gender*EduClass	214174371,665	2	107087185,832	1,952	,150	,056
Job*EduClass	372929019,822	1	372929019,822	6,798	,011	,093
Error	3620625281,599	66	54857958,812			
Total	33139478623,603	107				
Corrected Total	15805469106,654	106				

a. R Squared = .771 (Adjusted R Squared = .632)

3.4 Discussion

3.4.1 Insufficient infrastructure and unequal land distribution affect smallholders' livelihoods

The main constraints for smallholders were due to insufficient infrastructure and unequal land distribution. Several studies (Rada, 2013; Teruel and Kuroda, 2005; Untied 2005; Ut et al., 2000) underline the role of improvements of infrastructure for rural development. Low market power and the resulting high input costs and low producer prices, lack of commercialization alternatives, and missing storage capacities directly reduce the smallholders' income. Although experts and several farmers mentioned that the situation had improved in recent years, the fundamental problem did not differ from the one in previous studies (Untied, 2005; World Bank, 1998). Producer prices of the main perennial crops were far below the Brazilian and northeastern average as shown in Table 12. Despite decrease of rural criminality in the study region and overall Northeast Brazil (Scorzafave et al., 2015), armed robberies on the national roads still contribute to limited market access.

Table 12: Average prices of main perennial crops in the period from 2009 to 2012 in R$/kg

Crop	Irrigation schemes [a]	Petrolândia [b]	Northeast Brazil [b]	Brazil [b]
Banana	0.56	0.53	1.91	1.81
Coconut	0.22	0.12	0.95	0.94
Guava	0.61	0.52	1.30	1.27
Mango	0.41	0.49	1.98	1.92

Source: Own calculations after Codevasf (2013) [a] and IBGE (2013) [b]

Irrigated land appeared to be relatively equally distributed compared to pasture or arable land in general, especially when considering farms with areas up to ten hectares of irrigated land as small farms. Analyzing the irrigation schemes, a gap between Apolônio Sales and the other two schemes became clear. Additionally, statements of several farmers indicated a less than equal land distribution, as some farmers possessed several farms that were, on paper, run by relatives. Unequal land distribution was expectable in the light of the national content (Paulino, 2014) and the historical background of the region affected by corruption and clientelism (Andrade, 2011; Kenny, 2010). Since most interviewed farmers lacked land titles and therewith faced limited access to credits, only influential and wealthy farmers had the opportunity to increase their areas legally. On the one hand, several studies (Andrade, 2011; Berry and Cline, 1979; Cline, 1970) discuss the inverse relationship of farm size and productivity in Northeast Brazil. However, intensive cultivation combined with low capital availability to invest in soil fertility maintenance may lead to soil degradation on the long term. Sietz et al. (2006) also mention the high risk of resource overuse due to scarcity of irrigable land. The risk of land degradation is pointed out by Toni and Holanda Jr. (2008) discussing the negative impact of missing titles on investments in the area, such as measures to maintain soil fertility or water saving irrigation technologies. The impact of unequal land tenure on rural emigration is also well known (Shaw, 1974; Toni and Holanda Jr., 2008). Insufficient access to credits due to lack of land titles, aggravates this problem. Consequently, poor farmers were most affected by the insufficient infrastructure and the unequal land distribution.

3.4.2 Natural and economic developments increase pressure on irrigable areas

Agricultural production focused on few crops, mainly coconut. Especially owners of small areas with no capital available did not have sufficient opportunities to diversify their production. This increased vulnerability to price volatility which was a regular issue in the study region (Fig. 11) (Hagel et al., 2014). Low prices, as in the case of coconut during the study period, may reduce the low propensity to invest in farm infrastructure. Besides value adding activities, commercialization of crop residues may increase profitability of coconut production. For instance, Brígida et al. (2010) investigated the alternative uses of the fiber from green coconut.

High prices of most crops during the study period led to high farm income in comparison to the study of Untied (2005). Nevertheless, the mean income in Icó-Mandantes, although overrated by outliers (Fig. 12), provided an income from around 8,000 R$ per household and year, which nearly equals the minimum salary of 678.00 R$ per month in the year 2013 (Presidência da República, 2012). The low economic attractiveness of farming may lead to migration from the irrigation schemes and favor concentration of land ownership. Price shocks may reduce this relatively low attractiveness of agricultural activities in favor of off-farm activities. Sietz et al. (2006) identify price fluctuations and droughts as important reasons for poverty in the semi-arid region. Considering the particular price situation during the study period, the mean income gap between Apolônio Sales and the other two schemes may be bigger than the one identified in this study.

The effects of droughts on agricultural production can be estimated based on the harvested area of annual crops (Fig. 10). The drop in harvested area for 1993, 1997 to 1998, 2010, and 2012 occurred during severe droughts (Finan and Nelson, 2001; Gutiérrez et al., 2014). According to interviewed experts, all rainfed areas were affected and crops yielded solely on irrigated lots. As most yields of perennial crops in Petrolândia were produced on irrigated areas, the drought of 2012 hardly affected their agricultural production. However, yield losses on non-irrigated areas and high prices due to the declined supply led to intensified production of annuals on irrigated areas and illegal expansion to the adjacent Caatinga. Still, Damiani (2003) indicates positive effects of irrigated agriculture to off-farm income opportunities.

3.4.3 Impacts on farm income

As expected, crop choice had the highest influence on farm income, whereas socio-economic variables and irrigation scheme had no significant effect. During the interviews the impression arose that personal attributes related to self-esteem, charisma, and negotiating skills combined with (political) influence, wealth, and experience in irrigated cash crop production may have the highest impact on farm income. To support inexperienced farmers in regard to crop choice, cultivation methods, business administration, and reintroduction of agricultural extension appears to be necessary (Hagel et al., 2014), especially considering the preference of many smallholders towards traditional crops (Scott, 2004). Although there was no significant impact, the number of TLU and education class had higher effects (ETA-squared) on farm income than the other socio-economic variables. Several statements during the interviews indicated the importance of personal preference for livestock farming. Siegmund-Schultze et al. (2007) identified the role of cattle as instrument of finance which was in line with statements of interviewees with preferences for livestock in this study. To keep animals, farmers need capital for the purchase and areas to grow fodder or at least provide sufficient crop residues. So it can be estimated that wealthier farmers could afford bigger herds as well as they had more irrigated lots and could afford inputs of better quality. The high standard deviations in the stocking rates (Table 8) indicate that few farmers possessed relatively large herds and underline this explanation. Absurdly, the poor farmers who are more vulnerable to droughts would benefit the most from this production alternative that is less susceptible to droughts (Coutinho et al., 2013). The relatively high effect size of education can even be qualified by the interaction with irrigation scheme, and therefore imply effects of the irrigation scheme on farm income. Although the analysis did not indicate a significant impact of education, interviewed experts and farmers underlined the complexity of high value cash crop production, especially in perennial crop production with investments over more than ten years, where business skills are necessary. De Lima and Lopes (2011) discuss the importance of education for economic independence, Phillips (1994) and VanWey and Vithayathil (2012) underline the role of education and social capital on agricultural productivity and off-farm activities, and Finan and Nelson (2001) argue that less educated farmers with small areas are the most vulnerable ones in the semi-arid region of northeast Brazil. An example of this was observed with one of the interviewed farmers; the first son worked as a professor and the second one had run a small business before he returned to the irrigation scheme. However, this reveals a limitation of this study. Due to limited time for each interview, mainly the head of each interviewed household was considered. In this case, the high qualification of both sons and the regular and high monthly income of the older son were not considered, whereas relative financial independence may strongly increase the bargaining power and facilitate investments in the agricultural production. The role of income alternatives requires further research, especially considering the development, that Brazilian rural households diversify their income sources, which reduces risk of major income losses during droughts (Graziano da Silva and Eduardo Del Grossi, 2001).

3.5 Conclusions

This study contributes to literature (Untied 2005; World Bank, 1998) analyzing the farm income of smallholders in irrigation schemes at the Itaparica reservoir in detail. Farm income appears to be relatively high in comparison to low and normal price periods but, in many cases, is still below the minimum salary. Sufficient area of irrigable land seems crucial to provide sufficient income; an optimal land allocation of the scarce areas appears necessary. To avoid an overuse of natural resources, income increases should rather result from increased producer prices or decreased input costs than from intensified land use on the scarce irrigable areas, especially considering the semi-arid character of the study region. Therefore, the role of agricultural cooperatives and value adding facilities should be strengthened and, in general, infrastructure around the irrigation schemes should be improved (Hagel et al., 2015). Value-adding facilities may also contribute to create off-farm income alternatives, which may reduce the pressure on natural resources (Holden, 2001). However, high input costs can be seen as an opportunity to reduce fertilizer and pesticide application, given appropriate agricultural consultancy. Otherwise, reduced input costs and increased producer prices may minimize the incentives towards reduced input use and more sustainable production methods (De Souza Filho et al., 1999).

Acknowledgements

This study was conducted within the project “INNOVATE” (01LL0904C) and funded by the Federal Ministry of Education and Research (BMBF; Sustainable Land Management program). The authors would also like to thank all farmers who patiently participated at the interviews.

Chapter 4. The situation and perspectives of agricultural cooperatives in the surrounding of the Itaparica Reservoir in Northeast Brazil[5]

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Abstract

Over 20 years after the implementation of irrigation schemes in the surrounding area of the Itaparica Reservoir, in the semi-arid region of Northeast Brazil, insufficient infra-structure and low market power still impact smallholders' incomes and development of market strategies to support rental increase from the smallholders. Lack of access to credit, high input costs, and low producer prices for major crops have helped to maintain the poverty status of smallholders that equally affects small agricultural producers like cattle breeders. Agricultural cooperatives have contributed to increase their members' market power in agricultural commerce and facilitate their access to credits and agricul-tural extension. To analyze the historical background of this situation, as well as the potentials and constraints of agricultural cooperatives and associations, 24 qualitative

[5] **A version of this chapter has been published as:**

Hagel, H., Zavaleta Huerta, L.R., Hoffmann, C., Reiber, C., Ferreira Irmão, J., Doluschitz, R. The situation and perspectives of agricultural cooperatives in the surrounding of the Itaparica Reservoir in Northeast Brazil. In: Revista Brasileira de Ciências Ambientais – RBCIAMB, 36, 2015, 19-30. doi: 10.18461/ijfsd.v5i4.542

expert interviews were conducted among members of cooperatives or associations and consultants involved with technical assistance to smallholders. During the study period, no active agricultural cooperatives could be identified. Financial problems related with lack of financial resources, inadequate government support, absence of leadership and poor organization, and missing solidarity and mistrust were considered the main reasons for the cooperatives' poor situation. However, the potentials of cooperatives are illustrated by the efficiency of fishery and apiculture associations.

Keywords

Agriculture, cooperatives, Itaparica reservoir, semi-arid region

Resumo

Com mais de 20 anos da implementação dos projetos de irrigação no entorno do Reservatório de Itaparica, no Semiárido Nordestino, uma infraestrutura insuficiente e um baixo poder de mercado ainda impactam os rendimentos de pequenos proprietários e do desenvolvimento de estratégias de mercado para apoio ao aumento de renda dos pequenos produtores. A falta de acesso ao crédito, os elevados preços dos insumos e os baixos preços dos produtos agrícolas têm contribuído para manutenção do status de pobreza que a afeta tanto os pequenos produtores agrícolas como os pequenos pecuaristas. As cooperativas agrícolas têm contribuído para aumentar o poder de barganha na comercialização agrícola e facilitar o acesso ao crédito e à extensão rural. Com o objetivo de analisar a história dessa situação, os potenciais e as restrições das cooperativas e associações, foram aplicados 24 questionários aos técnicos envolvidos na assistência técnica aos pequenos produtores. Por ocasião deste estudo, não foram identificadas cooperativas em ação na região. Problemas relacionados com a falta de recursos financeiros, falta de apoio dos governos, falta de liderança e organização, desconfiança e descrédito na eficácia das cooperativas foram as principais razões para esse baixo desempenho das cooperativas. No entanto, o potencial impacto das cooperativas pode ser ilustrado pela eficácia das associações de pescadores e de apicultores.

Palavras-chave

Agricultura, cooperativas, Reservatório de Itaparica, semiárido

4.1 Introduction

Since the 1950s, Brazil's government and governmental authorities promoted the construction of several dams and reservoirs along the São Francisco River for hydroelectricity generation (World Bank, 1998). These processes involved the promotion of irrigated agriculture to compensate local people for flooded land and reduce the traditionally high poverty in the semi-arid region (Camelo Filho, 2011). Despite significant progress in poverty reduction in the recent decades (Rocha et al., 2012), the income level in the region is far below the national average. Around 61% of the local population is still classified as vulnerable to poverty[6] (ATLAS Brasil, 2013).

The situation in the irrigation schemes around the Itaparica Reservoir represents many aspects of the situation that family farmers face in the semi-arid region. After the construction of the reservoir, local smallholders and formerly landless laborers received irrigated land inside irrigation schemes (The World Bank, 1998). Due to several complications during the implementation, soils with low fertility and lack of infrastructure, many smallholders still live in poverty even after more than 20 years after the first irrigation schemes went into production (Da Costa, 2010; Untied, 2005). Despite indirect subsidies in the form of free irrigation water, returns from most crops are still low and depend on low wages for day laborers (Hagel et al., 2014).

Especially in the semi-arid Northeast with an agrarian structure characterized by a high share of small family farmers, agricultural cooperatives have the potential to improve small farmers' access to several means of production, markets for product commercialization, credits, and information and extension (Sabourin et al., 2004). Untied (2005) identified these issues as the major constraints of smallholders around the Itaparica Reservoir. When implementing the irrigation schemes of the Itaparica system, the dam operator CHESF (São Francisco's Hydroelectric Company) attempted to establish agricultural cooperatives. Although many farmers were organized in cooperatives and associations at the beginning, most of them were not satisfied with their support and so their influence was declining constantly (Untied, 2005). In 2006, 80% of the 8,724 farmers in the Itaparica region were not organized in any kind of association (IBGE, 2006).

Regardless, the potential of agricultural cooperatives were emphasized at the 2012 World Food Day "Agricultural cooperatives: key to feeding the world" at the University

[6] People earning less than R$ 255.00 (R$ of August 2010) where defined as vulnerable to poverty

of Hohenheim (Da Silva, 2012) and more recently by Altman (2015). The National Service of Learning about Cooperatives (SESCOOP) constantly registers increasing members of cooperatives (SESCOOP, 2012). Ribeiro et al. (2013) illustrate the benefits of agricultural cooperatives for family farmers in the municipality of Petrolina, around 300 km from the Itaparica Reservoir. Thus, this study intends to assess and analyze the historical and actual situation of agricultural and livestock cooperatives within the irrigation schemes around the Itaparica Reservoir, analyze the reasons for their success and failure, and identify their recent developments and potentials.

4.2 Material and methods

4.2.1 Study area

The study was conducted in Petrolândia, in Pernambuco state, and the three irrigation schemes within and around the municipality – Apolônio Sales, Icó-Mandantes (Block 3 and 4), and Barreiras (Block 1 and 2)[7]. The irrigation schemes were implemented in the late 1980s during the construction of the Itaparica Reservoir, to compensate about 4,900 rural families for flooded land (excluding around 1,000 so-called "para-rurals" who had moved to town, but retained the right to an irrigated lot). Due to administrative difficulties and unsuitable soils, all schemes were operational with a delay of many years and went into production in the mid and late 1990s (World Bank, 1998). During the study period in 2013, the last irrigation scheme – Barreiras Block 2 – had just recently started operations.

Irrigated land in the study area is relatively equally distributed. In Petrolândia, 83% of the total irrigated area (3,179 ha) belongs to the 714 farms (96% of total farms) with each possessing less than 10 ha (IBGE, 2006). Despite the seemingly equal distribution, the irrigation schemes differ by history, farm size, infrastructure, main crops, and production methods. The irrigation schemes Icó-Mandantes and Barreiras Block 2 are partially located in the municipalities of Floresta and Tacaratu respectively, but without significant influence on the structure of land distribution. In general, main perennial crops are coconut and banana; main annual crops are the subsistence crops beans, maize, and cassava. Watermelon and pumpkin are the main annual cash crops in the region (Ferreira Irmão et al., 2013).

[7] 2Before the dam construction there had been an irrigation project called Barreiras, which should not be mistaken for the new irrigation schemes Barreiras Block 1 and 2. References to the former project (flooded nowadays) are indicated by "Old Barreiras".

4.2.2 Data collection and analysis

Data were collected from March to May 2013 by semi-structured qualitative in-depth expert interviews following the guidelines of Atteslander (2010). The interview guideline was adapted to regional characteristics and supported by former agricultural consultants in the region. After the identification of the first experts in Petrolândia, further experts were found during the first interviews by snowball sampling. In total, 24 expert interviews were conducted representing experts from several institutions as illustrated in Table 13. To achieve a representative insight into the potential of agricultural cooperatives, three interviews were held in Curitiba, in the state of Paraná, which serves as an example for the successful implementation and promotion of agricultural cooperatives to empower relatively small family farmers (see also Ritossa and Bulgacov, 2009). All interviews were recorded with permission of the interviewees.

Table 13: Interviewed experts by category and interview location

Location	Category of expert	No. of interviews
Petrolândia/PE	Members of agricultural or livestock cooperatives	6
	Members of agricultural or livestock associations	7
	Members of the farmworker union	1
	Agricultural consultants	3
	Local authorities	3
Recife and Curitiba	Members of cooperative unions	3
Curitiba	Scientist	1
	Total	24

Data were analyzed using methods of the qualitative content analysis according to Atteslander (2010) and Mayring (2010). Retrieved information was coded and categorized in several steps and allocated to the research questions. Coding and categorizing allows the (quantitative) illustration of qualitative data and facilitates the analysis, interpretation, and the reproducibility of the study.

4.3 Results

4.3.1 Overview on the situation of agricultural cooperatives in Northeast Brazil

The analysis of the situation of agricultural cooperatives in the study region requires a general understanding of the history and situation of cooperatives in the Northeast of Brazil. Research from other sources and the two expert interviews in Recife provided the necessary information. Derr (2013) discusses the history of cooperatives in Brazil in detail. The interviews in Curitiba completed the findings and helped to widen the perspective considering the national context. In the South and Southeast of Brazil, agricultural cooperatives achieved high economic and social relevance. European and Asian immigrants owning small farms imported the ideals and values of cooperatives to the region. Favorable climate for agricultural activities, cash availability, high educational attainment of the rural population, economic growth in the region, and governmental support, such as the cooperative union of the state of Paraná (OCEPAR) favored this development (Duarte and Wehrmann, 2006).

In contrast to the development in the South and Southeast regions, agricultural cooperatives in the Northeast were facing various difficulties. Though Ribero et al. (2013) name the state of Pernambuco a precursor of cooperatives in Brazil, the interviewed experts and several authors mentioned that agricultural cooperatives were often misused in a system of clientelism to preserve the uneven balance of power. The first agricultural cooperatives were founded by owners of large or medium properties or politicians in order to receive governmental funds (Duarte and Wehrmann, 2006; Sabourin, 1999). Cooperatives founded by the government or governmental authorities later failed because their members did not identify strongly with the organization. The low levels of education of the rural population, unfavorable conditions for a reliable agricultural production due to droughts, farmers' lack of capital, and urbanization aggravated the situation. Despite these difficulties, there are positive examples of agricultural cooperatives in the more prosperous area around Petrolina such as COANA, COOPEXFRUIT, COOPEX VALE, or the farmers' association APRNVI analyzed by Ribeiro et al. (2013).

Interviewed experts mentioned the successful implementation of agricultural cooperation a slow process that requires, above all, the education and training of potential members to understand the benefits and invest their potential and human resources in the cooperative. The clear understanding that the cooperative belongs to all its members is crucial to reach identification with and confidence in the cooperative.

4.3.2 Actual situation of agricultural and livestock cooperatives in the study region

In the study region, three agricultural cooperatives and four agricultural associations could be identified with having 571 members in total, as illustrated in Table 14. All three cooperatives had been founded in the late 1990s when the irrigation schemes went into production. Their main tasks were the commercialization of agricultural and livestock products, collective purchase and cost reduction of means of production, improvement of credit accessibility, and provision of agricultural extension. During the instruction phase, the cooperatives received financial support by CHESF and sold the agricultural products of their members, especially green coconuts and guava, at the central markets (CEASA) in Recife and Caruaru. Although they achieved higher prices than with sales directly from the field, they stopped their activities after the financial support expired. During the study period, all identified agricultural cooperatives were inactive.

Table 14: Agricultural and livestock cooperatives and associations in the study region in 2013

Type of cooperation	Name of organization	Location	No. of members
Agricultural cooperative	COOPBARREIRAS	Barreiras Block 1 & 2	40
	CAPIM	Icó-Mandantes	ca. 260
	COOPERAGRI	Icó-Mandantes	80
Agricultural association	AAFE	Barreiras Block 1	18
	ACAMP	Apolônio Sales	100
Association of beekeepers	APIMA	Icó-Mandantes	23
Association of small ruminant breeders	ASCOPETRO	Petrolândia	50

In contrast to the inactive agricultural cooperatives, four smaller associations related to agricultural or livestock activities could be identified. With the exception of the ACAMP association in the irrigation scheme Apolônio Sales, these associations were founded in the period from 2000 (AAFE) to 2012 (ASCOPETRO) resulting from the lack of organization of smallholders and livestock farmers. ACAMP, founded in 1986 by the residents of Old Barreiras, is the oldest association in the study region. Its objective was to represent its members in the conflict with CHESF to receive more irrigated land and houses directly at the lots. During the study period, around 50 of the 100 members were regularly participating at meetings. Despite formal activities like regular meetings, no association was involved in any common economic activities. Cooperative support, such as provision of seedlings, residues from crop production as fodder, or the trade of manure, existed exclusively in friendly or family relations. Only APIMA, the association of beekeepers and farmers in Icó-Mandantes, merchandized honey under a common label. This association received technical support from the city of Petrolândia. To ensure its success in the future, interested farmers undergo a trial phase before they can become regular members. During the study period, there were 17 members on trial which was interpreted as an indicator of the success of the association. Due to its recent formation, the association of livestock farmers ASCOPETRO was yet to organize common sales and purchases, while support for the members consisted mainly of technical consultancy and organized support by veterinarians.

Along São Francisco’s riverbank, there were eight fishery associations of which four were active and four waiting for a credit assignment. Active associations organized common sales and purchases of means of production. Each association accepted 12 members maximum. These associations were not included in the study, but served as a positive example for the successful implementation organized by the city of Petrolândia involving the potential members who had participated in workshops and seminars about cooperatives in advance.

4.3.3 Constraints of agricultural and livestock unions

Interviewed experts identified six main reasons for the failed implementation of agricultural cooperatives, which are illustrated in Fig. 13. The most mentioned reason, which is lack of capital, occurred after CHESF stopped the regular payments, contextualizing its background in the history of the cooperatives’ implementation. The experts even assumed that the cooperatives had been founded exclusively to receive payments without trade-off. Consequently, there was no incentive to generate its own income, and common commercialization of produced commodities was not even considered.

After the expiration of the payments, common property, such as electronic devices and furniture, were sold and the cooperatives were declared inactive. Lack of access to credits, mainly due to bureaucratic reasons, had inhibited necessary structural improvements to start economic activities to continue any kind of cooperative activity. In the case of the smaller associations, common activities failed due to members’ lack of capital. For example, the association AAFE had once tried to organize common purchases of means of productions, but failed because several members had no capital available.

Seven of the 24 interviewees mentioned that cooperatives in the region failed because they did not receive any governmental support. None of the interviewed members or chairpersons of cooperatives or associations knew about governmental programs like the state-run SESCOOP-PE or the "Incubadora de Cooperativas" of the Federal Rural University of Pernambuco. Such programs provide seminars and workshops to communicate the knowledge and benefits of cooperatives. Most programs are developed in the state capital Recife and do not reach communities in the semiarid interior.

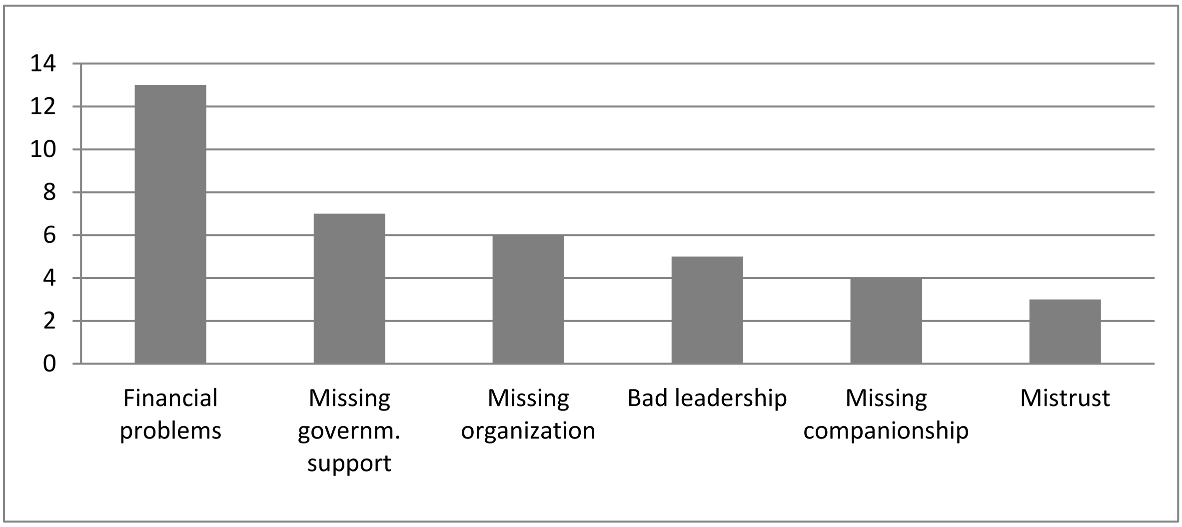

Fig. 13: Mentioned reasons for the failure of agricultural cooperatives and associations

The other four reasons can be summarized as lack of human capital. Lack of organization and leadership is a consequence of the knowledge gap about cooperatives and associations, aggravated by the general lower educational level in the semi-arid region compared to the coastal areas. Four experts shared the opinion that individualism and egoism prevented any success of cooperatives or associations. This lack of successful examples or individual failures, such as the earlier mentioned common purchase issue by the association AFEE, led to mistrust in such institutions, which is affirmed by the past failure of the other cooperatives.

4.3.4 Lack of market access and potentials for cooperatives and associations

Despite the past failure and actual inactivity of agricultural cooperatives and associations in the study region, experts underlined the potentials and crucial factors for a successful implementation of such organizations. Low market power and limited access to credits represented the main constraints for small family farmers in the study region.

Thus, the interviewed experts indicated the main potentials of farmer organizations lie in improved commercialization, common purchases of means of production, improved access to credits, sharing farm equipment, and purchase of high quality feed.

All experts interviewed in the study region mentioned the commercialization structure as the main constraint for farmers' income generation. Since the analysis of marketing structures in the irrigation schemes around the Itaparica reservoir by Untied (2005), only a few changes were observed. Most agricultural commodities are still sold to middlemen directly on the field because most farmers do not own the means of transportation for their products and, consequently, lack alternatives to commercialize their products. Due to the lack of commercialization opportunities, middlemen dominate the market comparable to monopolies, dictate producer prices, and even bring manipulated scales when collecting yields from the farmers. They also decide the sale conditions and frequently modify them after, usually verbal, contract conclusion. The middlemen even often organize harvests, which reduces the farmers' added value and provides the middlemen additional opportunities to manipulate the yields. Promised payments after resale can be reduced and parts of the harvest rejected and left on the field. The local farmer's market does not provide sufficient demand because of the low population. Furthermore, family farmers do not have the capacity to run a sales booth. The Brazilian Food Purchase Program (PAA) and School Feeding Program (PNAE) offer higher prices, but purchase small amounts, so few farmers sell small parts of their production to these programs. A coconut water factory in Apolônio Sales is the only relevant processing facility in the study region. Despite its vicinity to irrigated plots, most farmers cannot sell directly to the factory because they lack means of transportation.

Animals are also usually sold via middlemen due to lack of alternatives. Middlemen buy animals directly at the farm and resell them at the market or directly to slaughterhouses which sell the meat directly to the local supermarkets. Similar to the case of agricultural products, scales are manipulated to reduce producer prices. In the case of weighing at the slaughterhouse, farmers have few chances to control the weight. Few animals are sold directly at the farmers' market. Farmers slaughter solely for own consumption or sell small amounts in the neighborhood.

Due to the middlemen issue, interviewed experts identified the biggest potential of cooperatives and associations in an improved sales structure as illustrated in Fig. 14. Collective commercialization could strengthen the position of farmers at the expense of middlemen and was regarded as a necessary measure to successfully establish cooperatives in the study region. In the context of commercialization, experts mentioned that cooperatives should also conduct market research to identify potential markets and analyze agricultural commodity prices. Broad acquirement of means of transportation and weighing facilities could even lead to more wholesale markets (CEASA) opening and realizing higher prices than in the study region.

Five experts mentioned that cooperatives could financially support their members by provision of credits or improving the credit availability. Family farmers often lacked capital to invest in production infrastructure or inputs, especially after years of drought. Access to credit was often restricted due to lack of collateral and high bureaucratic difficulties. The five experts also mentioned shared ownership as it could permit the acquirement of agricultural machinery, whereas during the study period most fieldwork was conducted manually. Moreover, cooperatives could provide financial support to implement more efficient irrigation technologies and replace the prevailing conventional sprinkler systems.

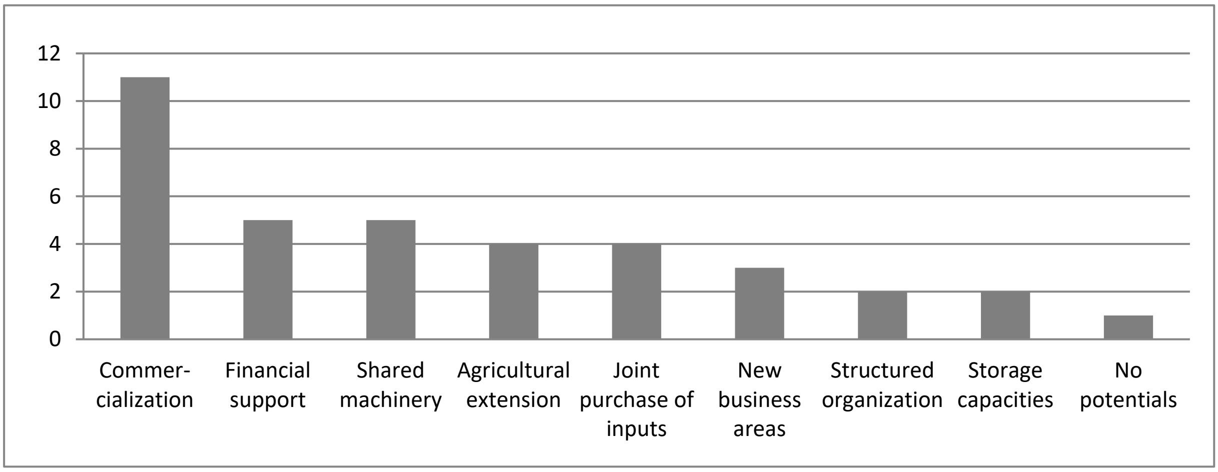

Fig. 14: Most mentioned potential of agricultural cooperatives in the study region

In the opinion of four experts, many farmers were overstrained with irrigated agriculture as it was implemented in the late 1990s. Thus, they required agricultural advisors especially for the cultivation of perennial cash crops, which had rarely been cultivated in the study region before the dam construction. Cooperatives could fill this gap since the dam operator had stopped providing agricultural advice during the study period. The state-run advisory service (IPA) was not responsible for the irrigation schemes and thus concentrated on farmers outside the schemes. Agricultural advice also played a role in the implementation of new technologies.

Joint purchase of inputs could reduce the input costs, as mentioned by four experts. During the study period, only a few shops that were well connected shared the market around Petrolândia. Similar to commercialization, farmers had the weaker position in the market, received far too low prices for their products and paid far too high prices for inputs.

Most experts commented that the coconut water factory was the only value adding facility in the study region when referring to the cooperatives' role for commercialization of agricultural commodities. Three of them had the vision that cooperatives could establish more value adding industries in the region. Production of jam and sweets made from fresh fruits already existed on a small scale. Increasing this production could keep a bigger share of the added value in the region and provide income opportunities besides primary agricultural production. Only one expert did not see any potential of agricultural and livestock cooperatives in the study region.

4.4 Discussion

Experts identified structural problems hindering the successful implementation of cooperatives and associations in Northeast Brazil. Mistrust against these forms of cooperation is based on their legal form and historical background (Duarte and Wehrmann, 2006; Sabourin, 1999). In contrast to the South, where agricultural cooperatives are well established (Ritossa & Bulgacov, 2009), major parts of the northeastern population have no positive experience with cooperative thinking (Albuquerque and Cândido, 2011). Pozzobon and Machado Filho (2007) underlined the need for organization and ethical behavior to successfully operate cooperatives. Considering the difficulties of the investigated cooperatives (Fig. 13), it is obvious that these basic requirements were not present in the study region.

In the difficult environment, complicated by the resettlement process, CHESF did not consider the "Statements on the Co-operative Identity" defined by the International Co-operative Alliance (ICA), which underline the importance of self-help and self-responsibility (ICA, 2005). Albuquerque and Cândido (2011) emphasized the importance of farmers' own initiative in the foundation process of cooperatives. Financial incentives in form of regular payments by CHESF influenced the voluntariness in joining a cooperative. Consequently, cooperatives were founded exclusively to receive payments without following the fundamentals of cooperatives. Despite the farmers' needs for commercialization alternatives, affordable means of production, and access to credits, the cooperatives did not implement any successful activity in these sectors. This conforms to findings of Untied (2005), who identified the top-down implementation of cooperatives by CHESF and the focus on technical assistance instead of economic activities, as reasons for the cooperatives' failure. The poor situation of agricultural and livestock cooperatives in the study region is in contrast to the basic need of promoting cooperatives and farmers' interest groups to increase bargaining power over product and input prices, as underlined in the report of the World Bank (1998) which analyzed the progress of the resettlements around the Itaparica Reservoir. Besides commercialization of agricultural commodities, food-processing cooperatives provide unexploited potentials to retain parts of the added value in the region (Bialoskorski Neto, 2001; Ortmann and King, 2007).

Cooperatives are facing high competition with middlemen who are interested in individual commercialization by the farmers. Contrary to the cooperatives, middlemen possess means of transport and are well connected to the wholesale market. The importance of fast, direct transportation of agricultural commodities to markets is due to lack of storage and cooling capacities and food processing facilities in the study region. However, before exploiting these potentials, cooperatives or farmers' associations have to be established successfully first.

The insufficient infrastructure also affects the cooperatives, limiting their access to information. Interviewees in the metropolises Recife and Curitiba mentioned governmental programs to support cooperatives by providing workshops and seminars educating existing and potential members. Rocha et al. (2012) stated that several governmental programs, such as PRONAF, PAA, and PNAE, have been established successfully in rural areas to support small subsistence family farmers and to improve food security. The interviewed experts also mentioned these programs, but many farmers do not benefit from them. Administrative barriers, lack of knowledge, and clientelism restrict access for individual farmers. Provision of required information, support in the application process, or even commonly organized participation at such programs could represent suitable services provided by agricultural cooperatives or associations.

Small associations of beekeepers or fishermen present positive examples of successfully operating unions. Before their foundation, potential members participated in several trainings and learned about ideals and benefits of associations. In this case, authorities provided the framework conditions without interfering or influencing the daily operations, following the recommendations by the FAO (2002) and Pires (2004). During the study period, these associations successfully conducted common purchase and commercialization. More recent studies also indicated a positive development of the association of livestock breeders ASCOPETRO. Common purchase of feed supplements, mainly maize, could be established successfully, which led to significantly reduced feed costs (Santos da Costa, 2014; Siemann, 2015). Moreover, members demanded common facilities for product processing and marketing (Santos da Costa, 2014). Siemann (2015) also referred to future potentials of livestock cooperatives, as 41% of the 60 interviewed livestock farmers in the area who were not members of a cooperative or association would like to participate in one. Main objectives were learning new practices, improving their production, improving credit access, and increasing marketing opportunities. These positive developments lead to the conclusion that smaller unions, encompassing only parts of their members' economic activities, have higher implementation potential before bigger and more complex cooperatives can be established. Duarte and Wehrmann (2006) also describe high potential for small associations, so-called cooperatives of resilience, which focus on diversification of rural production and serve mainly local markets. They recommend a focus on local markets due to high competition with big enterprises when trying to access the national or even the world market.

Finally, despite the failure of most of the agricultural cooperatives and associations in the study region, most interviewed experts mentioned the potentials and benefits of these forms of organizations. All interviewed farmers showed a general willingness to cooperate in commercialization and purchase. Only one interviewee did not believe in a successful implementation. To explore the open potentials, agricultural cooperatives should mentor smaller, less complex, fishery and beekeeping associations in the short-term and mid-term, and focus on the basic needs of their members to ensure their association with the union and maintain their motivation to participate actively. Restrictions due to inefficient cooperative laws were not analyzed in this study. However, considering the prosperous situation of cooperatives in Brazil's southern states, the legal framework seems to be appropriate for the successful implementation of cooperatives.

4.5 Conclusions

The qualitative approach based on expert interviews was chosen in order to investigate the role of agricultural cooperatives and associations in three irrigation schemes at the Itaparica Reservoir in semi-arid Northeast Brazil. Large memberships did not mirror the actual situation of the identified inactive cooperatives and associations in the region. Despite financial support during the implementation phase from the dam operator and a basic willingness to cooperate among smallholders, there were no efficiently operating agricultural cooperatives in the region. Due to the consensus of the interviewed experts with previously conducted studies, the obtained results of the study seem clear and further quantitative research on this topic would be unnecessary. Further activities should concentrate on knowledge transfer about cooperatives and increasing the awareness and familiarity of governmental programs supporting these efforts. Despite the results of this study, the farmer production structure in the study region brings high potentials for the implementation of cooperatives or associations.

Acknowledgements

This study was conducted within the project “INNOVATE” (01LL0904C) and funded by the Federal Ministry of Education and Research (BMBF; Sustainable Land Management Program), the Brazilian Education Ministry, and the Brazilian National Council for Scientific and Technological Development (CNPq).

Chapter 5. Mathematical programming models to increase land and water use efficiency in semi-arid NE-Brazil[8]

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Abstract

Construction of the Itaparica dam and reservoir induced changes in the agricultural production systems of the Itaparica micro-region, at the lower-middle São Francisco river basin. Extensive traditional systems were replaced by e.g. irrigated fruit production. However, over twenty years after the dam construction, many farmers are still facing income insecurity. A survey, consisting of expert interviews and structured on-farm interviews, has been conducted to analyze current production systems. A Linear Programming farm optimization model was applied to determine optimal land allocation considering changing production conditions. Income depended strongly on low wages for day laborers, free irrigation water, and stable prices of the main crop, coconut. Diversification of production and improved market access can help to improve farmers' income situation. Moderate water pricing can raise the awareness of water scarcity and lead to implementation of water saving production methods.

Keywords

Agriculture, linear programming, irrigation, water efficiency, decision support, rural development, Itaparica, Brazil

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[8] **A version of this chapter has been published as:**

Heinrich Hagel, Christa Hoffmann, and Reiner Doluschitz, 2014. Mathematical Programming Models to Increase Land and Water Use Efficiency in Semi-arid NE-Brazil. In: International Journal on Food System Dynamics 5 (4), 2014, 173-181. doi: 10.18461/ijfsd.v5i4.542

5.1 Introduction

Since the 1950s Brazil's government promoted irrigated agriculture to reduce the consequences of droughts and rural poverty in the semi-arid region of the country's northeast (Untied, 2005). The construction of several dams and reservoirs along the São Francisco River to provide energy to the growing economy and cities of northeast Brazil supported this intent (World Bank, 1998). Aside from their primary function, dams provide additional uses such as flood control, fishery, water storage for human and livestock consumption as well as for irrigated agriculture (Selge and Gunkel, 2013). Permanent water availability facilitated the implementation of irrigated agriculture under naturally unfavorable conditions for intensive agricultural production (Untied, 2005). One of those dam projects was the construction of the Itaparica dam and reservoir at the lower-middle São Francisco River, completed in 1988. Besides resettlement of about 10,400 households, its implementation induced significant changes of the traditional local agricultural production. Intensive irrigated vegetable and fruit production replaced extensive traditional systems, which had consisted mainly of dryland farming along the riverside and extensive livestock production on large areas in the interior (World Bank, 1998). Resettled smallholders received areas inside irrigation schemes equipped with sprinkler systems (center pivot) and free irrigation water as compensation for their flooded land. However, widespread sandy soils are not suitable for the planned intensive crop production (World Bank, 1998). In addition, farmers are still facing problems with the newly introduced production methods, lack of agricultural education and extension, and limited market access (Carvalho et al., 2013; Untied, 2005). Inappropriate irrigation practices, inaccurate use of agrochemicals, and low producer prices persist (Hagel et al., 2012). Despite governmental efforts to promote agricultural cooperatives and associations, most peasants farm on their own and, thus, have not sufficient market power in negotiation with traders (*atravessadores*), who, in most cases, dictate the prices of agricultural commodities (Hagel et al., 2013). Due to the resulting low income, farmers at the Itaparica reservoir still do not pay any fee for irrigation water. This is in contrast to other regions along the São Francisco River (Untied, 2005).

This study aims at economically analyzing current production systems and identifying the consequences of changing production conditions of perennial fruit production of small farms at the Itaparica reservoir. Farm analysis is conducted using a cost-benefit calculation. Effects of changing production conditions and corresponding changing resource allocations at farm level are analyzed using a linear programming model.

5.2 Material and methods

5.2.1 Study region

The Itaparica reservoir is located in northeast Brazil (Sertão) as shown in Fig. 15. The reservoir borders the Pernambuco state to its north and the Bahia state to its south (Ferreira Irmão et al., 2013). The Luiz Gonzaga Dam, formerly Itaparica Dam and therefore giving the name to the Itaparica reservoir, is one of the seven dams at the São Francisco River. These seven dams form four hydropower complexes (CHESF, 2014). This study concentrates on the irrigation scheme Apolônio Sales, near the town Petrolândia in Pernambuco. It is one of the four irrigation schemes around the Itaparica reservoir in Pernambuco state (Ferreira Irmão et al., 2013) and presumed to be a model for rather successful implementation of a small-scaled irrigated fruit production.

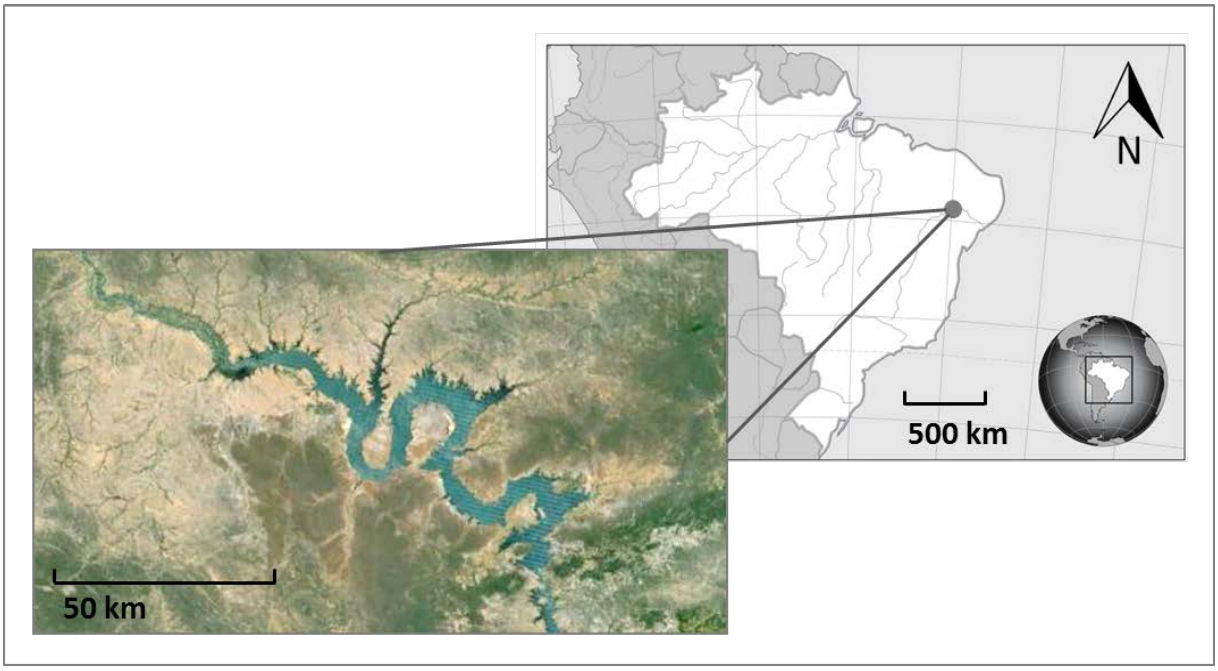

Fig. 15: Location of the Itaparica reservoir. Source: Own figure after Google Earth, (2014) and National Geographic, (2014)

Climate in the study region is semi-arid, characterized by average annual rainfall of around 300 mm and an average temperature of 25° C. Evaporation potential reaches up to 2,500 mm. According to the Köppen-Geiger Climate Classification, the climate type is BSh. Natural vegetation is the shrub and thorn forest Caatinga (Parahyba et al., 2004). Dominant soils are Arenosols, characterized by low nutrient availability and high water permeability (Araújo Filho et al., 2013).

Due to the semi-arid climate, agricultural production beyond subsistence farming depends on the perennial São Francisco River. Water for irrigation is pumped to the fields on farmers' personal responsibility or, in most cases, provided within irrigation schemes (FAO AQUASTAT, 2014). Unlike the humid high section and the adjacent less arid upper middle area of the river where private irrigation schemes dominate; practically all irrigation schemes along the lower-middle part were built or promoted strongly by the public sector (Calvacante, 1997). Due to the construction of hydroelectric power plants and promotion of irrigated agriculture, population and economy grew rapidly in the study region. For many rural households, irrigated agriculture is still the main income source (Ferreira Irmão et al., 2013). Currently, there are 34 public-sector irrigation schemes along the São Francisco River with a total irrigable area of around 120,000 ha (CODEVASF, 2014), whereas the total irrigated area in the river catchment exceeds 600,000 ha (ANA, 2013). Around 77% of the total water withdrawal (214.7 m^3/s of total 278.8 m^3/s) is used for irrigation (ANA, 2013).

5.2.2 Methodology

To evaluate current production methods and production alternatives, qualitative and quantitative methods were applied. First, secondary data evaluation and sixteen semi-structured expert interviews were conducted to gain an overview on agricultural production. Preparation, realization, and analysis of the interviews were conducted following general guidelines for qualitative data analysis (Bernard, 2006). An income statement for farm production and a Linear Programming (LP) farm optimization model were applied to determine site-adapted farm structures and efficient resource use. Mathematical programming models are widely used to solve resource allocation problems in agriculture (Kaiser and Messer, 2011). Due to their ability to predict farmers' reactions towards changing production conditions, they are suitable decision support tools for policy makers, extension services, and farmers (Berbel and Gómez-Limón, 2000). The model was adjusted to regional characteristics in cooperation with local extension service and uses farmers' preferences determined from twenty semi-structured on-farm interviews (Lienert et al., 2013). Data for the analyses were collected from smallholders in a random sample of 191 structured on-farm interviews. According to Ferreira Irmão et al. (2013) productivity in the irrigation scheme Nilo Coelho, around 300 km to the west of the Itaparica reservoir, is higher and technologically more advanced than in the schemes around the Itaparica reservoir. To get an insight into its agricultural production, 22 interviews were conducted there. A total of 139 interviews were conducted in irrigation schemes at the Itaparica reservoir. The remaining 30 interviews were conducted with independently irrigating farmers along the riverside.

Based on the primary data collected and secondary data received by local authorities, a LP model of a representative farm in the irrigation scheme Apolônio Sales was formulated.

As farmers mentioned in the interviews that they were mainly interested in profit maximization (own interviews and Lienert et al., 2013), the objective function of the model was formulated to maximize the farms' gross margin (GM, income less variable costs):

$$\max GM = \sum GM_i * X_i$$

where,

- GM is the Gross Margin,

- X is cultivated areas,

- and i = 1…n are the cultivated crops (Berbel and Gómez-Limón 2000).

Farmers in the Apolônio Sales scheme had a maximum irrigated land of eight hectares (ha) available. Thus, an area constraint was included into the model:

$$\sum X_i \leq 8\ ha$$

In addition, labor and water constraints were added as shown in chapter 5.3.3. To spread the risk of low prices or yield loss of one specific crop, farmers of the irrigation scheme chosen grow various annual and perennial crops. To consider this, the maximum area per crop was restricted, based on the cropping pattern of the irrigation scheme and the current allocation of the main represented crops in the irrigation scheme. To simplify the model, a cropping period of one year was assumed. As plantation costs did not differ strongly between the crops, they were not considered in the model. Hiring day laborers is included in the final LP model as shown in Table 15 in the next chapter. Sensitivity analysis was conducted to simulate farmers' reactions to a possible implementation of water pricing and increasing wages. Assumed wage increases and water prices are based on information received from farmers in Nilo Coelho. For possible water prices, secondary data (Do Amaral et al., 2004) were considered additionally.

5.3 Results

In the region around the Itaparica reservoir, the relation between annual and perennial crop production is balanced. However, the area of perennials increased constantly since the initiation of irrigated agriculture within the irrigation schemes, whereas the importance of annuals decreased (IBGE, 2013b). According to interviewed experts, data of local decision makers (CODEVASF, 2013c), and secondary literature (Ferreira Irmão et al. 2013), perennial fruit cultivation dominates especially in the irrigation scheme Apolônio Sales. Coconut (Cocos nucifera) is the dominant fruit cultivated on nearly 60% (470 ha) of the irrigated area. The other relevant perennials are banana (Musa ssp.) and mango (Mangifera indica). Annual crops, mainly maize, peanuts, beans, and watermelon, are grown on soils not suitable for perennials or as intercrops in recently planted perennial plantations.

Table 15 illustrates the average GMs of the main crops within the irrigation scheme, based on data of CODEVASF (2013c). All results presented in the following originate from the authors' interviews. Although mangos are harvested once per year, coconut and banana plantations provide yields through the whole year. Due to this and high tree maintenance requirements by the farmers, mango is cultivated on relatively small areas, despite its high GM.

Table 15: Area and Gross Margin of the main crops in Apolônio Sales 2012

	Cultivated area (ha)	Gross margin (R$/ha)
Coconut	470	2,400
Banana	90	2,700
Mango	42	7,500
Maize	20	3,100
Beans	12	4,100
Peanut	11	4,170
Watermelon	7	4,900

Source: CODEVASF, 2013c

Due to a long-lasting drought from 2012 to 2013 and combined with heavy rains in the south of Brazil, prices for annual crops increased strongly. Most subsistence crops are cultivated mainly rather extensively in a rain fed system and therefore strongly affected by droughts. Unlike perennial cash crops that require constant irrigation, annual cash crops can be cultivated on a limited scale in rain fed systems as well. Without irrigation opportunities, the drought caused severe crop failures in annual crop cultivation, which led to extremely high prices.

Fig. 16 illustrates the price development of the main annual (watermelon, pumpkin, beans) and perennial crops (coconut, banana) in the irrigation schemes. Despite temporary high prices for annual crops, farmers especially preferred the perennials coconut and banana because they provide yields monthly, hence, constant income.

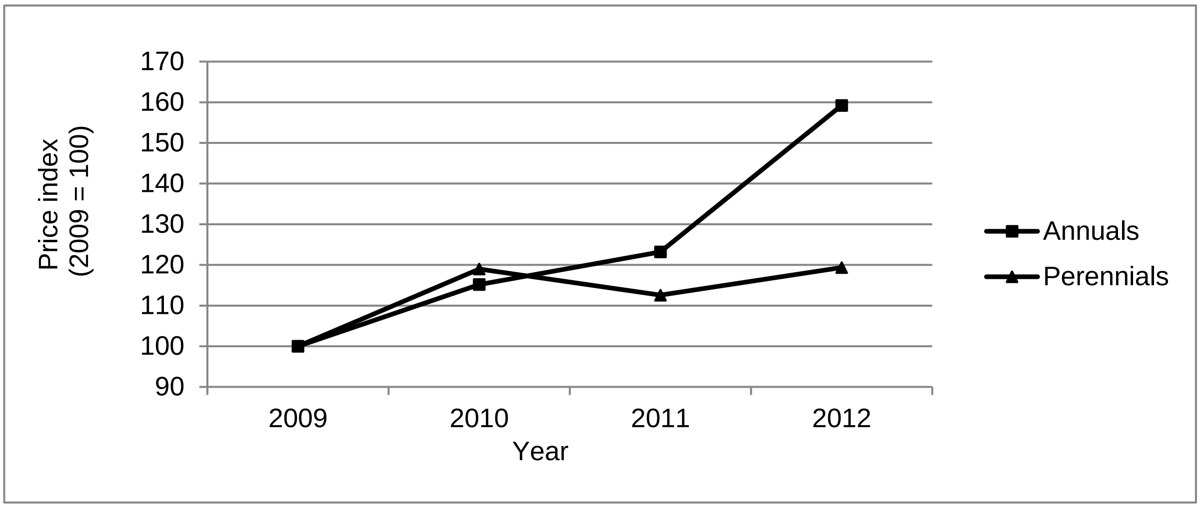

Fig. 16: Development of price indices of major annual and perennial crops in Apolônio Sales (Source: Own calculations after CODEVASF, 2013c)

5.3.1 Farmers' income depends strongly on low wages of hired labor

The share of hired labor for the generally labor intensive fruit production was around 60-70% of the total workload. As variable costs, the expenses for day laborers were already included in the GM presented in Table 15. During the study period, the average daily wage of a day laborer was 30 Brazilian Reais (R$), equal to the legal minimum wage. In the adjacent region of Petrolina with higher labor scarcity, the average wage was 40 R$ per day. As shown in Table 16, such an increase of daily wages can strongly affect the GM and therewith the smallholders' income.

Table 16: Average amount and costs of hired labor in 2013

	Hired day laborers (days/ha/year)	Costs with 30 R$/day*	Costs with 40 R$/day	Costs with 45 R$/day
Coconut	98	2,940 R$	3,920 R$	4,410 R$
Banana	89	2,670 R$	3,560 R$	4,005 R$
Mango	143	4,290 R$	5,720 R$	6,435 R$

* = Average wage during the study period

5.3.2 Returns from crop production are too low for a regular water price

A fee for irrigation water is not yet included in the GMs for the irrigation scheme. Consequently, and in addition to high implementation costs, most farmers still use old sprinkler systems on coconut and mango plantations, resulting in inefficient water consumption. Due to higher plant densities in banana cultivation, micro-sprinkler systems are broadly used for this crop. The low returns of the current production systems could reduce or become negative with the implementation of a water price. Farmers in the irrigation scheme Nilo Coelho in the adjacent Petrolina region pay around 900 to 1,800 R$ per hectare and year for irrigation water. This fee is divided into implementation costs for the necessary infrastructure, maintenance of the infrastructure, and a usage-bound water price per 1,000 m³. Do Amaral Santana et al. (2004) even assume water fees in banana cultivation in Bahia state of between 1,700 R$/ha and 2,600 R$/ha. Despite the negative impact of a water price to the farmers' income, irrigation water free of charges leads to an overuse of the scarce resource within the irrigation scheme. Local experts also assumed that large areas next to the irrigation schemes are irrigated illegally.

5.3.3 LP models to simulate the impact of water pricing and increasing wages

To quantify the role of labor availability and free irrigation water, three LP models were developed as shown in Table 17 and Table 18. To calculate the effect of increasing wages, the hired average labor costs (Table 16) were added to the respective GMs. Equation (I) in the models represents the objective function. Arising expenses for hired labor and water are also considered. Equation (II) illustrates the area constraint. To consider the farmers' preference towards crops with lower risks of income losses (banana and coconut), half of the available area had to be used for those crops (equation III). In average, a family farm had around 5,000 hours of family labor available per year. An additional day laborer (8 hours) could be hired as shown in equation (IV). Because water pricing is not included in the model and yields did not differ significantly between sprinkler and micro-sprinkler irrigation, the different irrigation methods are not considered in this model.

Table 17: Illustration of LP model with area and labor constraint under current situation

Decision	Coconut (1 ha)	Banana (1 ha)	Mango (1 ha)	Employ day laborer (8 hours)	Solution
Variable	$X_1 = 4$	$X_2 = 0$	$X_3 = 4$	$X_4 = 1{,}040$	Max
Objective					
(I) GM (R$/ha)*	5,340	5,370	11,790	-30	37,320 R$
Constraints					Goal
(II) Area (ha)	1	1	1		≤ 8
(III) Area low risk crops (ha)	1	1			≥ 4
(IV) Labor (h/ha)	1,200	1,550	2,130	-8	≤ 5,000

* Excluded hired labor costs, GMs calculated based on own data and CODEVASF, 2013c

As shown in Table 17, banana under current circumstances is theoretically not competitive to coconut. Disregarding the required high level of knowledge for mango cultivation, it is the most competitive perennial crop due to its high GM, as it is more productive per used area and labor. The most scarce factor in this solution is area with a shadow price of 3,802.5. This shadow price is equal to the GM of an additional hectare of mango excluding the required hired labor costs. The model in Table 18 contains an additional moderate water price. A fee of 53 R$/ha for maintenance and 56 R$ per 1,000 m³ consumed water was assumed, in accordance to information received by farmers in the Nilo Coelho scheme near Petrolina. As the irrigation scheme already exists and because governmental agencies resigned from charging farmers for implementation costs for infrastructure in comparable regions, these costs were not included in the model. In coconut and mango plantations, the sprinkler and micro-sprinkler irrigation systems exist. Thus, both production alternatives were included for both crops in equation (V). Average costs of micro-sprinkler systems, including implementation costs, were subtracted from the GMs (380 R$ in coconut cultivation and 300 R$ in mango cultivation). As bananas are cultivated mainly with micro-sprinkler irrigation, the model contains only this production alternative. The water constraint was added in equation (VI).

Table 18: Illustration of LP model with area and labor constraint included moderate water prices

Decision	Coconut sprinkler (1 ha)	Coconut micro (1 ha)	Banana (1 ha)	Mango sprinkler (1 ha)	Mango micro (1 ha)	Employ laborer (8 hours)	Buy water (1,000 m³)	Solution
Variable	X_1=4	X_2=0	X_3=0	X_4=0	X_5=4	X_6=1,040	X_7=61,1	Max
Objective								
(I) GM (R$/ha)*	5287	4907	5317	11737	11437	-30	-56	32,275.07
Constraints								Goal
(II) Area (ha)	1	1	1	1	1			≤ 8
(III) Area low risk crops (ha)	1	1	1	0	0			≥ 4
(IV) Labor (h/ha)	1,200	1,200	1,550	2,130	2,130	-8		≤ 5,000
(V) Irrigation water (m³/ha)	9,750	5,616	17,347	19,500	5,522		-1,000	≤ 0

* Excluded hired labor costs

As shown in Table 18, water pricing reduced the total GM by around 5,000 R$. It had no influence on the relation between coconut and mango production. Due to its high water demand, banana cultivation became less competitive and was not included in the solution. High water consumption of mango cultivation with sprinkler irrigation caused a switch to production with micro-sprinklers. Shadow prices for an additional area decreased to 3,140.

Finally, an increase of hired labor costs to 40 R$/day was assumed. The composition of the solution did not change, but the total GM declined to 21,875.07 R$. Consequently, the shadow price of irrigable area declined to 477.77. With an increasing wage, the shadow price of an additional hour of family labor increased from 3.75 to 5.

5.4 Discussion

Analysis of the current production methods showed relatively low income in irrigated fruit production and therefore high economic vulnerability of smallholders. The high dependency on low wages for day laborers make smallholders susceptible to changing production conditions – especially considering the rapid increase of minimum wages in the last decades (MTE, 2014).

The high share of coconut in the irrigation schemes leads to high dependency on prices of coconut, which may drop due to high supply and competition between farmers. Increased variability in production may reduce their dependence on single product prices. Thus, for a profound analysis of optimal area allocation of small farms, a broader selection of appropriate crops should be considered. The competitiveness of mango production seemed quite high, influenced by the relatively high prices obtained during the study, as well as in the period investigated by CODEVASF (2013c). However, farmers also mentioned that the average mango price was up to 50% below the price assumed in this study. The higher required knowledge in mango cultivation, especially due to several necessary prunings and variable irrigation, is also not yet considered in this study. One the one hand, the case of mango cultivation indicates the economic potential of site adapted and the diverse irrigated fruit production in the study region. To enable farmers use the existing potential, personal agricultural extension including intensive assistance in alternative crops is strongly recommended. On the other hand, irrigation water, and subsequently irrigable land, is limited. De Loreto et al. (2001) observed an overexploitation of arable land in comparable irrigation projects in Espirito Santo, Southeast Brazil. This leads to the conclusion that income alternatives besides irrigated agricultural are required to lower the economic pressure on the limited irrigable land and thereby ensure sustainable agricultural production.

Improved market access and higher producer prices are crucial to provide secure farm income. However, provided agricultural extension services are available, moderate volumetric water pricing may lead to implementation of more efficient irrigation technologies and water saving techniques. Rodorff et al. (2014) mentioned that the educative use of simulated bills in the study region already reduced water consumption. Still, to reduce illegally irrigated plantations, especially on unsuitable soils without drainage, water pricing can be a suitable tool. Furthermore, the implementation of micro-sprinkler systems in banana cultivation shows the farmers' willingness to implement water saving technologies. Developed models seem to fit well to actual production systems and can serve as easy and understandable decision support tools. Selective policy instruments can help to ensure the local farmers' livelihood under economically fragile production conditions.

Chapter 6. Optimal resource allocation in irrigated family agriculture in Northeast Brazil[9]

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Abstract

In the recent decades, Brazil's government promoted irrigated agriculture in the country's semi-arid northeast to foster rural development and to counteract rural exodus. Constructions of dams for hydropower generation facilitated constant availability of irrigation water. Over twenty years after the implementation of irrigation schemes around the Itaparica reservoir at the lower-middle São Francisco River, overuse of irrigation water and low farm income persist. A linear programming (LP) farm optimization model was developed for optimal land, water, and labor allocation considering local smallholders' preferences for crop attributes as well as their farming objectives. Results show high economic competitiveness of annual high risk and labor-intensive crops towards the perennial low risk banana and coconut crops that were preferred by smallholders. Still, given a favorable land allocation, an adequate livelihood could be generated on farm sizes of four hectares. Volumetric water pricing, combined with technical assistance, turned out to be a suitable tool to reduce water consumption. Efforts to improve the infrastructure and market access of smallholders seem essential to guarantee sufficient farm income in the future, considering the extremely low producer prices in the study region. The simple model presented in this study can be used worldwide with publically accessible spreadsheets as a decision support tool to optimize the allocation of scarce resources. However, site-specific adaptations have to be conducted.

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[9] **A version of the chapter has been submitted as:**

Hagel, H., Lienert, A., Doluschitz, R. Optimal resource allocation in irrigated family agriculture in Northeast Brazil.

Keywords

Land and water allocation, linear programming, water pricing, sensitivity analysis, semi-arid, Itaparica

6.1 Introduction

In the last 40 years, worldwide electricity consumption more than tripled (IEA, 2014a) and, driven by income and population growth in emerging non-OECD economies, is assumed to increase heavily in the following decades (IEA, 2014b; Wolfram et al., 2012). With this development, the role of electricity derived from renewable energy source increases strongly. Despite stronger predicted growth rates of other renewables, hydropower will contribute the main share (IEA, 2014b). Strong growths of hydroelectric generation are expected in the near future, especially in Brazil, China, India, and Southeast Asian nations (EIA, 2013). On the one hand, dams built to generate hydropower often bring improvements of infrastructure and provide services such as flood control, water resources for human consumption, industrial use, and irrigated agriculture. It is estimated that in 1999, 30 – 40 % of irrigated land worldwide relied on dams (WCD, 2000). On the other hand, dams have negative environmental and social impacts and their construction is often the cause of conflicts within and between nations (Imhof et al., 2010; Richter et al., 2010; WCD, 2000). Large dams especially are controversially discussed (Ansar et al., 2014).

Brazil, where hydropower contributes 65.2 % to the total domestic electricity supply (EPE, 2015), is a good example for this development. Despite the controversial discussion about dam constructions at the Amazon (Fearnside, 2006) and the positive effects of electrification on the country's infrastructural development (Lipscomb et al., 2013), constant water availability at the lower-middle São Francisco River in the semi-arid region in Northeast Brazil led to construction of three reservoirs for hydropower generation in eight hydropower plants (CHESF, 2015). Although their social and economic development is controversially discussed (Albuquerque and Cândido, 2011; Lima and Miranda, 2011; Collins, 1993), hydroelectric power generation and the implementation of intensive irrigated agriculture generated welfare in one of the country's poorest regions (Camelo Filho, 2011; Lima and Miranda, 2011). Since the early 1970s, the governmental São Francisco and Parnaíba Valleys Development Company (CODEVASF) implemented 34 irrigation schemes in the São Francisco River basin with a total irrigable area of 135,550.5 ha (CODEVASF, 2015c). It is estimated that the water supply of the São Francisco River provides further potentials for hydropower and irrigated agriculture in the semi-arid region (Hall, 2001; IEA, 2013). To tap these potentials, the so-called transposition (*transposição*) was built to extend the river basin to the northern states Paraíba, Rio Grande do Norte, and Ceará (Lee et al., 2014; Stolf et al., 2012). To promote rural development in the semi-arid region, CODEVASF is planning additional irrigation schemes with an estimated irrigable area of 255,000 ha (CODEVASF, 2015c). However, water availability is crucial for most economic developments along the lower-middle São Francisco River (Maneta et al., 2009) and likely to be negatively affected by climate change (De Lucena et al., 2008; Krol et al., 2006; Oyama and Nobre, 2004; Torres et al., 2012; Vieira et al., 2015). As irrigated agriculture is the main water consumer of the basin (77 % of total water demand), it will be most affected by reduced water availability (ANA, 2013). The planned expansion of irrigated agriculture and the climate change impacts require an adequate management of water resources (De Fraiture and Wichelns, 2010; Krol et al., 2006; Montenegro and Ragab, 2012).

While in the region Petrolina irrigated agriculture is characterized by modern production technologies and producing for the domestic and world market, most smallholders in the irrigation schemes implemented in the framework of the Itaparica reservoir construction around 400 km downstream are still facing poverty (Possídio, 1997; Untied, 2005). Due to social conflicts and delays during the implementation of the irrigation schemes and low farm incomes, farmers still receive free irrigation water. Consequently, old and inefficient aspersion irrigation dominates in the irrigation schemes (CODEVASF, 2015c; World Bank, 1998), whereas site-adapted water pricing can successfully control the water use (Döll and Hauschild, 2002). Even in the relatively wealthy Apolônio Sales irrigation scheme, farm incomes are too low to handle moderate pricing (Hagel et al., 2014).

Linear Programming (LP) optimization models are suitable decision support tools in irrigated agriculture, where various crops compete for the scarce land, water, and labor resources (Berbel and Gómez-Limón, 2000; Das et al., 2015; Moradi-Jalal et al., 2007). Singh (2015) discusses its benefits and limitations compared to more advanced optimization models, such as non-linear programming (NLP) models, in detail. This study aims at determining optimal resource allocation in the irrigation schemes in the surrounding of the Itaparica Reservoir considering local smallholders' preferences. The objective of the model is to provide an easily applicable decision support tool for local authorities (CODEVASF), agricultural consultants, and even smallholders on optimal crop choices and suitable water pricing instruments. Addressing these stakeholders, the LP approach, which is easily applicable with most spreadsheet applications, was chosen. Preferences of local smallholders' considering crop choice and farm management and socio-economic key factors for farm income were assessed to adapt the model to the local production conditions. Sensitivity analyses test several scenarios considering volatile producer prices and different water prices.

6.2 Material and methods

6.2.1 Study site description

The study area is located in the so-called drought polygon in the semi-arid region of Northeast Brazil. The study focuses on the Apolônio Sales, Barreiras, and Icó-Mandantes irrigation schemes in the surroundings of the town Petrolândia at the Itaparica Reservoir at the lower-middle São Francisco River, but also considers independently irrigating farms along the river and production in the irrigation scheme Nilo Coelho next to Petrolina as a reference for an economically successful region. Average annual rainfall over the last decades was around 340 mm and varied strongly over time (APAC, 2015). Irregularly occurring droughts are usually due to the El Niño Southern Oscillation (ENSO) phenomenon (Hastenrath and Heller, 1977), but can also occur during La Niña seasons, as was the case during the severe drought from 2011 to 2012 (Rodrigues and McPhaden, 2014). Observed evapotranspiration rates in irrigated pomiculture of around 1,400 mm exceed the annual rainfall heavily (De Teixeira and Bassoi, 2009). Most soils in the region are derived from sandy covers and characterized by low nutrient availability and high permeability. In some small areas, relatively fertile soils derived from fine sediments can be found (Filho et al., 2013).

In the framework of the Itaparica dam and reservoir construction, which was completed in 1988, the irrigation schemes Apolônio Sales, Barreiras, and Icó-Mandantes were constructed to compensate the affected rural population for flooded land. The town Petrolândia is one of the four flooded and rebuilt towns in Pernambuco and Bahia state (World Bank, 1998). Nowadays, six irrigation schemes form the Itaparica on the northern side of the reservoir in Pernambuco state (CODEVASF, 2015b). In the content of the Itaparica Reservoir construction, traditional agricultural production systems, such as recession agriculture, rainfed subsistence agriculture, and extensive livestock farming were replaced by irrigated fruit and vegetable production. Most farm work is done manually (Andrade, 2011; Hagel et al., 2015a; Untied, 2005). Main social and economic indicators are below Brazil's average, but slightly above the one of the semi-arid region.

The human development index, which considers life expectancy, education, and income, is at 0.623 (semi-arid region 0.617, Brazil 0.727). The economic impact of the irrigation schemes on employment is shown by the high share of agriculture on employment (39.53%). The service sector also benefits in form of shops for inputs and agricultural equipment (IBGE, 2010; Untied, 2005).

6.2.2 Methods

Assessment of local smallholders' preferences

It is assumed that smallholders tend to maximize at least one household objective (Lipion, 1968), whereas the realized objects, such as profit maximization, risk minimization, or drudgery reduction, depend on each smallholder's preferences (Ellis, 1993). To assess the smallholders' preferences considering crop choices and farm management, a random sample of twenty semi-structured interviews was conducted in the Apolônio Sales and Barreiras irrigation schemes. Ten of the interviewees were female, and ten were male farmers, to consider the importance of female labor in the everyday farm work (Ellis, 1993; Melo, 2002). To improve comparability of the mostly qualitative results, a ranking and scoring as well as a matrix scoring exercise, which provided quantitative data, were included in the questionnaire following established Participatory Rural Appraisal guidelines (Case, 1990; Chambers, 1994). The combination of qualitative and quantitative elements in the questionnaire followed Jick (1979). Due to the participatory character of the exercise and consequently, higher motivation of the interviewees, more detailed information can be obtained (Thattil and Wijesuriya, 2005). A local agricultural consultant assisted in choosing the interviewees and conducting the interviews. Data were analyzed in five steps by 1) transcription, 2) paraphrasing, 3) coding, 4) comparing, and 5) conceptualization, following established qualitative research methods (Huberman and Miles, 1983; Hycner 1985).

Assessment of agricultural production practices and alternatives

To assess the current production methods, a random sample of 193 structured on-farm interviews were conducted in the regions Itaparica and Petrolina in Pernambuco state. As shown in Table 19, 141 of the interviewees were farmers in the Apolônio Sales, Barreiras, and Icó-Mandantes irrigation schemes. Production in the Manga de Baixo irrigation scheme, located between the towns Itacuruba and Belem de São Francisco, (n=21) had nearly stopped due to unsuitable soils except few coriander and onion seed producers. As this production presented solely a market niche, the sample was not included in the detailed analysis. Outside the main irrigation schemes, 30 additional interviews were conducted by snowball sampling to compare productivity within and outside the irrigation schemes (Biernacki and Waldorf, 1981). Ten of those interviews were conducted in the surroundings of the town Itacuruba around 90 km from Petrolândia, the other 20 in the surroundings of Petrolândia. The interviews were conducted by one researcher and three former agricultural consultants (Hagel et al., 2015a). The sample from the Nilo Coelho irrigation scheme in Petrolina provided a basis to estimate potential yields and prices in a climatically comparable region.

Table 19: Overview on the conducted interviews by region and irrigation type

Region	Area characterization	Location	No. of interviews
Itaparica	Irrigation scheme	Icó-Mandantes	47
	Irrigation scheme	Apolônio Sales	34
	Irrigation scheme	Barreiras	39
	Irrigation scheme	Manga de Baixo	21
	Independent irrigation	Petrolândia	20
	Independent irrigation	Itacuruba	10
Petrolina	Irrigation scheme	Nilo Coelho	22
Total interviews			193

The Brazilian Corporation of Agricultural Research (EMBRAPA) provides detailed production data of several crops, which were tested under the conditions of the semi-arid region (EMBRAPA, 2014). These reports served to verify retrieved production data from the household survey and provided reliable data on crop alternatives for the final LP models. In addition, primary data were compared to the less detailed productivity analyses conducted by the agricultural consultancy in the irrigation schemes assigned by the irrigation schemes’ operator (CODEVASF, 2013a).

Assessment of farm income, and labor and water requirements

To achieve reliable results, questions were asked using the farmers’ commonly applied units. Consequently, retrieved information had to be transformed to computable units, for instance “harvested boxes of mango per area” into kilogram per hectare. Uncertain lot sizes, which occurred in few cases, could be reliably calculated by number of plants per area and the measured planting distance. To estimate the farm income, the contribution margin (CM = sales revenues less variable costs) per planted crop in one year on one hectare was calculated in Brazilian Reais (R$). Labor requirements and input costs were asked per treatment, for instance seeding, weeding, or fertilizing. In the case of perennial fruit plantations, investments were summed up and divided by useful life of the plantation. As own savings and free loans from family members or neighbors were the common capital sources, and few smallholders had access to credits due to lack of land titles (Hagel et al., 2015a), the interest rate was not included in the calculation. These equivalent annual costs were added to the variable costs to improve comparability of annual with perennial crops. The investments in irrigation infrastructure such as micro sprinkler and drip irrigation systems were calculated in the same way. Implementation costs were divided by useful lifetime and average maintenance costs were added to the yearly amount. To consider time preferences, which may have been overlooked considering the farmers' preferred crops, sensitivity analyses were conducted with interest rates of 2.5% and 10% calculating the equivalent annual costs of perennial plantations using annuity factors. The 2.5% interest rate corresponds to the interest paid by few interviewed farmers, who received a loan within the governmental rural credit program to enforce family farming (PRONAF). However, farmers' subjective interest rates can be higher than the market's interest rates due to poverty and time preferences (Holden et al., 1998). Thus, the interest rate of 10% was added. The selection of this interest rate and the calculation of the equivalent annual costs followed established methods (Belli et al., 1998; Raboin and Posner, 2012). The same method, assuming an interest rate of 2.5%, was applied to assess the real investment costs of irrigation infrastructure.

Water requirements were calculated by number and type of irrigation units (sprinkler or micro-sprinkler) and duration of irrigation. All farmers mentioned that they irrigated regularly and independently from actual rainfall which seems reliable considering free irrigation water in the irrigation schemes. Verification of the calculated water consumption was conducted with calculations of Kelman and Ramos (2005) based on data from CODEVASF (2013a).

During the study period, a severe drought strongly affected the prices of the main annual cash crops in the study region (Hagel et al., 2015a). Thus, farmers were asked for low, high, and average producer prices. The results, as well as publicly available data of the Brazilian Institute of Geography and Statistics (IBGE, 2013b) and the National Supply Company (CONAB, 2014), served to verify price information of the schemes' operator. Based on these data, an average price scenario with weighted mean prices of the period from 2009 to 2012 was created.

Linear Programming model

The farm optimization model consists of an objective function and several constraints. The objective was to maximize the annual CM considering the existent crop types in the region and previously assessed alternative crops.

$$\max CM = \sum a_i A_i - \sum (vc_i + lc + wc_i) \quad (1)$$

where CM = contribution margin; i = crop type = 1, 2,…,n; a_i = return for crop i (R$/ha); A_i = area of crop i (ha); vc_i = variable costs of crop i (R$/ha), including plantation implementation costs of perennial crops; lc = labor costs = labor demand per crop (ld_i) times labor costs per employed unit in the case that family labor was insufficient and day laborers had to be employed; and wc_i = water costs for crop i in the cases with assumed water prices. Relevant crops were selected according to the farmers' preferences and are presented in the results chapter.

The mean irrigated area was 4 ha, whereas the mean area differed between the three schemes (Apolônio Sales = 5.89 ha, Barreiras = 3.98 ha, and Icó-Mandantes = 2.32 ha). On the one hand, unofficial renting and sharing appeared to be a common practice in all irrigation schemes. On the other hand, available irrigable land was extremely scarce in the irrigation schemes. Thus, the mean irrigated area was restricted within the mean area of the sample (4 ha).

$$\sum A_i \leq 4; \quad \forall i \quad (2)$$

Total labor demand (ld) needs to accord with available family labor for field work (4,836 hours per household). Additional day laborers could be employed for the wage of 30 R$/8 hours, so that day laborers were added as production alternative to the model. The actual share of hired labor in the production process differed between the irrigation schemes in relation to farm size and job alternatives. Workload peaks occurred during the harvest, but farmers stated that hired labor is scarce but available during the whole year. Harvest time depended on crop type and, due to different land allocation, irrigation scheme. To facilitate the model, availability of hired labor during the whole year and complete substitutability of family labor with hired labor, and vice versa, was assumed.

$$\sum ld_i \leq 4{,}836; \quad \forall i \quad (3)$$

Farmers preferred secure income on a monthly base, so an area *n* of the total area A_{ij} was restricted to the crops banana (i = 1) and coconut (i = 4), which provide a relatively secure monthly income. The factor n was selected according to the analysis of the farmers' preferences.

$$\sum A_1 + \sum A_4 \geq n \tag{4}$$

Risk aversion was considered, as the crops onion (i = 11) and tomato (i = 17) required high input costs and lost their dominant role in the study region due to the high risk of yield losses and volatile prices (Andrade, 2011).

$$\sum A_{11} + \sum A_{17} \leq m \tag{5}$$

Agricultural consultancy strongly recommended crop rotation to maintain soil fertility and to reduce pest pressure. To avoid monoculture of the economically most attractive cash crops, each crop could not be cultivated on more than half of the remaining area, considering equation (4), as formulated in equation (6).

$$A_i \leq \frac{4-n}{2}; \quad \forall i \tag{6}$$

For the same reason, the Cucurbitaceae melon (i = 10), pumpkin (i = 16), and water melon (i = 18) may not be cultivated on more than half of the remaining area.

$$\sum A_i \leq \frac{4-n}{2}; \quad i = 10, 16, 18 \tag{7}$$

The water requirements for all crops must be satisfied in the models considering water pricing. Thus, water demand for all crops (wd_i in m^3) may not fall below purchased water (wp_i in m^3).

$$\sum wd_i \geq \sum wp_i; \quad \forall i \tag{8}$$

Planted area and purchased water may not become negative.

$$A_i \geq 0; \; wp_i \geq 0; \; \forall i \tag{9}$$

Sensitivity analysis of producer prices, labor and water costs

During the study period, farmers received free irrigation water, whereas farmers in the Nilo Coelho irrigation scheme run by the same operator, already paid for irrigation water (Hagel et al., 2014; Untied, 2005). To analyze the impact of volumetric water pricing on farm income and resource allocation, the following volumetric water prices were added after verification by literature (De Teixeira and Bassoi, 2009; Kelman and Ramos, 2005):

1. In the Nilo Coelho irrigation scheme, farmers were charged 56 R$ per 1,000 m³ irrigation water. The additional 53 R$ per hectare irrigable land for maintenance were left out due to the relatively small share on total water costs. Thus, a water price of 56 R$ per 1,000 m³ was added.
2. The mean variable costs of water provision in the three analyzed irrigation schemes was 80 R$ per 1,000 m³, which was added as second water pricing alternative (CODEVASF, 2011).
3. To identify the point of the implementation of water saving technologies, in both producer price scenarios water prices were raised until farmers would change the current irrigation systems to more water efficient ones. Reduction of water use was compared to the occurring farm income loss.

A sensitivity analysis for producer prices was also performed to consider the low producer prices in the study region compared to average prices in Northeast Brazil (Hagel et al., 2014; IBGE, 2013b), as crop prices do not necessarily correlate to farmers management decisions (Dal Belo Leite et al., 2015). In previous studies, low producer prices were identified as one of the main constraints of irrigated fruit production in the study region (Hagel et al., 2015; Untied, 2005; World Bank, 1998). Table 20 shows the average prices of the main perennials in the irrigation schemes from 2009 to 2012, which were used for the average price scenario, and the average prices in Northeast Brazil in the same period. To visualize the exceptional prices during the study period, producer prices assessed in the survey in 2013 were added. Average producer prices in the study region were below the prices in the Petrolina region and the average of Northeast Brazil (CODEVASF, 2013a; IBGE, 2013b).

In the semi-arid region, perennial crops tend to be more resistant to water shortages (Selge et al., 2015). Due to regular and relatively stable yields, perennials were promoted by the schemes' operator and these are preferred by farmers, if they can afford the plantation's implementation (Hagel et al., 2015a). To identify the level of economic attractiveness of the main perennials in the study region (banana, coconut, guava, and mango) sensitivity analysis of the crops' producer prices was conducted considering national and northeastern average prices. Returns from those crops under different prices, up to 300% over and 50% below the 2009-2012 average prices, were compared to the most profitable crops identified by the LP model considering the recommended water price.

Table 20: Average prices of main perennial crops in the period from 2009 to 2012 and in 2013 in R$/kg

Crop	2013	2009 - 2012					
	Irrigation schemes [a]	Apolônio Sales [b]	Barreiras [b]	Icó-Mandan-tes [b]	Irrigation schemes [b]	Petrolina [c]	Northeast Brazil [c]
Banana	1.00	0.53	0.71	0.57	0.56	0.61	0.53
Coconut	0.25	0.19	0.27	0.24	0.22	0.25	0.42
Guava	1.00	0.43	0.70	0.56	0.61	0.90	0.79
Mango	0.52	0.52	0.31	0.29	0.41	0,64	0.50
Orange*		-	-	-	-	0.43	0.28

* Not established in the study region

Source: Own calculations after survey data [a], Codevasf (2013a) [b], and IBGE (2013b) [c]

Profitability of agricultural production in the Apolônio Sales irrigation scheme relied on constant availability of day laborers at low wages (Hagel et al., 2014). Thus, the importance of hired labor at the smaller farm size in this sample (4 ha in comparison to 6 ha in Apolônio Sales) and the impact of increasing day wages on farm income were analyzed.

6.3 Results

6.3.1 Farmers' preferences

Most interviewed farmers (n=17) were content with their working and living conditions but mentioned several constraints of the region, such as the recent severe drought, new pests, lack of income alternatives, and low farm income. However, eighteen farmers stated that they would like to continue working in the irrigation projects, favored by high producer prices during the study period. The 17 farmers, who were content with their actual situation, also said that they were satisfied (n=8) or rather satisfied (n=9) with the outcome of their work, especially in comparison to the income of farmers outside the irrigation schemes. In twelve households, the head or at least one family member contributed off-farm income to the household budget. In eight cases, the off-farm income contributed more than 70% of the overall income; in the other four cases off-farm income amounted to 60% - 50% of the household budget.

In the ranking exercise, farmers preferred crops providing secure income by good or secure commercialization and secure yields, as illustrated in Table 21, which shows the average scores of predetermined crop properties. The low relevance of high yields and drought tolerance were due to constant water availability in the irrigation schemes and relatively high yields compared to yields in rainfed agriculture. Farmers mentioned grape, passion fruit, guava, and papaya as crops providing high prices, and the annuals tomato and onions as high yielding crops. Due to high implementation costs and therewith higher economic risk, such crops received lower scores. Farmers' preferences did not differ strongly between female and male farmers or between the two studied irrigation schemes.

In the pairwise ranking, where two paired crop properties were compared directly, farmers tended to prefer higher yielding varieties with higher input costs to low yielding varieties with low input costs. Eleven farmers (55%) distributed the five available points nearly equally. Seven farmers slightly preferred high yielding varieties (score 3:2), whereas four farmers slightly preferred low input costs (score 2:3). The average score in favor of high yielding varieties (2.85) was slightly higher than the one in favor of low yielding varieties (2.15).

Table 21: Ranked preferred crop properties

Rank	Crop property	Mean Score (max. 5)
1	Good commercialization	4.65
2	Secure yields	4.50
3	Relevant for own consumption	3.85
4	Low input costs	3.65
5	Pest and disease tolerance	3.40
5	High prices	3.40
6	Usable as fodder	2.85
7	Multipurpose crop	2.60
8	Low labor requirements	2.40
9	High yields	1.85
10	Drought tolerance	1.80
11	Usable as firewood	0.10

Considering livestock farming the opinions differed widely. While some farmers underlined the importance of livestock, other farmers preferred to concentrate on crop production, especially due to low survival rates of livestock during the recent drought. Thus, within the irrigation schemes and given sufficient income by crop production and off-farm activities, livestock farming appeared to be strongly influenced by personal affinity. In relation to possible changes in the production methods, farmers were willing to substitute leisure time with farm income or increased soil fertility. Most farmers (n=17) already used manure or retained crop residues on the field (n=12) in order to maintain soil fertility and improve water holding capacity. In general, farmers were skeptical towards alternative crops because they doubted the suitability of the natural on-site conditions. However, given sufficient agricultural consultancy and proven economic attractiveness, they would consider cultivating newly introduced crops. Almost all interviewees (n=19) preferred micro-sprinkler to the previously installed conventional sprinkler systems and drip irrigation. The main obstacle for its implementation was lack of capital, but farmers also underlined its low workload, water use efficiency, precise irrigation, and suitability for all cultivated crops. Due to their preferred crop properties, farmers were classified as highly risk averse. However, from the results of the pairwise ranking and the low relevance of leisure time, they also tried to maximize their low profits from agricultural activities.

6.3.2 Actual cultivated crops and alternatives

Interviewed farmers cultivated in total 21 crops, of which 19 are presented in Table 22. The crops elephant grass (*Pennisetum purpureum*) and zucchini were not considered as suitable production alternatives for the following reasons. Elephant grass was cultivated solely by three farmers to ensure their livestock's survival during the drought. One farmer cultivated Zucchini but said that the prevalent Cucurbitaceae melon, pumpkin, and watermelon, were economically more attractive. The only farmer who cultivated oranges had recently started and could not provide information about the profitability of the plantation. Still, orange was added as production alternative based on secondary data (Azevedo et al., 2005). In general, coconut and banana were the most common perennial crops, whereas beans, corn, pumpkin, and watermelon dominated in annual crop production (see also Hagel et al., 2015a).

Table 22 shows the cropping alternatives, their profit per ha and cultivation, and their labor and water requirements. Implementation and maintenance costs of irrigation systems are not considered in this table, but presented in the course of this section. Due to the severe drought during the study period, profits of most crops were higher than in those calculated with four-year average prices. Considering two possible cropping cycles per year of most annuals, this gap would be doubled. On the other hand, labor requirements of high value annuals easily exceed the yearly available family labor capacities. The strongest price increase occurred in bean cultivation, which is a typical subsistence crop in rainfed systems and therewith strongly influenced by the drought. The biggest gaps between both price scenarios occur in the cases of grapes, onions, and tomatoes, which have high capital and labor requirements and are rarely cultivated in the study region. Cultivation of manioc with strong irrigation also provided high profits, but farmers mentioned that extremely high prices persisted since 2009 and did not see long-term potentials for large-scale cultivation.

Table 22: Profits, and labor and water demand of investigated crops

Crop	Profit (R$/ha)		Labor demand (hrs/ha)	Water demand (m³/ha)		
	2013 prices	2009-2012 prices		Sprinkler	Micro sprinkler	Drip irrigation
Banana	6,309.87	2,207.70	1,100.27	19,500	13,010	-
Beans[1]	3,578.48	868.14	550.87	5,625	2,999	-
Cashew	1,864.05	1,009.05	628.00	9,750	4,680	-
Onion[1]	12,753.36	840.86	1,383.15	-	7,500	5,625
Papaya	3,479.52	-37.28	1,886.98	14,625	8,665	-
Paprika[2]	3,916.48	3,712.48	1,447.31	10,562	5,633	5,228
Passion Fruit	13,871.55	8,351.55	1,724.03	-	10,405	-
Peanuts[2]	3,716.30	1,940.97	771.06	7,500	-	4,950
Pumpkin[1]	3,373.01	3,815.50	660.97	-	4,333	3,218
Tomato[1]	30,781.49	3,623.99	1,344.63	-	5,000	3,713
Watermelon[1]	3,970.19	3,339.45	631.19	-	2,778	2,063
Orange (Alternative)	-	1,540.03	616.00	-	6,802	-

[1] Two growth periods per year applicable

[2] 1.5 growth periods per year applicable

The perennials coconut and banana, which farmers preferred as they provide yields monthly and require less input, were economically not competitive to high value fruit plantations, such as guava or mango. In banana cultivation, frequent harvests and prunings caused relatively high labor requirements; and the plant density of 1,111 plants per hectare combined with high water requirements of the plants lead to the highest water consumption of the investigated crops.

Table 23: Depreciation and variable costs of water efficient irrigation systems without and with 2.5% interest rate

Crop	Costs (R$/ha/year)			
	Micro sprinkler		Drip irrigation	
	No interest rate	2.5% interest rate	No interest rate	2.5% interest rate
Banana	450	500	-	-
Beans	320	351	-	-
Cashew	420	466	-	-
Coconut	380	420	-	-
Corn	-	-	600	643
Grape	550	614	-	-
Guava	420	466	-	-
Mango	300	329	-	-
Manioc	330	363	-	-
Melon	400	443	530	563
Onion	400	443	800	871
Papaya	380	420	-	-
Paprika	380	420	530	563
Passion Fruit	380	420	-	-
Peanuts	380	420	530	563
Pumpkin	400	443	530	563
Tomato	400	443	540	574
Watermelon	400	443	530	563
Alternative crop				
Orange	300	329	-	-

Water demand was highest with the conventional previously installed sprinkler systems, whereas drip irrigation required least water. Still, drip irrigation had highest costs for implementation and maintenance, whereas the previously sprinkler systems had been provided free with maintenance by the schemes' operator. Costs for implementation and maintenance of micro sprinkler and drip irrigation systems are listed in Table 23. When an irrigation method was not relevant for a specific crop type, water requirements were not considered. For instance, no farmer used the old sprinkler system in banana cultivation, because the high pressure damaged the plant's leafs. In many cases farmers and consultants mentioned that drip irrigation was not applicable because of high implementation and maintenance costs, big distances between the plants, or because the system is damaged during the harvest.

Implementation costs between micro sprinkler and drip irrigation did not differ significantly (around 2,500 R$/ha varying by crop type and plant density). Mean maintenance costs for drip irrigation (around 300 R$/ha/year) were three times as high compared to micro sprinklers, because in case of a defect single sprinklers can be exchanged easily. Assuming an interest rate of 2.5%, the equivalent annual costs were slightly higher than the costs without considering time preferences. This effect was lower in drip irrigation due to the high maintenance costs.

6.3.2 Optimal land allocation under current and average prices

Due to the small farm size, many lots of the interviewees were smaller than one hectare. Thus, data presented in Table 22 were adapted to the practically applicable lot size of 0.5 ha. To satisfy the farmers' preference for safe and regular income, $n \geq 1$ ha was determined to the crops banana or coconut following equation (4). The farmers' risk aversion was considered determining $m \leq 1$ ha for the high risk crops tomato, onion, and paprika according to equation (5). Grape cultivation was excluded from the calculation as it requires high specialization and is the most challenging crop concerning input costs, management, and requirements of skilled day laborers.

Table 24 shows the optimal resource allocation calculated by the LP model as formulated in equation 1 under the conditions in 2013 and the average producer prices of the period from 2009 to 2012. The high prices in 2013, especially for tomatoes, led to high farm profits which were almost three times higher, considering average producer prices. In both scenarios, the total available irrigable land was used for cultivation. The shadow prices for an additional hectare of irrigable land were around 8,000 R$ in both scenarios, influenced by the constraint of high-risk crops in the 2013 scenario. The low price level of tomatoes in the period from 2009 to 2012 led to non-consideration of this crop in this scenario. Under 2013 prices, banana cultivation was the more attractive secure crop, whereas in average prices coconut provided higher income. High labor demand in tomato cultivation claimed most available family labor capacities. Consequently, farmers' preferences shifted from passion fruit to the less labor intensive melon cultivation. The non-consideration of tomatoes in the average price scenario led to a shift towards passion fruit cultivation. Still, family labor capacities were not exploited and no hired labor was employed. The preference for secure income led to farm profit reduction off around 5,000 R$ in both scenarios. Recommended crop rotation appeared advisable as, under average prices, farmers may tend to cultivate more melon, shown by the shadow price of 2,068 R$ for one additional hectare available for Cucurbitaceae. Orange, as the presented alternative crop could not compete economically with existing cropping alternatives; whereas the high shadow prices for one hectare of grapes show the economic potential of this crop.

Table 24: Optimal revenues, resource allocation, and shadow prices under current (2013) and mean (2009-2012) producer prices

Variable	Scenario	
	2013 producer prices	2009-2012 producer prices
Farm profit (R$)	87,833.63	30,978.45
Input of hired labor (hours)	1,110.39	0
Used area (ha)	4.0	4.0
Area banana (ha)	1.0	0.0
Area coconut (ha)	0.0	1.0
Area melon (ha)	1.5	1.5
Area passion fruit (ha)	0.5	1.5
Area tomato (ha)	1.0	0.0
Shadow price area (R$/ha)	7,481.56	8,351.56
Shadow price safe income (R$/ha) [1]	-5,297.73	-5,529.40
Shadow price grape (R$/ha)	2,621.06	25,752.06
Shadow price Cucurbitaceae (R$/ha)	715.62	2,067.74

[1] Due to farmers' preferences for banana and coconut, see also equation (4)

Sensitivity analyses considering time preferences had low impact on the optimal resource allocation. The preferred high-value annuals melon, passion fruit, and tomato were not affected by the time preference. The only perennials considered in the optimal allocation were the low risk crops banana and coconut following equation (4). Due to the time preferences, perennials became less attractive compared to annuals. Thus, the allocation itself did not change. However, the assumed interest rates reduced the CM of banana and coconut cultivation and therewith reduced the total farm profit. In the 2013 price scenario, farm profit declined by 34.91 R$ with an assumed interest rate of 2.5%, and by 194.12 R$ with an interest rate of 10%. Assuming the same interest rates in the average price scenario, farm profits declined by 66.44 R$ and 235.51 R$ respectively. The longer useful economic life of coconut plantations caused stronger declines in the average price scenario due to the effects of compound interest.

6.3.3 Impacts of water pricing, price increase of main perennials, and increased labor costs

Fig. 17 shows the impact of volumetric water pricing on farm income and water consumption. With producer prices of 2013 (Fig. 17, up), moderate water pricing (56 R$/1,000 m³) may lead farmers to implement drip irrigation in tomato cultivation. High water prices (195 R$/1,000 m³) may increase the attractiveness of coconut cultivation against banana cultivation, both irrigated with micro sprinkler systems. Water consumption would decline by 28% (from 35,211.5 m³ to 25,243.5 m³), whereas farm profits would decline by 12% (from 86,793.55 R$ to 76,784.10 R$).

In the average price scenario (Fig. 17, bottom), water consumption did not differ with the suggested water price of 56 R$ and the actual provision costs of 80 R$ per 1,000 m³. At water costs of 92 R$/1000 m³, in coconut cultivation, a shift from sprinkler to micro sprinkler irrigation would lead to reduced water consumption of 4,134 m³, which accounts for 13% of the total water consumption.

Farm income would decline from 30,408.45 R$ to 27,431.98 R$ (10%). Extreme water pricing (334 R$/1,000 m³) may lead to the implementation of drip irrigation in melon cultivation. In that case, relative profit losses from 30,408.45 R$ to 20,603.34 R$ (32%) would exceed the reduced water consumption by 18% (from 32,356.5 m³ to 26,422.5 m³).

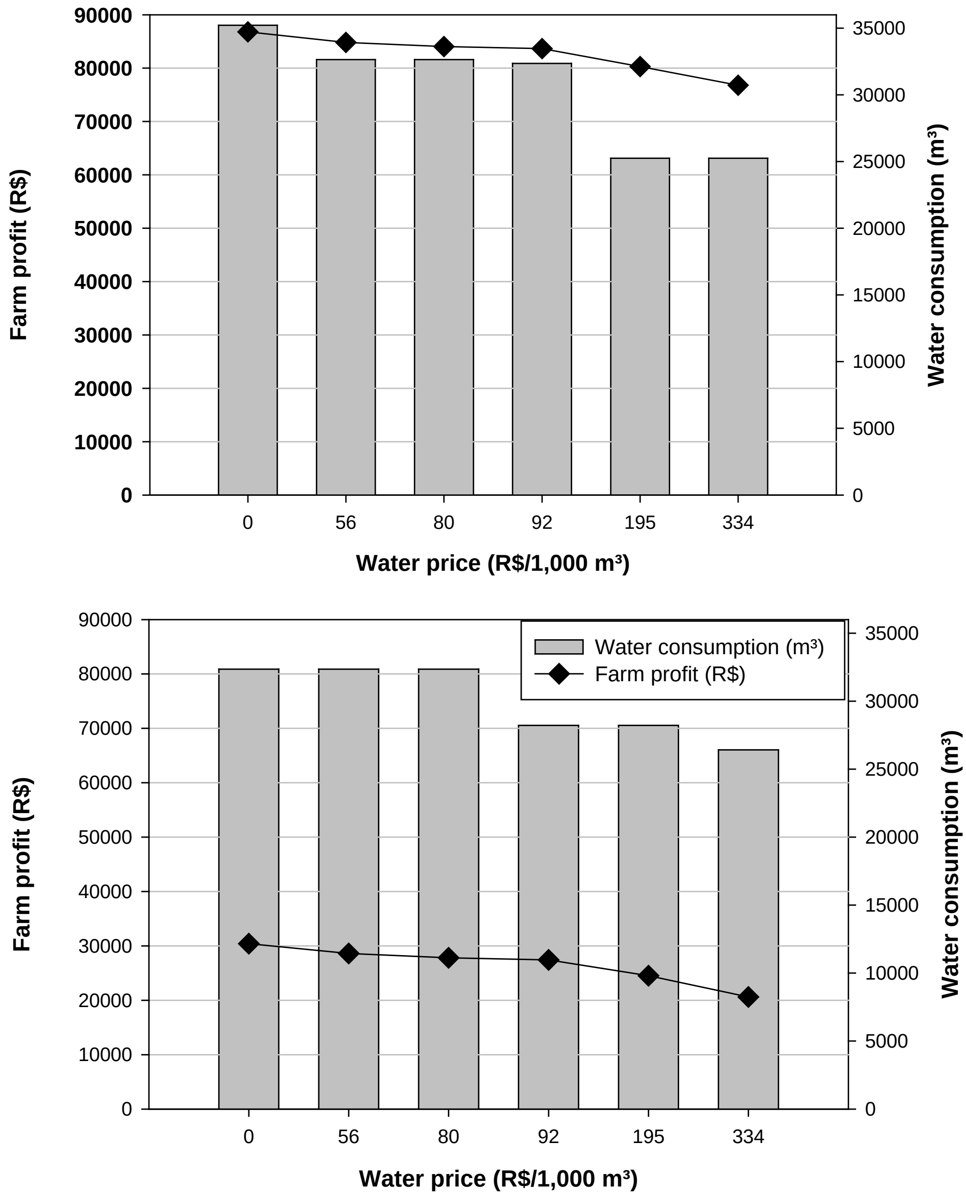

Fig. 17: The impact of volumetric water prices on water consumption and farm income at 2013 producer prices (up) and four-year average prices (bottom)

Fig. 18 illustrates the impact of changing producer prices of the main perennials banana, coconut, guava, and mango, all under micro sprinkler irrigation, on their profitability per hectare. Reduction of producer prices for banana and coconut by 50% would lead to negative profits; in guava cultivation profits were almost zero. Profitability of banana and coconut cultivation was almost similar. Prices had to increase by over 200% to be economically competitive with passion fruit, and by 250% to compete with melon. Mango was the most profitable of the four investigated crops and could compete with a price increase of 150% with passion fruit, and 200% with melon. Assuming a water price of 93 R$ per 1,000 m³ and a price increase of mango by 150% to 1.03 R$/kg, farmers would prefer mango to passion fruit. Considering the described constraints, farmers would cultivate 1 ha coconut, 1.5 ha melon, and 1.5 ha mango, all irrigated with micro sprinkler systems. In that case, farmers would consume 20,898 m³ irrigation water (-33% compared to the average price scenario) to generate a farm income of 27,474.62 R$ (-10% compared to the average price scenario).

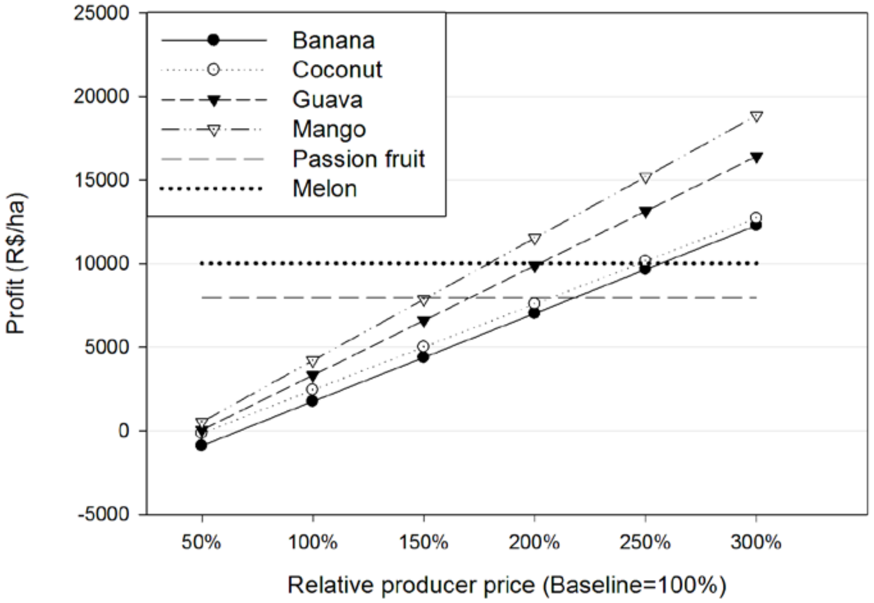

Fig. 18: Competitiveness of the most relevant perennials at different prices levels

Assuming a farm size of four hectares, family labor could satisfy the labor demand of farming activities. Considering high mango prices and water pricing, family labor would be sufficient for an area of five hectares. Consequently, increasing wages of day laborers had no effect on farm income in this study. Still, at a farm size of six hectares, slight increases of wages to 35 R$ per day would affect the farmers' decisions under average prices and high mango prices. In the 2013 price scenario, increase in daily wages up to 50 R$ would have no effect on resource allocation.

6.4 Discussion

This study shows that the current agricultural production systems in the investigated irrigation schemes, given sufficient availability of irrigable land, can provide an adequate farm income under current and average production conditions. The used model had the objective of profit maximization, which was identified as one but not the only objective of the local smallholders. Farmers' risk adversity and preference towards crops providing secure predictable yields agree with findings of Hildebrand et al. (2003) and can be explained by the former subsistence farming practice before the reservoir construction (World Bank, 1998). This study aims at reducing the weakness of the LP model considering preferably the most profitable production alternative by adding the constraint of minimum banana and coconut production. However, the unequal land distribution between the irrigation schemes with irrigable areas from 2 to 6 hectares leads to unequal production conditions so that farm income differs between the irrigation schemes (Hagel et al., 2015a). Despite extremely high prices of many annual crops in 2013, Hagel et al. (2015) identified several households with nearly no farm income.

The model presents an optimized solution for land, water, and labor allocation accessing to detailed production data. In most farmers' everyday life, access to information and the possibility to switch between several crops are restricted. In the study region, farmers were facing lack of extension and access to information and capital, which strongly reduces their adaptation potential to changing frame conditions or their possibility to invest in perennial plantations or modern irrigation technologies (Hagel et al., 2015a). Concentration on the recommended, economically most attractive cash crops may not work in reality, as the demand for a surplus of commodities is not linear, and the price of a commodity will decline if its supply increases (Delgado-Matas and Pukkala, 2013). Increased production of few crops may lead to declining producer prices. Low market power of farmers compared to middlemen, as is the case in the study region (Calvacanti, 2004; Hagel et al., 2015a), may increase this effect. The crisis of tomato cultivation in the Petrolina region in the mid-2000s shows the risk of the concentration on few cash crops (Sampaio et al., 2006). Consequently, and to adapt to the price volatility, further diversification of the production is recommendable.

In this study, high volumetric water pricing appears to be an adequate method to reduce water consumption by counterbalancing the costs of micro sprinkler and drip irrigation. Considering interest rates and time preferences of the invested capital in water saving irrigation technologies may lead to even higher recommended water prices. However, with an interest of 2.5% the effect was assumed as rather low. Still, considering the income insecurity of many smallholders and extremely low producer prices in the study region, promotion of water efficient irrigation technologies seems necessary when implementing water prices. Instead of subsidies, efforts to approximate the producer prices to the regional level seem more appropriate. Agricultural cooperatives or associations can contribute to increase producer prices by joint commercialization (Hagel et al., 2015b). Another aspect of water pricing, which is not easily quantifiable, is raising the awareness of the value of water in the semi-arid environment and therewith lead to reduced water consumption (Rodorff et al., 2014). In this study, considered water consumption was based on counting the number of irrigating units and the statements on how long and how often farmers irrigate. These statements orientated conspicuously at the recommendations of the local technical assistance, but there were indications that farmers irrigated twice as long than recommended and therewith the actual water consumption was significantly higher than assumed. As water meters do not exist on farm scale but only on higher scales, such as sub-units of each irrigation scheme, exact water consumption by farm is not traceable. Water consumption of the resulting illegal irrigation on adjacent drylands may result in even higher water consumption. Both wasteful and illegal irrigation may be drastically reduced by installation of water meters, which are crucial to implement volumetric water prices. The probable aggravation of water scarcity in the study region induced by climate change (De Lucena et al., 2009) underlines the importance of improving the water use efficiency (Maneta el al., 2009). Remote sensing may provide an applicable alternative to measure water use in irrigated areas (Folhes et al., 2009). Excessive irrigation may also increase nutrient leaching and subsequently, pollution of drainage water (Sims et al., 1998; Zotarelli et al., 2007). Combined with the necessary agricultural consultancy and consequent site-adapted fertilization, water pricing and subsequent reduced irrigation may also have positive external effects. Considering the evidence of overuse of irrigation water and the wide distribution of sprinkler irrigation with low water use efficiency, the implementation of an appropriate water price combined with agricultural consultancy and support to increase the farmers' market power appears recommendable.

Increasing wages of day laborers were not relevant for the farm size and the identified economically most attractive crops considered in this study as available family labor was not totally exploited. Still, farm income of many farmers in the, admittedly wealthier, Apolônio Sales irrigation scheme could be influenced strongly by increasing wages (Hagel et al., 2014). On the one hand, irrigation agriculture provides employment opportunities in an economically underdeveloped region; on the other hand, the micro sprinkler and drip irrigation technologies allow fertigation, which significantly reduces the workload.

In this study, no economic favorable cropping alternatives could be identified. The high distribution of banana and coconut reflects the farmers' preference towards secure predictable yields. Cucurbitaceae and beans were cultivated due to relatively high prices during the study period (see also Hagel et al., 2015a), and corn to ensure livestock survival rate during the severe drought. Orange, investigated as a cropping alternative in the semi-arid region by the governmental research institution Embrapa, was not competitive as there was no established market and therefore low producer prices which were one tenth of the northeastern average. The same applies to sparsely cultivated crops coriander, lemon, cotton, and rice. For these crops, further research is recommended to assess their potential as production alternatives to the dominant established crops. The biggest deviation of registered yields in comparison to secondary data (CODEVASF, 2013a; IBGE, 2013b) occurred in paprika cultivation, probably due to the small sample size. Whereas the three paprika producers in the sample harvested around 11.8 t/ha, CODEVASF (2013a) indicates yields of 25-50 t/ha. Consequently, in further planning, paprika should be considered as production alternative. Besides cropping alternatives inside the irrigation schemes, development of off-farm income alternatives seem crucial particularly in the context of scarce irrigable land.

6.5 Conclusion

This study aims at a scientific contribution to improve the livelihoods of smallholders in irrigation schemes at the Itaparica reservoir in semi-arid northeast Brazil and to support local decision makers to implement an improved water management. Applying site-adapted optimization models can support decision makers and farmers to plan their organizational and economic activities towards optimal resource allocation. The economic impact of farmers' preferences and the recommendations of agricultural consultancy in favor of low risk crops could be quantified. Also, recommendable water prices and their impact on farm income could be identified. The agricultural production system in the study region has changed recently due to the dam and reservoir construction and following the implementation of irrigation schemes. Farmers, of which most used to be subsistence farmers of rainfed agriculture, still require agricultural consultancy and support to improve their organizational structure. While water pricing seems to be a suitable tool to reduce water consumption, infrastructural improvements leading to increased producer prices are more complex. Considering the recent droughts in semi-arid northeast Brazil, income alternatives besides irrigation farming, such as value adding facilities of agricultural commodities or off-farm activities, gain importance.

Acknowledgements

This study was conducted within the project “INNOVATE” (01LL0904C) and funded by the Federal Ministry of Education and Research (BMBF; Sustainable Land Management program). The authors would also like to thank all farmers who patiently participated at the interviews.

Chapter 7. Characteristics of agricultural production systems outside the irrigation schemes of the Itaparica region

In the previous chapters, this dissertation provides a detailed overview on irrigated agriculture in the Itaparica region. As mentioned in the general introduction and considering agricultural censuses (IBGE, 2006; IBGE, 2013b), irrigation schemes, which are mainly set up for smallholders, play a major role for irrigated agriculture in the study region. Considering the plans of CODEVASF to expand irrigation schemes, their relevance will increase significantly in the next decades (CODEVASF, 2015a). However, agricultural production outside the irrigation schemes, which provides the livelihood for many subsistence farmers, has to be considered to understand the whole context of agricultural production in the study region. Another facet of agricultural production along the lower-middle São Francisco is added by the intensive fruit production systems in the Petrolina region. Differences and similarities between the Itaparica and Petrolina regions are well described by several sources (Ferreira Irmão et al., 2013; Untied, 2005) and several studies investigated the irrigation schemes in the Petrolina region (Andrade, 2011; Calvacanti, 2004; Collins, 1993; Damiani, 1999; Damiani, 2003; Lima and Miranda, 2001; Possídio, 1999; Rocha et al., 2008; Scott, 2006 among others). However, detailed data on agricultural production outside the irrigation schemes in the Itaparica region and on production in irrigation schemes in the Petrolina region for the study period were not available. To get a common and completely comparable database, 22 interviews in the Nilo Coelho irrigation scheme and 30 interviews in the Itaparica region outside the irrigation schemes were conducted as had been shown in Table 19 in Chapter 6. During the study period, production in the Manga de Baixo irrigation scheme, the fourth public irrigation scheme in the Itaparica region, had almost stopped. Still, few smallholders identified a market niche so few results of this sample (n=20) are presented in the chapter as well.

The consideration of key statistics is a valuable tool to understand complex contexts such as the diversity of agricultural production systems and the gap of agricultural production between the Itaparica and the Petrolina region. In the following, a short comparison between the three agricultural production systems – the irrigation schemes in the Petrolina region, the irrigation schemes in the Itaparica region and the production outside of the irrigation schemes in the Itaparica region – is presented using descriptive statistics. Finally, the main characteristics of agricultural production in the Manga de

Baixo irrigation scheme and of subsistence farming in the Itacuruba municipality are described.

7.1 The Nilo Coelho irrigation scheme in comparison to agricultural production in the Itaparica region

As shown in Table 25, lot size between the three main production systems strongly differed. The high standard deviation (6.11) in the irrigable area of farmers outside the irrigation schemes reflects the land tenure structure. Smallholders in the Nilo Coelho irrigation scheme possess, theoretically, nearly equal irrigated areas. In the schemes of the Itaparica region, areas differed by irrigation scheme. In practice, several farmers in the Petrolina region reported that they possessed additional areas, which were, officially, the property of close relatives. The same situation was reported in single interviews in the Apolônio Sales irrigation scheme. By doing so, wealthier farmers circumvented the officially planned equal land tenure.

The high variance of dryland areas in comparison to the mean areas in the whole sample indicates specialization of few farmers towards livestock farming. This is confirmed by the high variance of stocking rates. The low stocking rates in the Nilo Coelho irrigation scheme indicate high workload, sufficient income in irrigated agriculture, or even economically more attractive off-farm income alternatives. In the case of independently irrigating farmers outside the irrigation schemes, livestock farming provided an important income alternative, especially considering the lack of guaranteed availability of irrigation water. The apparently low numbers of TLU do not reflect low stocking rates as small ruminants, which are common in the study region, equal 0.1 TLU per animals (Chilonda and Otte, 2006; Jahnke, 1982). Whereas interviewed household heads did not differ significantly in age, the interviewees in the Nilo Coelho were on a higher educational level than the ones in the Itaparica region.

Considering the main crops, farmers in the Nilo Coelho irrigation scheme appeared to be more specialized in high value fruit production than those in the Itaparica region. Although farmers in the Nilo Coelho scheme also cultivated banana and coconut, the production of higher value, but also more labor, technology, and knowledge intensive crops dominated. In the Itaparica region, the lower importance of *Cucurbitaceae*, such as pumpkin and watermelon, outside the irrigation schemes indicate recurrent water scarcity, especially on lots distant from the river or reservoir. Crop yields and producer prices can be clearly distinguished by region. Except in the case of banana cultivation, yields and producer prices in the Nilo Coelho irrigation scheme were significantly higher than the ones in the Itaparica region, independent from the exact location of the farm. This may be mainly due to the better infrastructure as mentioned in the previous chapters and identified by Untied (2005), among others. However, the relatively high yields and producer prices indicate the potential of irrigated agriculture in the study region, although high mechanization and use of modern technology in the Nilo Coelho scheme requires knowledge and availability of capital. The main crops in this region, grape and mango (CODEVASF, 2013b), especially when cultivated for exportation, require high specialization. However, higher yields and producer prices in coconut and guava cultivation show the potential of regionally or nationally commercialized products.

Table 25: Main characteristics of interviewed farmers in the Itaparica and Petrolina regions

	Nilo Coelho scheme	Itaparica region*	Independent irrigators
Mean irrigable area [ha]	8.83 ± 3.18	4.55 ± 2.32	7.25 ± 6.11
Mean drylands [ha]	6.93 ± 12.82	0.55 ± 5.93	5.70 ± 5.66
Livestock [TLU]	1.29 ± 2.89	4.02 ± 8.80	5.89 ± 9.97
Age HH head [yrs]	52.5 ± 13.36	51.95 ± 12.69	50.85 ± 14.12
Education HH head [yrs]	12 ± 3.52	8.00 ± 3.25	9.35 ± 2.96
Main crops	Acerola, Coconut, Guava, Grape, Mango	Beans, Banana, Cucurbitaceae, Coconut	Beans, Coconut, Cassava, Mango
Mean yields [kg/ha]			
- Banana	12,000 ± 1,633	9,394 ± 1,702	10,000
- Coconut	39,110 ± 4,891	23,335 ± 6,544	11,667 ± 3,605
- Guava	24,000 ± 9,391	10,730 ± 5,555	6,000
- Mango	23,867 ± 9,775	16,625 ± 5,118	12,000 ± 2,645
Mean prices [R$/kg]			
- Banana	1.250 ± 0.289	0.998 ± 0.071	1.6
- Coconut	0.367 ± 0.137	0.254 ± 0.049	0.219 ± 0.011
- Guava	1.160 ± 0.089	0.977 ± 0.166	1
- Mango	0.833 ± 0.287	0.515 ± 0.108	0.467 ± 0.076

* Apolônio Sales, Barreiras, and Icó-Mandantes irrigation schemes

7.2 Agricultural production in the Manga de Baixo scheme

In the Manga de Baixo irrigation scheme agricultural production had nearly stopped during the study period. Of the 21 interviewed farmers, 17 cultivated beans, coriander, and onions on small lots of each 0.5 to 1.5 ha. Mean farm size was 2.86 ha (SD = 1.70). Three farmers used their irrigable land exclusively for forage grasses, one for cassava. Only seven farmers did not keep animals, the others possessed cows, goats, and sheep (average 3.92 ± 4.38 TLU). Farmers mentioned during the interviews that soils were not suitable for efficient crop production but, to a limited extent, sufficient for fodder production and subsistence agriculture. For that reason, only one farmer had to grow forage grass on additional 3 ha of dryland.

7.3 Analysis of the interviews conducted in the Itacuruba municipality

The sample interviewed in the surroundings of the Itacuruba municipality was more diverse and represented small subsistence farmers as well as owners of larger areas. The mean irrigable area was 5.60 ha (SD = 5.55). As there were no irrigation schemes and irrigation water limited, only one farmer cultivated perennial fruits (papaya). Main crops were the annuals beans, onions, and forage grass. Main irrigation method was flood irrigation supported by small diesel pumps. Only one farmer possessed a micro-sprinkler irrigation system. Two wealthier farmers, one using micro-sprinkler and one using flood irrigation, had built small reservoirs and were using a similar system as in the irrigation schemes, where the water is distributed from smaller reservoirs in higher altitudes to the lots by gravity. However, agricultural production still relied on rainfall, as irrigation could not meet the total water demand of crop production. Two interviewees cultivated beans, corn, and forage grass solely in a rainfed system. Mean dryland area was 24.45 ha (SD = 25) and farmers possessed an average of 23.44 TLU (SD = 38.31). Although there was no observed correlation between irrigable area, drylands, and herd size, the bigger herd sizes and dryland areas in this sample hint at the importance of livestock as income source in case of limited irrigation water availability.

Chapter 8. General discussion and conclusions

Due to the cumulative character of this dissertation, the methods and results of each study have been discussed in the respective chapters. However, this dissertation aimed at answering overall research questions which go beyond the content of the single chapters. Likewise, the methodology was designed considering the content of the overall study. For this reason, in this chapter the comprehensive study design and methodology are looked at in their entirety. In the following sections 8.2, 8.3, and 8.4, the main hypotheses presented in Chapter 1, are verified and the overall results of this dissertation are discussed.

8.1 Study design and methodology

The suitability of the chosen methodology to achieve each chapter's objectives is discussed in the corresponding chapters. For that reason, the overall structure of the applied methods, the organization within the five chapters, and the process of the studies are discussed.

8.1.1 Preparation of the survey

As mentioned in Chapter 3, sixteen expert interviews were conducted to get a detailed insight into the socio-economic situation of irrigated agriculture in the study region. Whereas big quantitative surveys are time and cost intensive, qualitative approaches, such as group interviews, focus group discussions, key informant interviews, informal surveys, or direct observations, represent rapid low-cost methods for data collection. Especially when further hypotheses need to be formulated and research questions have to be refined, key informant interviews and literature reviews are widely used (Kumar, 1987). Despite the relatively low input requirements considering time and budget, interviewed experts have to be selected carefully to provide a sufficient quality of retrieved information. To correctly interpret the answers and to interact constructively during the interview, the interviewer needs to be fully familiar with the research topic. Experience in the methodology and knowledge of the experts' language are also crucial to receive significant information (Kumar, 1987; Kumar, 1989). Although open questions allow adaptations during the interview and provide certain flexibility, the guidelines for the interviews require precise and thoughtful preparation (Atteslander, 2010; Kumar, 1987). Comparing the retrieved results with previous studies (Untied, 2005; World Bank, 1998) and the information retrieved during the quantitative survey (see also Chapter 3) from various residences in the study region, it can be concluded that the methodology suited well to the objective of an in-depth understanding of the socio-economic situation of irrigated family farming in the study region and the semi-arid Northeast.

8.1.2 Questionnaire design and data collection

Intensified economic evaluation of agricultural production at farm level requires detailed quantitative data of agricultural production, especially considering the complexity of modern agricultural production, and the precise formulation of farm optimization models (Hazell and Norton, 1986; Murphy and Sprey, 1983; Nuthall, 2011). Also decision makers, representing the target stakeholder group for the practical implementation of this dissertation's results, prefer recommendations based on quantitative data as precise numbers are easier to interpret (Kumar, 1987).

For that reason, the main part of this dissertation is based on the quantitative data collected during the farm household survey in 2013. Similar to qualitative interviews, farm surveys require accurate preparations (Murphy and Sprey, 1983). Due to the rural character of the study region, a farm survey was preferred to multiple mode surveys described by De Leeuw (2005) or Groves and Heeringa (2006). There are several guidelines and compilations of tools about the conduction of empirical social research and farm surveys available (e.g. Atteslander, 2011; Bernard, 2006; Kumar, 1986; Murphy and Sprey, 1983; Nuthall, 2011; Schnell et al., 2011). Based on these guidelines, contacts to local stakeholders and farmers were established during two field trips in 2012. The questionnaire was tested during the second field trip in 2012 and adjusted to local farmers' idiom, supported by experienced agricultural consultants. During the pre-test, it turned out that few farmers kept an account of their applications of fertilizer and agrochemicals. Applications in the field as well as yields were calculated in specific units – e.g. yields were usually calculated in boxes per lot, agrochemicals in sprayed tanks per lot, and fertilizer in "a scoopful per plant" as described in Section 0. Accordingly, the questions asked in the field had to be adapted to these characteristics and, either in the field or later when entering the data, converted to numerical data such as ton per hectare. For such calculations, further details which had originally not been included in the questionnaire were necessary. For instance, lot sizes could be calculated by number of plants per lot and the distances between rows and plants; yields by number and weight of filled boxes per day and number of days per harvest. To ensure the compliance with these requirements and therewith the quality of collected data, several trainings with the interviewers including common interviews in the field were conducted. Murphy and Sprey (1983) also underline the importance of field visits to comprehend inconsistent answers. Consequently, most interviews were conducted on the lots. During the few interviews in the center of Petrolândia, the experienced interviewers, who had worked for years in the irrigation schemes, could usually identify outliers and ask immediately for reasons, for example low yields caused by pests.

Despite accurate planning of the field survey, the study had to be adapted several times during the interview period. During the second field visit in 2012, PLANTEC was identified as the main stakeholder for the survey interviews and one of the main stakeholders for the implementation of results. Thus, contacts were established in the Itaparica and Petrolina irrigation schemes and PLANTEC officials assured assistance for the whole project's period. In this time and in all the irrigation schemes operated by CODEVASF, PLANTEC had hired numerous consultants and had several means of transportation available. The existing infrastructure was supposed to support the team of interviewers, consisting of the junior researcher of this study and several Brazilian students. However, at the beginning of the interview period, the contract between PLANTEC and CODEVASF had expired and there was no agricultural consultancy in the irrigation schemes. Officials and most of the consultants had left the region or found employment elsewhere. Lack of consultancy also reduced the farmers' willingness to cooperate with strangers; in this case, foreign researchers. In addition, at the beginning of the study period in February 2013, there were water shortfalls due to a strike by the operator of the schemes' infrastructure, HIDROSONDAS, in the Barreiras and Icó-Mandantes irrigation schemes. As a consequence, farmers occupied several pumping stations and blocked the main roads in the scheme which made any research in the area impossible (see also Campos, 2013).

Fortunately, the help of PLANTEC consultants could be enlisted for the field survey. On the one hand, hiring experienced consultants as interviewers was more costly than conducting the interviews with a team of students. On the other hand, working with experts on agricultural production in the study region accelerated the field work and partly compensated the delays caused by the adaptation of the research plan. Two interviewers resigned during the beginning of the survey because they found a more profitable employment. However, alternative interviewers could be identified and were comprehensively trained with the questionnaire. All interviewers were well integrated in the local society, which facilitated the access to farmers significantly. Some of the randomly selected farmers agreed to the interview after a typical personal deal, a so-called *jeitinho*. For instance, the farmer agreed to give two hours for the interview but received technical advice, such as pest control or pruning, in return. Experience about the particular situation in the irrigation scheme was also valuable as there was a risk of armed robberies, especially on less frequented roads and areas where Cannabis production still persisted (see also Untied, 2005; World Bank, 1998).

Finally, 193 farm household interviews could be conducted successfully. Fig. 19 shows the conduction of interviews at the lots (left and middle) and in front of a farmer's house (right). Due to either a personal relation to most interviewers or one established during the field work, nearly all farmers were willing to share personal and business details. Retrieved data conformed to available secondary data (e.g. CODEVASF, 2013a; CODEVASF, 2013b; IBGE, 2006; IBGE, 2013b) so there were no quality improvements necessary (see also Wolff, 1997). Slightly lower yield levels than the ones reported in secondary data can be explained by the lack of technical assistance during the study period. Variable production costs were higher than those reported by CODEVASF (2013a) – probably due to increased minimum salary (Presidência da República, 2010) and increased inputs such as fertilizer and agrochemicals, as the observed amounts of inputs exceeded official recommendations, such as Embrapa (2014).

Fig. 19: Household interviews in the field (left, middle) and in front of the farm (left)

8.1.3 Trade-offs

As mentioned earlier, the field work of this dissertation took place in a period in which agricultural consultancy was not provided. Considering the historical background of the irrigation schemes and the resulting importance of consultancy on agricultural production as analyzed in Chapter 3, the yield levels used in this dissertation are below the potential yields in the study region. However, the gap between observed yields and those of previous years (CODEVASF, 2013a) was not significant, which can be explained by the short period without consultancy.

Another disadvantage of the timing of the field work is discussed in detail in Chapter 5 and Chapter 6. As illustrated in Fig. 11 in Chapter 3, producer prices for agricultural commodities had increased strongly as a consequence of a severe drought. Thus, for the LP models, average prices for the period 2009 to 2012 were used to obtain representative results. Analyzed data and concluded recommendations were presented on the 9th and 10th of November 2015 to farmers during a workshop in Apolônio Sales and CODEVASF officials in Petrolina, respectively. The presented findings were discussed in detail and fit well to the perception of the audience. However, expanded time series including yield levels, input prices, and labor and opportunity costs for the same period as producer prices might have led to more precise results.

Calculated water consumption, as mentioned in Chapter 6, was based on the farmers' statements on frequency and duration of irrigation. As the study was conducted during a severe drought, interviewees may have been sensitized to the overuse of irrigation water. During few interviews, relatives or neighbors of the interviewed farmer stated that the actual irrigation amount exceeded the interviewee's indications. However, more precise information on this was unavailable. A calculation based on the actual water consumption per irrigation scheme appeared pointless, considering the estimated extent of illegally irrigated areas. Consequently, the real water saving potential in the irrigation schemes may exceed the calculated potentials of Chapter 5 and Chapter 6.

In general, data quality of farm surveys strongly depends on the interviewer's qualification, content quality of the questionnaire, and the preparation of the field work (Murphy and Sprey, 1983). As several interviewers were involved in the field work and many statements had to be converted several times on their process from the field to the digital database, errors cannot be completely excluded. The presence and probably different productivity of illegal plantations may also have affected the results. Nonetheless, the sample size and consideration of outliers could reduce these negative effects. The conformity of the results with existing studies and farmers perceptions argue for the quality of retrieved data in the content of this dissertation.

The suitability of LP models to provide farm optimization plans has been discussed in Chapter 5 and Chapter 6. The models, considering the local farmers' preferences, turned out to be an easily understandable tool, delivering reasonable results for decision support. However, the implementation of alternative crops and improved production methods, such as water efficient irrigation systems, requires further site- and stakeholder-adapted reviews. Theoretical models can not consider all transaction costs, which differ between regions and even farmers. Whereas researchers have a comprehensive dataset and detailed information available, small family farmers with limited access to capital and information cannot easily implement previously unknown crops or production methods. Considering the risk adverse character, as identified in Chapter 6, target-oriented agricultural consultancy and guaranteed adequate support during the implementation phase seems crucial for the successful implementation of production alternatives.

8.2 Farm income is affected by the socio-economic status of the household head

The role of the socio-economic status of the household heads on the household's farm income was discussed in detail in Chapter 3. Analyses of qualitative data pointed out, that family status, especially considering political influence and land and capital availability, strongly impacts the farm and also the total income. However, significant differences could be solely identified between the Apolônio Sales irrigation scheme and the Barreiras and Icó-Mandantes irrigation schemes. Socio-economic characteristics of the household head and the location of the farm had no significant impact on farm income. The statistical model explained the farm income (adjusted R Squared = .632) mainly as a function of crop choice and land availability. However, a correlation of crop profitability and planted area with agricultural income is apparent. As the interviews conducted in the irrigation schemes of the Itaparica system ranged over three irrigation schemes, the sample size may have been too small for significant results. Nonetheless, the integration of the three major irrigation schemes in the study region was necessary to retrieve representative data on the whole range of agricultural production. The chosen statistical tests, analysis of variance and regression analysis, are well established (Adebayo and Idowu Oladele, 2013; Ayenew et al., 2010; Baig et al., 2014; Safa, 2005). However, even if the methodological approach was carefully chosen, there may remain some doubts. Recent research underlines the impact of chosen statistical tests to retrieved results (Silberzahn et al., 2015). To obtain objective results, MacCoun and Perlmutter (2015) even recommend blind analysis to eliminate the impact of existing publications on new studies.

Although there was no significant impact of the irrigation scheme variable on farm income, the significant income gap between the Apolônio Sales irrigation scheme and the Barreiras and Icó-Mandantes irrigation schemes indicates relevant effects. The impact of the status of family members was not included in this analysis. As discussed in Chapter 3, family members in many cases significantly contributed parts of their off-farm income to the household. As these assets were also available for investments in agricultural production, they may influence the farm income indirectly. The role of off-farm income for farm households has been outlined by Boos (2015) (see also the contribution Boos et al., 2015 in the Annex). Off-farm income provided 45.2% to the household income in the Icó-Mandantes irrigation scheme; in the Apolônio Sales irrigation scheme the share of off-farm income was 56.7% (Boos, 2015). Graziano da Silva and Eduardo del Grossi (2001) highlighted that farmers with off-farm income could generate higher farm income. Finan and Nelson (2001) also analyzed the importance of off-farm income. In the study region of this dissertation, the intensive fruit production on soils with low fertility involves high input requirements in comparison to the traditional subsistence or recession agriculture. Considering also the risk of yield losses caused by water shortages and volatile producer prices, alternative income sources represent an important competitive advantage. In addition, regular off-farm income can improve the access to credits which, in turn, may positively influence farm income. Water pricing may, besides the assumed necessity to economize water, favor wealthier farmers who can easily handle the transaction and implementation costs of efficient irrigation methods. Personal connections, as also stated by Kenny (2010), play an important role concerning access to state services. In the case of the study region, farmers in the Apolônio Sales irrigation scheme seemed to be better connected to political decision makers – for instance one of the farmers was the mayor of Petrolândia – and therewith more influential than farmers in the other irrigation schemes.

By any means, farm income in the irrigation schemes of the Itaparica system was highest in the wealthier Apolônio Sales irrigation schemes. Considering profitability per area (R$/ha) the income gap decreased strongly. However, it cannot be clearly stated whether capital availability, irrigable area, soil fertility, political or social influence, access to infrastructure, or personal characteristics of the household's decision maker was the key determinant on farm income. Natural factors, such as soil fertility, and social factors, such as political and social influence or personal characteristics, were out of the scope of this dissertation and could not be analyzed in detail. Thus, due to the lack of significant impact of the chosen socio-economic characteristics of the households' heads on farm income, the hypothesis *"Farm income is affected by the socio-economic status of the household head"* has to be rejected. However, there are strong indications that a combination of the listed factors is crucial for the economic success of agricultural production. This conforms to findings of Untied (2005), who identified capital, influence, and income alternatives as factors of success of family farmers, and of Finan and Nelson

(2001), who identified social and cultural constraints as inhibiting forces weakening the potentials of scientific and technological progress to reduce the impacts of droughts.

Irrigated family farming is highly vulnerable to changing production conditions

Recent analyses on social vulnerability in Brazil underline the critical situation in the country's northeast (IPEA, 2015). The Brazilian Index of Social Vulnerability (IVS)[1] indicates high to very high social vulnerability in the northeastern region, although there was a significant decrease in vulnerability in the last decade. Similar to the average values for Pernambuco state (IVS=0.414), the social vulnerability in Petrolândia is classified as "high" (IVS=0.419). Due to the city's reconstruction in the context of the Itaparica Reservoir construction, the infrastructure is well developed which distorts the overall IVS. The IVS considering urban infrastructure was 0.173 ("very low"), whereas the IVSs for human capital and income were 0.556 and 0.528 respectively (Aurélio Costa and Oliveira Marguti, 2015; IPEA, 2015). These analyses conform to results of Untied (2005) considering social vulnerability of irrigated family farming. It is underlined that improvements in the content of the dam and reservoir construction set in, but were mainly related to basic urban infrastructure, such as quality of dwellings, water and electricity supply, or waste management. Despite infrastructural benefits in the *agrovilas*, as also described in Chapter 3, the rural population benefited less from those improvements. Most of the interviewed smallholders stated that they considered their livelihood endangered in the long term (Untied, 2005).

Besides the discussed social vulnerability of the rural population, the economic vulnerability considering irrigated family farming could be identified in this dissertation. The vulnerability of agricultural production against annual rainfall variability was investigated in Chapter 1. Although susceptibility to droughts was highest in rainfed systems with annual crops, perennial crop production was also affected – even in the following year due to memory effect, as shown in Chapter 2. However, the main adaptation strategies consisted of the switch from the cultivation of annual to perennial crops and the

[1] The IVS is calculated based on indicators of the IDHM for the years 2000 and 2010. The considered indices can be divided into three classes: 1) Urban Infrastructure, 2) Human Capital, and 3) Income and Employment. The index reaches values between 0 and 1. Values between 0.401 and 0.5 indicate high vulnerability; values above 0.5 indicate very high vulnerability (Aurélio Costa and Oliveira Marguti, 2015).

increase of stocking rates of small ruminants and chicken. However, increased stocking rates of grazing ruminants, such as the locally common goats, may lead to overgrazing and degradation of the natural Caatinga vegetation (Leal et al., 2003; Leal et al., 2005; Santo et al., 2012). Reduction of land cover in the semi-arid region is likely to negatively affect the local climate and therewith induce further degradation of the native vegetation and yield losses in agricultural production (Burney et al., 2014; Oyama and Nobre, 2004).

Whereas the study presented in Chapter 1 considers solely local rainfall, water availability of the reservoir and therewith for the irrigation schemes depends on rainfall in the whole watershed of the São Francisco River. Therefore, the vulnerability of irrigated family farming may even be dramatically higher than indicated in Chapter 1, especially considering the severe drought from 2013 lasting until 2015 and the resulting endangered water availability in the reservoirs. Fig. 20 illustrates the development of the average annual water levels of the Luiz Gonzaga (formerly Itaparica) and the Sobradinho Reservoir for the last ten years.

Whereas no interviewed farmer suspected water scarcity in the future during the study period in 2013, farmers were facing water scarcity in 2014. During the field visit in October 2014, technicians from PLENA – the new operator of the schemes' irrigation infrastructure – started preparing the farmers for water shortages with plans of possibly

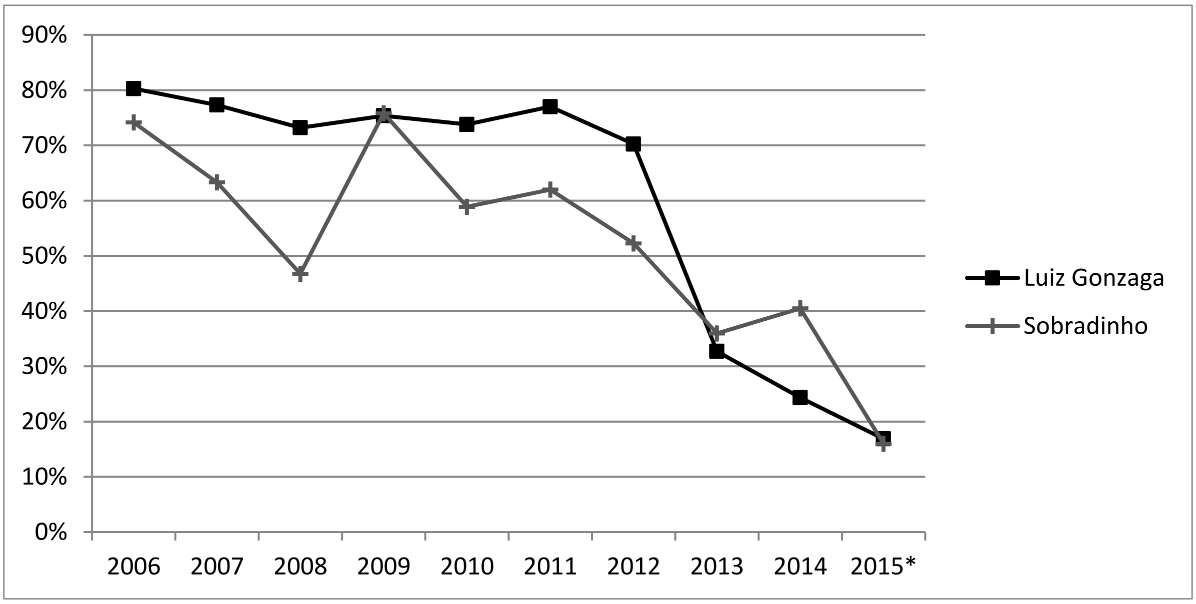

Fig. 20: Development of the water levels of the Luiz Gonzaga (formerly Itaparica) and the Sobradinho Reservoir. Source: Own figure and calculations after ONS, 2015.

*: Due to missing values for November and December 2015, a mean value from January to October 2015 was created.

cutting down irrigation water to every second day. During the field visit in November 2015, the water-level of the reservoir had declined even further and the reservoir was filled to only 10.71%. The situation in the Sobradinho reservoir, the biggest reservoir at the São Francisco River was even worse (1.11% of the capacity) (ONS, 2015). Consequences of the drought and the irrigation infrastructure on agricultural production in the Icó-Mandantes irrigation scheme are discussed within the farmers' community (Campos, 2015).

The analyses of the farm household data collected in the context of this dissertation underlined the vulnerability of the farm income in the study region. As illustrated in Fig. 12 in Chapter 3, nearly half of the interviewed farmers (n=50) in the Itaparica irrigation schemes had an annual farm income below 8,136 R$ which equals the minimum monthly salary of 678 R$ in the year 2013 (Presidência da República, 2012). In the Icó-Mandantes irrigation scheme, limited availability of irrigable areas was identified as the main reason. In this irrigation scheme, 68% of the interviewed farmers (n=32) generated farm incomes below the minimum salary. The suitability of the minimum salary as a poverty or vulnerability indicator for small family farmers in the study region will be discussed in detail in section 8.3. However, low producer prices and high input costs affected the profitability per hectare in all three irrigation schemes. Chapter 4 illustrates the reasons for the very limited success of agricultural cooperatives, which might have the potential to increase the smallholders' market power. As the analysis in Chapter 3 was conducted during a period of high prices and the absence of agricultural consultancy had no significant effect on yields yet, it can be assumed that the farm income is significantly lower in periods of low or average prices. Consequently, limited commercialization opportunities combined with price volatility can be considered as one of the main reasons for vulnerability of irrigated family farming in the study region.

In Chapter 5, the impact of changing production conditions on the profitability of the three main perennial crops in the region, banana, coconut, and mango, is analyzed at the example of the Apolônio Sales irrigation scheme. Low water pricing and moderately increasing daily wages could reduce the annual farm income by over 30% (from 37,320 R$ to 21,875 R$). It has to be emphasized, that this analysis was conducted as an example of the economically wealthiest of the three irrigation schemes of the Itaparica system, assuming a farm size of eight hectares. In the Icó-Mandantes irrigation scheme, 29 households (61.7%) had maximum three hectares of irrigable land available.

The analyses conducted in this dissertation could clearly show the vulnerability of irrigated family farming towards changing production conditions. The rapid decline of the water level in the reservoir indicates an even higher vulnerability, as assumed from the collected data.

8.3 Irrigated family farming has the potential to provide an appropriate livelihood in rural areas

Despite the high vulnerability of irrigated family farming, several benefits and potentials of the production systems could be identified. As discussed in Chapter 1, perennial crops are more resilient against droughts than annual crops. In general, it is obvious that irrigation can dampen the negative effects of droughts. For these reasons, the potential of appropriate irrigation to increase family farmers' drought resilience appears evident.

Although many farmers generated low revenues with agricultural activities as discussed in section 0, more than half of the interviewed farmers in the Itaparica irrigation schemes (n=57) had a farm income above the minimum salary. The farm income of 26 households exceeded two minimum salaries. Although 17 of those farmers had their lots in the Apolônio Sales irrigation scheme, some efficient farmers could be identified within the other two irrigation schemes as well as outside the official schemes. Few farmers managed to sell parts of their production to the school feeding program at higher prices; other farmers brought parts of their production to the local market and sold them directly to the retailers. Thus, these farmers could, at least partially, avoid the dictated lower prices of the middlemen. There were also farmers identified who bridged gaps in the market, such as quail egg production for the local supermarkets or the fabrication of fruit puree.

Additional off-farm income, which accounts for approximately 50% of the total household income, was not considered in this analysis (Boos, 2015). In addition, the suitability of the minimum salary requires clarification. On the one hand, several authors assume three minimum salaries per family as sufficient to cover the living costs (Denaldi, 2013; Untied, 2005). On the other hand, three minimum salaries appear too high to be classified as sufficient income considering the general income situation of rural families in northeast Brazil. In 2013, over four million northeast Brazilian rural households had less than three minimum salaries available, which accounts for 88.4% of the total rural households in that region. During several on-farm interviews and one expert interview with a former agricultural consultant, an annual income of 3,600 R$, less than half of the minimum salary, was identified as the minimum subsistence wage which could still meet the basic needs of a poor family. A salary of 9,600-12,000 R$, around 1.2-1.5 minimum salaries, was identified as sufficient to provide the livelihood for a family in the study region. Consequently, a monthly income of 1.5 minimum salaries was considered as an "attractive" salary; two minimum salaries were mentioned as appropriate for employees with a higher education, such as graduates from universities or technical colleges. Nonetheless, a successful implementation of agricultural cooperatives or associations appears to contain high potentials to increase the agricultural income significantly, as discussed in Chapter 4. Visits to large agricultural cooperatives in Paraná state confirmed the estimated potentials of agricultural cooperatives in Brazil (see also Fajardo, 2006).

Whereas in Chapter 5 primarily limitations of irrigated fruit production were identified, the modeled revenues between 21,875 R$ and 37,320 R$ conform to actual revenues farmers reached in the Apolônio Sales irrigation scheme. However, few farmers in the sample reached comparable revenues from agricultural activities, mainly due to limited irrigable areas. Thus, the results of above-average farmers in the wealthiest irrigation scheme of the Itaparica system, considering ideal production conditions, can serve solely as a benchmark to determine the economic potential of irrigated family farming. In Chapter 6 LP farm optimization models estimate the economic potentials of irrigated family farming. Estimating an average farm size of four hectares, the scarcity of irrigable area in the irrigation schemes is considered. Possible agricultural revenues of over 30,000 R$, calculated with average producer prices, even exceed the recommended three minimum salaries.

Combining the positive examples identified in the analyzed sample with the modeled optimal revenues, it can be concluded that irrigated family farming has the potential to provide an adequate income and therewith livelihood for rural families. It could also be observed, that agricultural production in the schemes of the Itaparica system developed well since the study period of Untied (2005). The biggest gap occurred in coconut production, where Untied (2005) observed a mean yield of 4,000 nuts per hectare; the mean yield in the sample of this dissertation was around 15,000 nuts per hectare.

Despite the identified potentials of irrigated agriculture in the study region, some important aspects have to be considered for the further development of the irrigation schemes. Vital and Sampaio (2007) underlined five main determinants for the successful implementation of irrigated family farming. On the one hand, the potential economic attractiveness of irrigated family farming could be shown in this dissertation, although the farmers' market access was insufficient. Electricity for irrigation was fully available, appropriate irrigation technology at least partially. On the other hand, there was still a lack of farmers' experience in irrigated agriculture. Agricultural consultancy, which could reduce this constraint, had stopped at the beginning of 2013 because the contract between the schemes' operator and PLANTEC had expired and, until 2015, had not been renewed yet. Despite few exceptions, agricultural cooperatives and cooperation between the farmers beyond a mutual aid system between friends and neighbors had nearly failed. From the start of the irrigation schemes until the study period, constant water availability was secured. However, the critical situation of the reservoirs caused by the recent severe drought urgently requires approaches to economize water. As illegal irrigation and over-use of irrigation water on legal lots caused by free irrigation water, small lot sizes, and lack of control mechanisms aggravate the climate induced problems, the implementation of an adequate volumetric water pricing seems inevitable.

8.4 Conclusions and recommendations

In this dissertation, the main benefits and potentials as well as the driving factors for vulnerability of irrigated family farming could be identified. The dissertation could expand and amplify existing knowledge on irrigated family farming in the study region. The combination of qualitative with quantitative methods ensured the accuracy of the retrieved results. The compliance with the family farmers' everyday life was approved in several discussions with farmers and stakeholders during the implementation trip in November 2015. The interest on the part of CODEVASF officials underlines the practical relevance of the study. The case of irrigated agriculture along the lower-middle São Francisco River, especially in the irrigation schemes, not only serves as an example for further planned irrigation schemes in northeast Brazil, but also for irrigation schemes in semi-arid regions worldwide. Consequently, the findings of this dissertation provide a scientifically based key performance analysis and can serve as decision support for stakeholders and political decision makers.

Based on the findings of this dissertation it can be concluded, that irrigated family farming presents one opportunity to provide an adequate livelihood for the rural population in Brazil's semi-arid region. However, several existing limitations have to be envisaged. The consequences of the recent severe drought emphasized the **limitations of water supply** and therewith the **limited availability of irrigable land**. This conforms to the necessary limitation of areas for agriculture and pasture due to the importance of preservation of the Caatinga biome (Leal et al., 2005; Lewinsohn, et al., 2005; Menezes et al., 2002). During severe droughts and increased water scarcity, multiobjective optimization models can support decision makers to ensure an adequate water allocation (Mendes et al., 2015).

Insufficient market access and **inordinate market power of mobile middlemen** represent the major economic constraint of irrigated family farming in the region. Agricultural cooperatives and associations have the potential to increase the farmers' market power but yet, could not be successfully established in the region. The role of cooperatives especially should be strengthened, as they have the potential to provide several benefits for instance, assistance in adopting innovative and more sustainable production technologies (De Souza Filho et al., 1999), or the provision of value adding facilities to complement the primary production (Bialoskorski Neto, 2001). The support to implement new production technologies is highly relevant considering the **overuse of agrochemicals** or the probable implementation of water prices.

Consequently, to achieve a more sustainable agricultural production in the study region, it is recommended to reintroduce agricultural consultancy in the irrigation schemes, considering recently studied production methods such as the use of more efficient rhizobial strains in bean cultivation (Marinho et al., 2014) or of green manure in mango plantations (Mouco et al., 2015). However, the technical assistance should not solely concentrate on agricultural production but be carried out in an integrative way, including farmer education and training as to increase the human capital in the region to provide "help for self-help". Recommended educational programs and trainings could be lectures and workshops in business skills, about the benefits and organization of agricultural cooperatives, and about environmental issues such as good agricultural practice, integrated pest control, and appropriate irrigation. Increasing human capital and promoting value adding facilities seem crucial to ensure sustainable agricultural production, as on- and off-farm income alternatives can reduce the pressure on the scarce water and land resources.

Further research and implementation activities should be conducted in the fields of agricultural cooperatives and associations. A better understanding of the driving factors for the successful implementation of cooperatives in south Brazil may help to foster their implementation in the study region. In accordance to the conclusions of Berbel and Mateos (2014), the developed LP models represent the situation in a simplified way.

Several effects of changing production conditions have been tested, but to make more precise statements, further details such as yield functions and transaction costs, should be considered.

Abstract

Written records about severe droughts in Brazil's semi-arid northeast reach back until the country's colonization in the early 17th century. Since the late 19th century, irrigated agriculture was implemented to reduce the effects of droughts on the livelihood of the rural population. Supported by the construction of large dams and reservoirs for hydropower generation in the 1960s, irrigated agriculture was promoted on larger scales. In this context several irrigation schemes were implemented along the lower-middle São Francisco River. Despite economic growth and poverty reduction in the region, large parts of the rural population who strongly depend on agricultural income suffer from precarious living conditions. This dissertation aimed at a) a detailed analysis of the current production systems and the socio-economic situation of irrigated family farming along the lower-middle São Francisco River, b) identifying the natural, economic, and social constraints as well as benefits and potentials of irrigated agriculture, c) modeling and evaluating optimized resource allocation including alternative crops, and d) estimating the impact of changing the production conditions on agricultural production and its profitability. In the framework of this dissertation, a total of 60 expert interviews were held and a random sample of 193 farm household interviews was conducted to gather detailed information on crop and livestock production. Time series of secondary data were analyzed by regression analysis, qualitative data by content analysis, and socio-economic household data by regression analysis and analysis of variance. Farm optimization models were developed using Linear Programming.

Results showed a high vulnerability of irrigated family farming to changing climate and infrastructural production conditions. Nearly half of the interviewed farmers had a farm income below the Brazilian minimum salary. Insufficient infrastructure, limited market access, volatile producer prices, lack of cooperation, overuse of irrigation water and agrochemicals, and insufficient knowledge about irrigated fruit and vegetable production aggravated by lack of agricultural consultancy turned out to be the main limitations of irrigated family farming in the region. Availability of irrigable land and proper crop choice were most relevant for the agricultural income. Innovative and efficiently managing farmers underlined the potential of irrigated family farming to counteract rural poverty. Integrated agricultural consultancy considering the development of human capital may provide the required inputs to support economic and social sustainability of agricultural production. Technical assistance combined with volumetric water pricing may help to reduce the excessive use of agrochemicals and water.

Zusammenfassung

Seit jeher wird der semi-aride Nordosten Brasiliens von schwerwiegenden Dürren heimgesucht. Schriftliche Überlieferungen reichen bis in die Zeit der Kolonialisierung des Landes gegen Ende des 17. Jahrhunderts zurück. Gegen Ende des 19. Jahrhunderts begann Brasiliens Regierung mit dem Bau größerer Reservoirs, um den Bewässerungslandbau zur Sicherung der Lebensgrundlage der ländlichen Bevölkerung zu fördern. Erst jedoch die Errichtung zahlreicher Staudämme und Stauseen zur Elektrizitätsgewinnung seit den 1960er Jahren ermöglichte die großflächige Verbreitung der Bewässerungslandbaus, wie im Falle des Rio São Francisco, an dessen Mittellauf zahlreiche Bewässerungsgebiete etabliert wurden. Trotz einer positiven wirtschaftlichen Entwicklung und beachtlichen Fortschritten in der Armutsbekämpfung leben große Teile der Landbevölkerung weiterhin in prekären Verhältnissen.

Ziel dieser Dissertation war zunächst eine detaillierte Analyse der vorhandenen landwirtschaftlichen Produktionssysteme und der sozio-ökonomischen Situation der Bewässerungslandbau betreibenden Familienbetriebe entlang des Mittellaufs des Rio São Francisco. Zudem wurden die natürlichen, wirtschaftlichen und sozialen Beschränkungen sowie die Vorzüge des Bewässerungslandbaus identifiziert. Modelle einer effizienteren Ressourcennutzung wurden erstellt und bewertet. Mit Hilfe dieser Modelle wurde schließlich der Einfluss sich verändernder Produktions- und Rahmenbedingungen auf den Bewässerungslandbau evaluiert. Als Datengrundlage dienten die Ergebnisse aus 60 Experteninterviews und einer Farm-Haushaltsbefragung mit 193 zufällig ausgewählten kleinbäuerlichen Familienbetrieben, ergänzt durch Sekundärdaten. Zeitreihen wurden mittels Regressionsanalyse, qualitative Daten mittels Inhaltsanalyse und die Daten der Farm-Haushaltsbefragung mittels Regressionsanalyse und Varianzanalyse ausgewertet. Einzelbetriebliche Optimierungsmodelle zu einer effizienteren Ressourcennutzung wurden mit Hilfe von linearer Programmierung optimiert.

Veränderte klimatische oder infrastrukturelle Rahmenbedingungen stellten sich als große Risikofaktoren für die Produktivität des kleinbäuerlichen Bewässerungslandbaus heraus. Bereits im Untersuchungszeitraum, einer Phase mit sehr hohen Erzeugerpreisen, erzielte knapp die Hälfte der interviewten Haushalte ein landwirtschaftliches Betriebseinkommen unterhalb des gesetzlichen Mindestlohns. Unzureichende Infrastruktur, mangelhafter Marktzugang, volatile und von Zwischenhändlern bestimmte Erzeugerpreise, mangelhafte Kooperation zwischen den Kleinbauern, exzessive Bewässerung und Ausbringung von Pflanzenschutzmitteln und schließlich mangelhafte Erfahrung im

intensiven Obst- und Gemüsebau wurden als wesentliche Beschränkungen des kleinbäuerlichen Bewässerungslandbaus in der Studienregion identifiziert. Das Fehlen landwirtschaftlicher Beratung verschärfte viele dieser Probleme. Auf der anderen Seite waren eine geeignete Wahl der angebauten Kulturen und eine großzügigere Flächenausstattung die Hauptfaktoren für wirtschaftlichen Erfolg. Innovative, geschäftstüchtige Kleinbauern, darunter einige mit geringen verfügbaren Flächen, verdeutlichten dennoch das Potential des Bewässerungslandbaus zur Bekämpfung der ländlichen Armut in der Studienregion. Die Wiederaufnahme landwirtschaftlicher Beratung, kombiniert mit Bildungsangeboten zur Steigerung des Humankapitals insbesondere bezüglich landwirtschaftlicher Betriebslehre und Kooperationsformen zwischen Kleinbauern, kann wesentlich zu einer Verbesserung der landwirtschaftlichen Produktion und der Lebensbedingungen der ländlichen Bevölkerung in der Studienregion beitragen. Der exzessiven Bewässerung können ein volumetrischer Wasserpreis und die Förderung effizienterer Bewässerungsmethoden entgegenwirken.

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Annex

A1 List of additional reviewed publications

This section presents all reviewed scientific contributions, such as book chapters and contributions to scientific conferences, which were developed in the context of this dissertation but not integrated in the previous chapters. The presentation of each contribution includes the corresponding title, authors, type and location of the contribution, and the abstract.

A1.1 Macroeconomic aspects of the micro-regions São Francisco and Itaparica

Authors

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Type

Book chapter

Status

Published in: Gunkel, G., Aleixo da Silva, J., do Carmo Sobral, M. (Eds.). Sustainable Management of Water and Land in Semiarid Areas. Editora Universitária, Universidade Federal de Pernambuco (UFPE), Recife, pp. 245-264.

Abstract

Construction of hydroelectric power stations and promotion of irrigated agriculture led to high economic and, as a consequence, population growth along the sub-medium São Francisco basin in the semi-arid Northeast Brazil. Irrigated perimeters were built in the micro-regions São Francisco and Itaparica among others. Due to their different historic frameworks, both regions developed differently despite proximity and similar climate conditions. Excellent climate conditions and infrastructure in the São Francisco region provide the opportunity to produce fruits in an export orientated system delivering to

costumers worldwide. The agricultural production in the Itaparica system is concentrated on local markets achieving lower prices. Therewith it generates less welfare for the local communities.

Keywords

São Francisco basin, Itaparica, economic development, irrigated agriculture

A1.2 The contribution of innovative agricultural systems to sustainable water reservoir use in NE-Brazil

Authors

Heinrich Hagel [a], Christoph Reiber [b], Ana Paula Amazonas Soares [c], Christine Beusch [d], Reiner Doluschitz [a], Jose Ferreira Irmão [c], Jörn Germer [e], Christa Hoffmann [a], Martin Kaupenjohann [d], Jan Mertens [e], Joachim Sauerborn [e], Marianna Siegmund-Schultze [b], Karin Stock de Oliveira Souza [b], Anne Valle Zárate [b]

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Type

Conference contribution

Status

Published in: Tropentag 2012. Resilience of agricultural systems against crises. Book of abstracts, Cuvillier Verlag, Göttingen, p.192.

Abstract

The construction of the Itaparica dam and reservoir induced changes concerning the agricultural production systems in the micro-region Itaparica, Sao Francisco river basin. Traditional systems — mainly a combination of dryland farming in the river flood plains and livestock farming in the adjacent dryer areas — were replaced by irrigation agriculture. Even though wide areas with irrigation infrastructure were established the sandy soils of many areas are not suitable for irrigation farming. Lack of adequate arable land causes a shortage of income opportunities for local farmers. Thus large share of many household incomes is derived by compensatory payments from the dam operator. Persistent problems are inappropriate farming practices in irrigation, inaccurate use of agrochemicals and overstocking of livestock. As a consequence soil salinization, overgrazing, erosion, and contamination and eutrophication of the reservoir increase and threaten local peoples' livelihoods. The joint research project INNOVATE aims at innovatively coupling nutrient cycles to counteract erosion, soil degradation, and emission of greenhouse gases. The agriculture-related sub-projects "Terrestrial Production" and "Economy" will do research with the implementation of a sustainable and productive agriculture with closed nutrient cycles. This can contribute to reduce the above mentioned negative impacts, ensure food supply, and additionally provide an important income source for the local population. Biochar, lake sediments, and manure combined with micro-catchments and multipurpose leguminous perennial food crops and feeds, shall improve soil quality and water storage capacity. The combination of local and fast-growing trees to the crop areas meets the needs for firewood and forage for the dry season and reduces the pressure on natural vegetation, conserving its biodiversity. The results will be assimilated in a model system quantifying soil organic matter dynamics. Economic analyses on farm level monitor the profitability of these systems and facilitate recommendations for extension service and policy makers to sustainably establish them. Field trials for soil amendment and micro-catchment will be installed on dryer areas next to the main irrigation areas, while surveys and measurements on livestock systems and socio-economic data will be assessed on farm level by structured questionnaires, participatory methods, and structured observations and measurements.

Keywords

Agriculture, soil amendment, micro-catchment, reservoir

A1.3 Agricultural Cooperatives to Reduce Rural Poverty in NE-Brazil

Authors

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Type

Conference contribution

Status

Published in: Tropentag 2013. Agricultural development within the rural-urban continuum. Book of abstracts, Cuvillier Verlag, Göttingen, p.291.

Abstract

Although Brazil’s government scored success in reducing poverty in the last two decades rural poverty is still pervasive. With about 67% of its rural population living in poverty, Brazil’s Northeast is considered as one of the poorest and least developed regions in Latin America. In the course of the construction of the Itaparica dam and reservoir at the São Francisco river basin, irrigation projects were established to ensure the livelihood of the local population. Insufficient infrastructure and low market power of smallholders result in high purchase prices of means of production, lack of access to credits, and low producer prices. As a consequence many smallholders and livestock owners live in poverty. Agricultural cooperatives are considered to be a key factor to improve food security and to guarantee a safe income for smallholders. Especially by increasing smallholders’ market power, cooperatives can improve their living conditions. Therefore the objectives of this study were to assess and analyse the history, the actual situation, and the potentials of agricultural and livestock cooperatives in the Itaparica reservoir region. Data were collected by 24 qualitative in-depth expert interviews and analysed using coding, categorising, and qualitative content analysis techniques. Interviewees were chosen from local authorities, chairmen and members of agricultural

cooperatives and cooperative unions, agricultural consultants, local farmers, and scientists. Based on previous investigations within the INNOVATE project, interviews were held from March to May 2013 in the four main irrigation projects at the reservoir which differ significantly in history, farm size, infrastructure, and production methods. Though the dam operator promoted the implementation of cooperatives and there is a basic willingness of smallholders to cooperate, there are as yet no efficient agricultural or livestock cooperatives. Lack of financial support, organisation, knowledge about and trust in cooperatives caused the failure of most cooperatives. Still there exist efficient ones in fishery and apiculture. The success of these cooperatives provides an example for prospective agricultural and livestock cooperatives. Due to its peasant production structure the study region is particularly suitable for agricultural and livestock cooperatives. Main problems of local farmers could be moderated significantly by cooperative action.

Keywords

Agricultural cooperatives, irrigation agriculture, rural poverty

A1.4 Acceptance of local farmers towards resource efficient production methods at the Itaparica Reservoir in North East-Brazil

Authors

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Type

Conference contribution.

Status

Published in: Tropentag 2013. Agricultural development within the rural-urban continuum. Book of abstracts, Cuvillier Verlag, Göttingen, p.62.

Abstract

The rural areas of the north-east of Brazil are characterized by poverty, food insecurity, and rural exodus. Due to the construction of the Itaparica dam and reservoir, about 40,000 inhabitants were resettled and agricultural production systems changed. Extensive dryland farming and livestock husbandry were replaced by irrigation farming. The reallocated smallholder farmers were confronted with improper soils, insufficient drainage, and deficient expert consultation. The farmers' economic situation deteriorated. A tense relationship between them and the dam operator was the consequence. Furthermore, the environment suffered from the non-sustainable farming practices. Considering farmer's acceptance is an important step to establish alternative, resource efficient production methods as farmers' collaboration is essential for their successful implementation. For that reason the objective of this study was to assess local smallholders' perception on their current situation, their preferences regarding alternative crops, and their willingness to change their actual production methods. Research was conducted by semi-structured on-farm interviews. Each interview contained a quantitative and a qualitative part as well as a scoring and ranking exercise. By means of this tool, that is also included in the Participatory Rural Appraisal, farmer´s preferences could be shown and different alternatives could be compared. Half of the interviewees were female farmers in order to consider gender issues. By doing so, different needs and preferences of men and women could be regarded. The interviews were carried out in three irrigation projects at the Itaparica reservoir. These projects differ significantly in history, prosperity, and infrastructure. In this way possible discrepancies between farmers´ preferences and opinions, but also their motivations and visions, could be compared. First analyses show no significant differences between female and male farmers. Most of the farmers are willing to change their production methods in order to improvements but are, on the other hand, highly risk averse. As a consequence, income security was considered as the most important factor of any production method. In spite of lack of free time, farmers would substitute free time for higher income. These results can be explained by crucial constrains such as bad commercialization, restricted access to loans, and absence of consultancy.

Keywords

Agriculture, farmers' preferences, local acceptance, resource efficiency

A1.5 Mathematical programming models to increase land and water use efficiency in semi-arid NE-Brazil

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Type

Conference contribution.

Status

Published in: CIGR Proceedings, 2014 World Congress on Computers in Agriculture, University of Costa Rica, San Jose Costa Rica, July 27th-30th, 2014. http://CIGRProceedings.org

Abstract

Construction of the Itaparica dam and reservoir induced changes of the agricultural production systems in the micro-region Itaparica, at the lower-middle São Francisco river basin. Extensive traditional systems were replaced by irrigated fruit and production. Over twenty years after the dam construction, many farmers are still facing income insecurity. A survey consisting of expert interviews and structured on-farm interviews was conducted to analyze current production systems. Farm income depended strongly on low wages for day laborers, free irrigation water, and stable prices of the main crop, coconut. Diversification of production and improved market access can help to improve farmers' income situation.

Keywords

Mathematical programming, farm optimization, water efficiency, decision support, rural development, Brazil

A1.6 Improving agricultural water use efficiency in the lower-middle São Francisco River basin in NE-Brazil

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Type

Conference contribution.

Status

Oral presentation at the 13th IWA Specialized Conference on Watershed and River Basin Management organized by the International Water Association (IWA) in San Francisco, United States, 09.09.-12.09.2014.

Abstract

In the course of the Itaparica dam and reservoir construction at the São Francisco River extensive agriculture in the river flood plains was replaced by intensive irrigated fruit and vegetable production. Resettled smallholders received areas equipped with sprinkler systems and free irrigation water as compensation for flooded land. Farmers are still facing problems with the new production methods, lack of extension service, and low market power. Inappropriate farming practices in irrigation persist. Linear Programming farm optimization models were applied to determine site-adapted farm structures and more efficient resource use considering land, labor, capital, and especially water constraints. The models were adjusted to regional characteristics in cooperation with local extension service and by following farmers' preferences investigated by twenty semi-structured on-farm interviews. Data for the models were collected from smallholders in a random sample of 191 structured on-farm interviews. Analyses indicate low farm returns on investment still relying on the availability of free water. Improved market access and therewith higher producer prices are crucial to provide secure farm income. Still, provided agricultural extension, moderate water pricing can lead to an implementation of more efficient irrigation technologies and water saving techniques and therewith contribute to sustainable reservoir use. In addition it may raise the awareness of water scarcity in the region.

Keywords

Linear programming, farm optimization, irrigated agriculture, water efficiency

A1.7 Socio-Economic Determinants Affecting the Farm Income of Small Fruit Producers in NE-Brazil

Authors

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Conference contribution

Status

Published in: Tropentag 2014. Bridging the gap between increasing knowledge and decreasing resources. Book of abstracts, Cuvillier Verlag, Göttingen, p.466.

Abstract

Since the 1960s, Brazil’s government promoted irrigated agriculture in the country’s semi-arid Northeast to decrease poverty and reduce rural exodus. Especially in the last two decades, irrigated agriculture within big irrigation schemes along the lower-middle São Francisco river basin increased rapidly. Irrigated fruit production using modern irrigation techniques played an important role in the economic growth of this region. Although favorable climate conditions, constant water availability, and efficient production techniques provide the fundamentals required for prosperity and economic independence of smallholders, many smallholders are facing poverty, despite similar initial situations to prosperous farmers. An analysis of socio-economic key factors was conducted to assess their impact on farm income. Sixteen experts were interviewed to gain an overview on irrigated fruit production in the regions Petrolina and Itaparica at the lower-middle São Francisco. Additionally a random sample of 132 farmers within the main

irrigation schemes in those regions was interviewed to identify driving forces of economically successful crop production. Qualitative data were analyzed using content analysis and quantitative data by multiple regression analyses. Inhibiting forces affecting farm income were insufficient infrastructure and therewith bad access to markets, low market power, and low availability of credits for means of production. Lack of knowledge about the new production methods increased these negative effects. Smallholders with less available capital had fewer chances to invest in perennial fruit plantations and modern irrigation infrastructure. However, these measures are crucial to generate higher and more secure income in the long term, thereby providing an escape from the poverty gap. Prospective water shortages, due to expansion of irrigated areas and climate change will increase the importance of water efficient production methods and consequently the requirement for capital and knowledge for their implementation.

Keywords

Irrigated agriculture, Northeast Brazil, regression analysis

A1.8 Income Alternatives of Smallholders at the Itaparica Reservoir in NE-Brazil

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Type

Conference contribution

Status

Published in: Tropentag 2015. Management of land use systems for enhanced food security – conflicts, controversies and resolutions. Book of abstracts, Cuvillier Verlag, Göttingen, p.511.

Abstract

Irrigation farming is seen as a suitable tool to promote rural development in the semi-arid Northeast region of Brazil. Especially in the last two decades, federal and state-owned authorities established several irrigation projects along the lower-middle São Francisco River to provide local smallholders the opportunity to generate income and consequently, reduce rural exodus. Due to lack of infrastructure and scarcity of irrigable areas, income derived from agricultural activities is, in many cases, still not sufficient to provide the livelihood for smallholders. Thus, they depend on income alternatives outside irrigation farming.

This study identifies and evaluates income alternatives of smallholders in the Apolônio Sales and Icó-Mandantes irrigation projects in the municipality Petrolândia, Pernambuco. It also weighs the alternatives' importance from an economic perspective as well as by the farmers' perspective. Furthermore, potential innovative income alternatives are assessed concerning their economic viability, social acceptance, and practicability. A special interest lies upon Umbu production, the fruit of the endemic xerophytic tree Spondia tuberosa Arruda, on drylands to reduce the pressure on irrigated areas and contribute to a more sustainable land use. A random sample of 50 farmers were interviewed - 20 interviews were conducted in the rather prosperous community of Apolônio Sales and 30 in Icó-Mandantes. Although being planned and constructed at the same time, the communities differ in many aspects, such as farm size, farmers' networks, education, capital availability, infrastructure, and social and political influence. Additionally, ten experts were interviewed to gain an overview of the socio-economic situation of the smallholders and to analyse other potential income sources. Although most smallholders still consider themselves as farmers and mentioned crop production as their most important income source, only two of the interviewed smallholders gain their living solely with farm income. Especially in Icó-Mandantes, most households relied strongly on non-agricultural income – mainly social benefits and off-farm work of family members. Three promising income alternatives were identified. Umbu production, beekeeping, and fishery may, despite existing limitations, have the potential to improve the middle or long term income situation of the smallholders and help to reduce the pressure on the irrigable land.

Keywords

Alternative land use, income alternatives, irrigated agriculture, Northeast Brazil

A2 Questionnaire farm household survey

Questionário
Questionaire

Município; *village*: ______________________________
Perímetro irrigado e bloco; *irrigation area*: ______________
Primer nomem; *name*: ______________________________
Número de telephone; *telephone number*: _____________
Entrevistador; *interviewer*: ________________________
Data de entrevista; *date of interview*: ________________

Sobre o projeto INNOVATE: Fazemos entrevistas com os agricultores para analisar e avaliar a agricultura, pecuária e piscicultura. Assim, queremos ajudar no aumento da produtividade para que os agricultores possam aumentar a sua renda e melhorar seu nível de vida.

1. Informações básicas da fazenda, colheita e rendas
Household Basic Information, Harvest, and Income

1.1 Por favor liste os membros da família que trabalham no lote. Descreva também o tempo de trabalho utilizado no lote.
Please describe every family labor that lives in your farm household (only for family labor, not every family member).

Nomem e grado parentesco; *relation*	Sexo; *gender*	Idade; *age*	Nivel de educação e profissão; *education, profession*	Quanto tempo trabalha na empresa? *How much time does each member work?*		
				Horas por dia?	Dias por semana?	Semanas por mês?

1.2 Algum membro da familia vai tomar conta da fazenda no futuro? ***Will one family member take over the farm in the future?***
□ Sim □ Não; se não, porque não?____

1.3 Você utiliza mao de obra contratada? ***Do you use hired labor?***
□ Sim □ Não

1.4 Quando (em quais meses) e para que serviço? ***In which months and for which kind of work?***
Meses:
Serviços:

1.5 Quanto paga por dia? Por hora? Tem diferenças no preço? ***How much do you pay per day and hour?*** **(R$/dia) (R$/h)**
R$/dia:

1.6 O senhor vivenciou falta de mão de obra? ***Have you experienced scarcity of working hours?***
□ Sim □ Não; se sim, quando e para quais trabalhos:

1.7 Por favor descreva os tipos de culturas, pastagem e estado legal da sua terra. NOTA: Se cultiva dois o mais culturas juntos no mesmo lote, indique com (CM) descreva as duas culturas mas trata como lavoura normal. ***Please describe crop types, pasture, and land use rights of your household.***

Área total e condição legal das terras e sistema produtivo. *Total area and legal status* (ha)	Terra própria (com escritura). *Own land.* (ha)	Terra sem título definitivo (sem escritura). *Land without title.* (ha)	Alugada o arrendamento. *Leased land.* (ha)	Preço de arrendamento. *Price of leased land.* (R$/ha)	Área irrigada total; *irrigated land* (ha)	Sequeiro total; *dryland* (ha)
Lavoura temporária						
Lavoura permanente						
Pastagem/Caatinga						

Especificação de uso das terras. *Details of land use.*	Área de cultura A. *Area of crop A.* (ha)		Área de cultura B. *Area of crop B.* (ha)		Área de cultura C. *Area of crop C.* (ha)		Área de cultura D. *Area of crop D.* (ha)	
Nota: Indique lavouras temporárias e permanentes	Cultura A:	Área:	Cultura B:	Área:	Cultura C:	Área:	Cultura D:	Área:
Intercalar								

Pecuária: Quais espécies possui? *Which species?*																														
Quantas animais de cada tipo com qual finalidade possui? *How many animals?* (Code A)	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Onde mantém os animais? *Where is it held?* (Code B)																														

A: (1) fêmea para criação; *breeding female* (2) macho para criação; *breeding male* (3) animal para engorda; *fattening animal* (4) animal jovem; *young animal* (5) animal de tração; *draught* (6) outro; *other:*

B: (1) estábulo; *barn* (2) presos; *fenced in pasture* (3) caatinga aberta (4) outro; *other:*

1.8 Por favor descreva o processo da colheita e a renda da sua fazenda. Please describe your harvest process;

	Cultura A	Cultura B	Cultura C	Cultura D
Quantas colheitas tem por ano? *How often do you harvest?*				
Intercalar				
Quem é responsável? *Who is responsible?* (code A)				
Intercalar				
Método de colheita? *Method?* (code B)				
Intercalar				
Se por máquina, code C. *Machine :C*				
Intercalar				
Se usou máquina, preço de aluga, condutor e de combustível? *If machine, prices?* (R$/h) ou (l/h)				
Intercalar				
Quanto mão-de-obra familar? *Duration of harvest with family labor?* (h/ha)				
Intercalar				
Quantas horas de trabalho contratado? *How many hours of hired labor?* (h/ha)				
Intercalar				
Rendimento da área colheita? *Yield per area?* (kg/ha) ou (unidade/ha)				
Intercalar				
Parte para consume próprio; *share for personal use* (kg, unidade ou %)				
Intercalar				
A quem se vende a safra? *To whom did you sell the product?* (Code 1)				
Intercalar				
Preço de venda? *Sales price?* (R$/kg) ou (R$/unidade)				
Intercalar				

Tem alternativos compradores? Se sim, quais? *Are there alternative clients?*				
Intercalar				
Distância ao lugar de venda? Se ido buscar = 0 *Distance to selling place?*				
Intercalar				
Tem preços diferentes dependente do comprador ou temporada? Especifique. *Price differences related to the client/time?*				
Intercalar				
A: (1) Familia; *family* (2) Contratado; *hired* (3) Atravessador; *trader* (4) Arrendado; *subcontractor* (5) Outro:	**B:** (1) Manual; *own hands* (2) Com máquina; *machine assisted* (3) Outro; *other:*	**C:** (1) Máquina própria; *own machine* (2) Máquina alugada sem condutor; *rent machine without driver* (3) Máquina alugada com condutor; *rent machine with driver* (4) Outro; *other:*		

1.8 Uso de restolhos (várias repostas possível); *residue handling (multi-option possible)*

Cultura. *Crop.*	Por favor descreva para que se usa os restos de cultura. *Please describe the use of the residues.*					No caso de venda; *if the residue is for selling*: Qual resto de cultura? *Which residue?*	Quanto mão de obra?	Rendimento (kg/ha)? *Yield?*	Preço de venda; *price* (R$/kg)
A	□ Incorporação ao solo; *back to soil*	□ usa como pasto; *feed livestock*	□ utiliza na cozinha; *cooking*	□ vender; *for sale*	□ outro; *other*:				
Intercalar									
B	□ Incorporação ao solo; *back to soil*	□ usa como pasto; *feed livestock*	□ utiliza na cozinha; *cooking*	□ vender; *for sale*	□ outro; *other*:				
Intercalar									
C	□ Incorporação ao solo; *back to soil*	□ usa como pasto; *feed livestock*	□ utiliza na cozinha; *cooking*	□ vender; *for sale*	□ outro; *other:*				
Intercalar									

D	□ Incorporação ao solo; *back to soil*	□ usa como pasto; *feed livestock*	□ utiliza na cozinha; *cooking*	□ vender; *for sale*	□ outro; *other:*				
Intercalar									

1.10 Rendas e espesas da pecuária; *other incomes*

	Valor por ano (R$) *Yearly amount*	Valor mensal (R$/mês) *Amount per month*	Quantidade de anos ou meses com renda; *months, weeks, days you get paid*
Renda de pecuária, leite, ovos…; *income from livestock*			
Gastos para os animais (Ex. Pasto, veterinário, vacina…)			

1.11 Quais impostos ou taxas pela produção agrícola paga mensal? *Which taxes and fees does the household pay per month?*

Tipo de imposto/taxa (v. ex.); *type*							
Valor; *amount* (R$)							
Exemplos: Eletricidade, água, K1 e K2 (só Petrolina),…							

1.12 Você está recebendo atualmente algum crédito ou financiamento? *Are you currently taking a loan?* □ Sim □ Não

Se sim por favor indique o valor, duração e os juros (R$ + anos + juro); *if yes, please specify the amount, duration of the loan, and interest rate:*

____

1.13 Por favor clasifique a disponibilidade de créditos; *please classify the availability of loans*:
□ Muito má □ Má □ Meio □ Boa □ Muito boa

2. Máquinas, meio de transporte e equipamento para o trabalho no campo; *machinery and field work equipment*

2.1 Por favor liste as máquinas e o equipamento para o trabalho na fazenda que possui. Inclua carro, moto...se usa na fazenda; *please provide information below*

	Quantidade; *number*	Ano da compra; *purchasing year*	Preço de compra ou construção; *buying/construction price* (R$)	Financiamento; *capital sources*			Tempo de vida estimado; *estimated life time* (anos)	Gastos médios da mantunenção; *average maintenance cost* (R$/ano)
				Capital próprio; *own capital* (R$)	Crédito; *loan*			
					Quantidade (R$)	Juro; *interest rate* (%)		
Trator; *tractor*								
Ceifeira-debulhadora; *combine harvester*								
Sistema de irrigação (asperção, gotejo,...); *irrigation system*								
Bomba; *pump*								
Canais/tubos; *channels*								
Tanque de fertilizante, *fertilizer mixing tank*								
Pulverizador mochila, *knapsack sprayer*								
Trator com pulverizador; *tractor with sprayer*								
Outra (ex. carro, moto, caminhão); *other:*								
Outra máquina; *other:*								
Outra máquina; *other:*								

3. Preparo de solo e adubação; *soil preparation and fertilization*

3.1 Por favor descreva os detalhes do preparo de solo. ***Please describe soil preparation of your crops.***

Cultura; *crop*	Quantos veces por ano? *How often?*	Quem faz o preparo de solo; *who conducts soil preparation?* (code A)	Se organizada da familia: como faz o prepara de solo? *If family organized: how was soil prepared?* (code B)	Se máquina: que tipo de máquina? *If machine, which type?*	Quantas horas por ha? *How many hours per ha?*	Preço para terceirizado e/ou máquina (com o sem condutor) (R$/h)? *Price for rental machine and/or contractor?*	Se máquina propria: Quantos litros de diesel/ha? *If own machine: How many liters of diesel per ha?*
A							
Inter							
B							
Inter							
C							
Inter							
D							
Inter							
A: (1) familia; *family* (2) trabalhador contratado; *hired labor* (3) arrendado; *subcontractor* (4) cooperativa; *cooperative* (5) outro; *other*:				**B:** (1) Máquina própria; *own machine* (2) Máquina alugada sem condutor; *rent machine without driver* (3) Máquina alugada com condutor; *rent machine with driver* (4) Mão de obra propria; *own hands* (5) mão de obra contratada; *rent hands* (6) Outro; *other:*			

3.2 Quais tipos de abubo utilizou nos seus lotes; ***which types of fertilizer do you use?***
□ Adubo químico, *chemical* □ Adubo orgânico; *organic fertilizer*

3.3 Se utiliza os dois, mistura os adubos?
□ Sim □ Não. **Se sim indique em qual fertilização se mistura:**

Nota: Se o produtor misturou o adubo químico com o adubo orgânico, indique na primeira pergunta de 3.4 com (m). *Note: If mineral fertilizer is mixed with organic fertilizer, add (m) at the first question of 3.4*

3.4 Por favor descreva a fertilização das suas culturas com adubo químico. ***Please explain fertilization of your crops using mineral fertilizer.***

		Cultura A							Cultura B						
		Fundação		Cobertura		Appl.	Mão de O		Fundação		Cobertura		Appl.	Mão de O	
							F	C						F	C
Quantas veces se aduba por ano? *How often do you fertilize?*															
Intercalar															
		1)	2)	1)	2)				1)	2)	1)	2)			
Nomem do adubo: *Name:* 1) Quantidade de adubo? *Amount?* 2) Valor de adubo? *Costs?* (R$) 3) Applicação: Fertigação (A) ou no solo (B) 4) Mão de obra (hm/dia)															
Intercalar															
Adubo orgânico: Qual animal? Próprio ou comprador?															

		Cultura C							Cultura D						
		Fundação		Cobertura		Appl.	Mão de O		Fundação		Cobertura		Appl.	Mão de O	
							F	C						F	C
Quantas veces se aduba por ano? *How often do you fertilize?*															
Intercalar															
		1)	2)	1)	2)				1)	2)	1)	2)			
Nomem do adubo: *Name:* 1) Quantidade de adubo? *Amount?* 2) Valor de adubo? *Costs?* (R$) 3) Applicação: Fertigação (A) ou no solo (B) 4) Mão de obra (hm/dia)															
Intercalar															
Adubo orgânico: Qual animal? Próprio ou comprador?															

4. Semear ou plantar; *seed resources and plantation*

4.1 Por favor indique o processo da sementeira detalhadamente. ***Please explain detailed information about sowing.***

	Cultura A	Cultura B	Cultura C	Cultura D
Quando plantou? *When did you plant?* (Mês, se cultura permanente ano e mês de plantação)				
Intercalar				
Quem é responsável? *Who is responsible?* (code A)				
Intercalar				
Se organizada pela familia : como semeou? *If family organized: how did you seed?* (Code B)				
Intercalar				
Se utiliza máquina preencher: que tipo de máquina? *If machine: which?*				
Intercalar				
Se usou máquina, preço de aluga, condutor e de combustível? *If machine, prices?* (R$/h) ou (l/h)				
Intercalar				
Quanto mão-de-obra familar? *How much family labor?* (hm/dia)				
Intercalar				
Quantas horas de trabalho contratado? *Hours of hired labor?* (hm/dia)				
Intercalar				
A: (1) Familia; *family* (2) Trabalhador contratado; *hired labor* (3) Arrendado; *subcontractor* (4) Outro; *other:*	**B:** (1) Manual (2) Máquina própria; *own machine* (3) Máquina alugada sem condutor; *rent machine without driver* (4) Máquina alugada com condutor; *rent machine with driver* (5) Outro; *other:*			

4.2 Por favor descreva o uso de sementes ou mudas nos seus lotes; *please describe seed or plant usage of your plots.*

	Cultura A	Cultura B	Cultura C	Cultura D
Origem de semente/muda? *Seed/plant origin?* (Code A)				
Intercalar				
Procura de semente; mudas? (kg/ha numero de mudas/ha) *Seed/plant demand per ha?*				
Intercalar				
Se comprou as sementes/mudas: Preço de semente/muda (R$/kg) ou (R$/muda); *seed/plant price*				
Intercalar				

A: (1) Muda própria; *own plant* (2) Muda comprada; *bought plant* (3) Sementes da produção própria; *own seeds* (4) Sementes compradas; *bought seeds*

5. Irrigação e qualidade dos solos; *Irrigation and soil quality*

5.1 Por favor descreva a irrigação das suas culturas; *please describe irrigation demand for your crops.*

	Cultura A	Cultura B	Cultura C	Cultura D
Se irriga constantemente todo o tempo no mesmo modo? *Do you irrigate constantly the whole time?* SIM ou NÃO				
Intercalar				
Se **NÃO**, por favor, indique as diferencas. *If no, which differences?*				
Intercalar				
Como se irriga? Método? *Method?* (Code A)				
Intercalar				
Duração cada vez? *Duration of each appl.* (h/dia)				
Intercalar				
Quanto mão-de-obra familar? *How much family labor?* (h/ha/dia)				
Intercalar				
Quantas horas de trabalho contratado? *Hours of hired labor?* (h/ha/dia)				
Intercalar				
Quantidade? *Quantity?* (m^3/ha)				
Intercalar				
Gastos para eletricidade? *Electricity?* (R$/dia)				
Intercalar				
Combustível? *Fuel?* (l/dia)				
Intercalar				

A: (1) Gotejo; *drip irrigation* (2) Asperção; *sprinkler* (3) Micro-asperção; *micro-sprinkler* (4) outro; *other:*

5.2 O que é o mais importante para a sua irrigação? *According to what do you decide about your irrigation techinque?*
□ cultura; *crop variety* □ propiedade de solo; *soil characteristics* □ dica de consultor; *advice from specialists* □ intruções na embalagem das sementes; *instructions on seed package* □ preço da safra; *market price of the crop* □ experiência própria; *own experience* □ outro; *other:* ___________________

5.3 Recebe algum tipo de apoio da communidade/consultores/cooperativa na irrigação? *Are you supported by the village community/consultants/cooperative for the irrigation of your crops?*
□ Sim □ Não

5.4 Por favor descreva como é o apoio; *please describe how you get supported.*
____

5.5 A qualidade de água melhorou ou piorou nos últimos anos? *Did the water quality improve or deteriorate in the recent years?*
□ Melhorou; *improve* □ Piorou; *deteriorate* □ Sem mudança; *no change*

5.6 Se mudou, por favor estime o melhoramento ou a piora; *please estimate the degree of improvement or deterioration*
□ pouco; *small* □ médio; *medium* □ muito; *strong*

5.7 No futuro, pagaria uma taxa/ imposto para a água? *Would you be willing to pay a water price/fee?*
□ Sim □ Não

5.8 Se sim, quanto pagaria para um abastecimento garantido com asistencia técnica durante da toda estação de crescimento? *If yes, how much would you be willing to pay for the following guaranteed water delivery to your farm during entire growing season?* (R$/ha e ano):

5.9 Se já paga (K1, K2): acha que o preço é justo? ***If you are already paying: do you think the water taxes are fair?***
□ Sim □ Não

5.10 Observou se houve diminuição da fertilidade dos seus solos na sua área no ano pasado? ***Did you experience soil degradation in your fields?***
□ Sim □ Não

5.11 Observou se houve salizinação do solo na sua área? ***Did you experience salinization in your fields?***
□ Sim □ Não

5.12 Se sim, em qual % da seu terra? ***If yes, on how many % of your land?*** **___________%**

5.13 Sofreu de perdas de rendimento por causa de solos salinizados nestas áreas? ***Did you suffer yield losses due to high salinity on those lands?***
□ Sim □ Não

5.14 Se sim, por favor, estime a perda de rendimento nestes campos em % em comparação com o rendimento normal ___________ % ***(If yes, estimate yield losses on those lands in % compared to normal yield)***

5.15 Como se desenvolveu a salinidade dos seus campos nos últimos anos? ***Did the degree of salinity in your fields increase or decrease in the last years?***
□ Aumento; *increase* □ Redução; *decrease* □ Sem mudança; *no change*

5.16 Se mudou, por favor estime a extensão do aumento ou a redução? ***Please estimate the degree of increase or decrease in the last years?***
□ Pouco; *small* □ médio; *medium* □ muito; *strong*

6. Applicação de pesticidas (fungicidas, inseticidas, herbicidas, regulador de floração); *pesticide application*

6.1 Por favor descreva a applicação de pesticidas nos seus lotes, se mistura pesticidas, descreva juntos; ***please describe the application of pesticides.***

	Nomem dos agrotóxicos	Cultura A						Cultura B					
		1)	2)	3)	4)	5)		1)	2)	3)	4)	5)	
						F	C					F	C
1) Quantas veces mensal? 2) Método de applicação (Code 1) 3) Quantidade? *Amount?* *4)* Valor de agrotóxico? *Costs?* (R$) 5) Quanto mão de obra (hm/dia) Nota: Se fertigação marque com 1, no solo 2													
Intercalar													
A: (1) manual com mochila; *backpack sprayer* (2) trator; *tractor* (3) tração animal; *animal* (4) barra; *bar* (5) outro; *other:*													

	Nomem dos agrotóxicos	Cultura C						Cultura D					
		1)	2)	3)	4)	5)		1)	2)	3)	4)	5)	
						F	C					F	C
1) Quantas veces mensal? 2) Método de applicação (Code 1) 3) Quantidade? *Amount?* *4)* Valor de adubo? *Costs?* (R$) 5) Quanto mão de obra Nota: Se fertigação marque com 1, no solo 2													
Intercalar													
A: (1) manual com mochila; (2) trator; (3) tração animal; (4) barra; (5) outro													

7. Arrancar ervas; *weeding*

7.1 Por favor, descreva como retirar ervas; ***please describe your weeding in different crops***

	Cultura A	Cultura B	Cultura C	Cultura D
Quantas veces arranca por ano? *When?*				
Intercalar				
Quem é responsável? *Who is responsible?* (code A)				
Intercalar				
Como se retira? *Method?* (code B)				
Intercalar				
Se por máquina, code C. *Machine: C*				
Intercalar				
Se usou máquina, preço de aluga, condutor e de combustível? *If machine, prices?* (R$/h) ou (l/h)				
Intercalar				
Quanto mão-de-obra familar? *How much family labor?* (h/ha)				
Intercalar				
Quantas horas de trabalho contratado? *Hours of hired labor?* (h/ha)				
Intercalar				

A: (1) Familia; *family* (2) Trabalhador contratado; *hired labor* (3) Arrendado; *subcontractor* (4) Cooperativa; *cooperative* (5) Outro; *other:*	**B:** (1) manual (com estrovenga); *manual* (2) tração animal; *animal* (3) trator com enxada; *tractor com hoe* (4) trator roçadeira; *tractor* (5) outro; *other:*	**C:** (1) Máquina própria; *own machine* (2) Máquina alugada sem condutor; *rent machine without driver* (3) Máquina alugada com condutor; *rent machine with driver* (4) Outro; *other:*

8. Gestão das lavouras permanents; *management of permanent cultures*

8.1 Por favor descreva a gestão media das suas lavouras permanents; ***please describe your fruit tree management***

	Cultura A	Cultura B	Cultura C	Cultura D
Tipo de trabalho? *Type of work?*				
Intercalar				
Quem faz o trabalho? *Who is responsible?* (Code A)				
Intercalar				
Quanto mão-de-obra familar? *How much family labor?* (h/ha)				
Intercalar				
Quantas horas de trabalho contratado? *Hours of hired labor?* (h/ha) ou (hm/dia)				
Intercalar				

A: (1) Familia; *family* (2) Trabalhador contratado; *hired labor* (3) Arrendado; *subcontractor* (4) Cooperativa; *cooperative* (5) Outro; *other:*

Última pergunta: por favour liste as mudanças mais importante quais melhorariam a sua sitação como agricultor? ***Last question: List the three most important changes that would improve your current situation as a farmer?***

1.)
2.)
3.)

Curriculum Vitae

Personal Details

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Marital status	Married
Nationality	German
Date of birth	May, 28th 1984

Education/Academic studies

2012 – 2015 (expected)	PhD student, Agricultural Sciences, University of Hohenheim, Stuttgart/Germany
2008 – 2011	Agribusiness MSc, University of Hohenheim, Stuttgart/Hohenheim Master of Science in Agribusiness
2009 – 2010	ERASMUS study abroad „Ingeniero Agrónomo“, University of Almería/Spain
2004 – 2008	Agricultural Sciences BSc, University of Hohenheim, Stuttgart/Germany Bachelor of Science in Agricultural Sciences
2004	Intensive course of Russian language, Belarusian State University, Minsk/Belarus
2003 – 2004	Mathematics, Goethe University, Frankfurt/Germany
2000 – 2003	Gymnasium, an academic senior high school, Heinrich-Mann-Schule, Dietzenbach/Germany

Professional experience

01.02.2012 – 31.12.2015	Research associate, Department of Computer Applications and Business Management in Agriculture, University of Hohenheim
01.10.2008 – 31.01.2009	Tutor of Statistics in the courses Agricultural Biology and Renewable Energy (both BSc), Department of Biostatistics, University of Hohenheim
23.04.2007 – 20.07.2007	Internship at the Institute for Plant Breeding, Department of Oilseeds and Field Crops, KWS Saat AG, Einbeck/Germany
02.10.2006 – 13.03.2007	Internship at the Cooperative project “Nachhaltiges Naturressourcenmanagement KfW-GTZ”, GTZ GmbH, San Lorenzo/Paraguay
23.08.2004 – 17.09.2004	Agricultural Internship, Peters, Tornow & Creutzburg GbR, Varchentin/Germany

Affidavit

pursuant to Sec. 8(2) of the University of Hohenheim’s doctoral degree regulations for Dr.sc.agr.

1. I hereby declare that I independently completed the doctoral thesis submitted on the topic
   ……………………………………………………………………………
   ……………………………………………………………………………
2. I only used the sources and aids documented and only made use of permissible assistance by third parties. In particular, I properly documented any contents which I used - either by directly quoting or paraphrasing - from other works.
3. I did not accept any assistance from a commercial doctoral agency or consulting firm.
4. I am aware of the meaning of this affidavit and the criminal penalties of an incorrect or incomplete affidavit.

I hereby confirm the correctness of the above declaration. I hereby affirm in lieu of oath that I have, to the best of my knowledge, declared nothing but the truth and have not omitted any information.

S-Hohenheim, October 2016

Heinrich Karl Hagel