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Socio-economic aspects of irrigation agriculture as livelihood for rural families in Brazil's semi-arid northeast

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Abstract

Along the lower-middle São Francisco River, in the semi-arid region of Northeast Brazil, irrigated agriculture contributes 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 favourable production conditions for irrigated agriculture, many smallholders in the irrigation schemes are facing poverty. To identify socio-economic key indicators on farm income, expert interviews (n=16) and a household survey (n=120) were conducted. 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 intensive 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, investments 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: ANOVA, family farming, income, Itaparica reservoir, productivity, smallholder

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 colonisation as summarised by Wagner & Ward (1980). Most recently, economic crises in the 1980s and 1990s led to a rural exodus in the country's semi-arid Northeast (Perz, 2000). Main driver 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 centre 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 (Finan & Nelson, 2001; Sieber *et al.*, 2011). Despite several drought adaptation strategies, such as small-scale irrigated agriculture (Burney *et al.*, 2014), and extensive governmental social support programmes (Herwehe & Scott, 2017), 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).

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 favoured the implementation of irrigation schemes along the lower-middle São Francisco River. In the case of the Itaparica Reser-

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voir, irrigation schemes were implemented to compensate the affected population from land losses (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; Naranjo, 2012), resettled smallholders in the irrigation schemes in the surrounding of the Itaparica Reservoir are facing income insecurity. Supported by the World Bank, the Brazilian government had intended to organise 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 (VanWey & Vithayathil, 2013), 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.

2 Materials and methods

2.1 Study site description

The study area is located in Petrolândia municipality, and includes the surrounding irrigation schemes of the Itaparica Reservoir construction at the lower-middle São Francisco river basin in Pernambuco state/Northeast Brazil (Fig. 1, right).

The area is part of Brazil's semi-arid region – the so-called drought polygon (Fig. 1, left). Climate is semi-arid and characterised 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 & Heller, 1977). In the last decades, yearly average precipitation was around 340 mm, but during droughts values fall below 100 mm (APAC, 2018). Therewith the study area is located in one of the driest regions of Brazil's semi-arid Northeast (CONDEPE, 1998).

Most of the soils in the study region are Arenosols (IUSS Working Group WRB, 2007) and characterised by low nutrient availability. Despite their susceptibility to salinisation and erosion (Araújo Filho *et al.*, 2013; Parahyba *et al.*, 2004), presence of reservoirs, constant temperatures, and additional governmental support favoured the implementation of irrigation schemes (Untied, 2005).

Traditional land use consisted of extensive livestock farming, recession agriculture, and marginal rain fed crop production in the hinterlands supported by extensive irrigation systems along the river flood plains (varzea) (Antonino *et al.*, 2005; Sietz *et al.*, 2006). Typical subsistence crops were beans, corn, and manioc (World Bank, 1998).

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*' – small rural villages located close to planned irrigation schemes and equipped with basic infrastructure. 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. 1, 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* and received irrigated lots between 1.5 ha and 6 ha per family depending on family size. An exception was the scheme Apolônio Sales, where experienced farmers of the former irrigation project Barreiras were resettled and received lots of 8 ha per household and dwellings directly on their lots. Households were also promised land for rainfed farming, agricultural extension, monthly compensation payments until the first harvest (VMT: "verba de manutenção temporária"), and guaranteed commercialisation of their yields in the first five years of production (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 being established during the study period in 2013. As a consequence

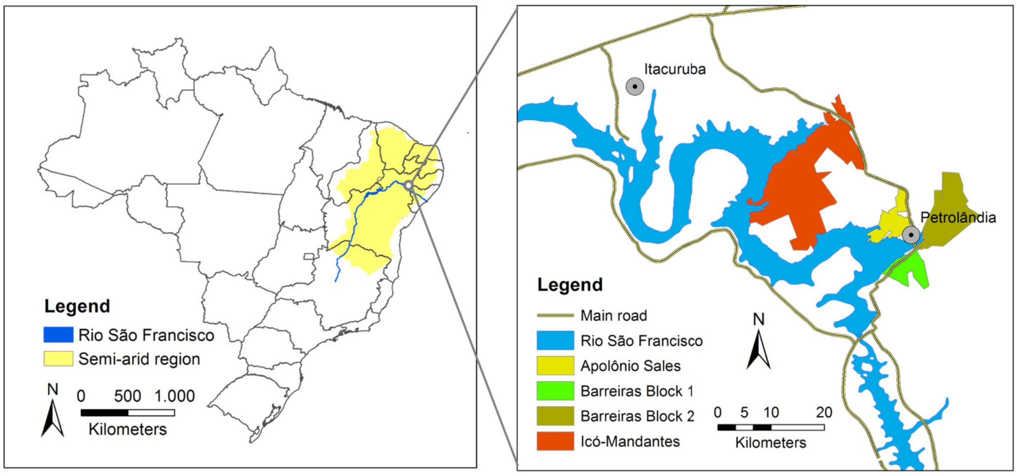

Fig. 1: *Location of the investigated irrigation schemes. Source: Own figures after IBGE, 2013a.*

of the delayed provision of irrigation water, the VMT was extended (De Arroxelas Galvão, 1999). Even 10 years after the resettlement process there were still families receiving VMT (Untied, 2005).

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 from August 2012 until June 2013.

A socio-economic and agricultural profile of Petrolândia and Petrolina municipalities was created analysing demographic and agricultural censuses. Literature review and reports about agricultural production received from local authorities (CODEVASF) and agricultural consultants (PLANTEC) completed this analysis. A guideline for semi-structured key informant interviews was created following established guidelines to assess the historical and current situation of agriculture in the Itaparica and Petrolina regions and to determine the regions' main strengths and weaknesses (Atteslander, 2010; Bernard, 2006). 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 & Waldorf, 1981), until the last interview provided no additional information (n=16) (Guest *et al.*, 2006). Results were analysed 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. Rain fed agriculture is practiced extensively on subsistence level, providing only marginal extra income. Thus, the survey focused on production within irrigation schemes. A structured and standardized questionnaire was developed to collect socio-economic, demographic, and agricultural data on farm level. The questionnaire was pretested and adjusted with the support of local agricultural consultants. For the interviews inside the irrigation schemes, a stratified random sample of n=120 of the total 914 households was selected. This sample aimed to cover more than 10 % of total households with at least 30 interviews per irrigation scheme. Forty-seven of the interviews were conducted in Icó-Mandantes, 35 in Barreiras, and 32 in Apolônio Sales.

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 neighbourhood. 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 analysing 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 CM.

In the scheme Barreiras, twelve 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 (IBM Corp., 2013). 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 labour in hours per year;

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

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) Edu – Education of the HH head based on visited school years;

h) Ar_C – Area of crop C1-22 (includes all recorded crops and fallow areas).

3 Results

In the first three sections the socio-economic and agricultural situation of Petrolândia and the adjacent irrigation schemes is analysed 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.

3.1 *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 centres such as Petrolina/Juazeiro. Socio-economic indicators, such as the Human Development Index (HDI), confirm these statements as illustrated in Table 1. Experts mentioned electricity generation in the hydropower plant Luiz Gonzaga as the main factor for the city's prosperity. 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 fertiliser, 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 678 R$ in 2013 (Presidência da República, 2012).

Table 1: *Socio-economic profile of Petrolândia.*

	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
HDI*	0.623	0.617	0.727
Share of most relevant economic sectors on employment [%]†			
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$]			
Urban	464.18	397.88	1,451.34
Rural	296.73	237.71	563.58

*Human Development Index; †Excluded sectors 'non-specified activities' and 'international organisations'.
Data source: IBGE 2010

3.2 *Agricultural production systems*

Similar to the whole semi-arid region, agricultural production outside the irrigation schemes is characterised by subsistence rain fed or irrigated crop production on a small scale, and extensive livestock on large areas. Farmers conduct most farm work manually in large part supported by day labourers. Tractors are used for soil preparation and in few cases to support the application of agrochemicals.

There are 1,006 farms in Petrolândia of which 125 farms operate 5,054 ha ranch land 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 (66.8 %) with a range of 15 meters, but the use of micro-sprinkler and drip irrigation is increasing (IBGE, 2006).

After the completion of the irrigation schemes in the mid 90's, irrigated fruit production increased strongly. On recently planted fruit plantations, farmers cultivate annuals in an intercropping system to generate income until the plantations provide stable yields. Besides the subsistence crops beans, maize and manioc, watermelon is the main annual cash crop. 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.

Whereas agricultural production in Apolônio Sales concentrates on perennial fruit trees, annual crop production dominates in Icó-Mandantes and Barreiras. In those two irrigation schemes most relevant cash crops are watermelon and pumpkin (CODEVASF, 2013). 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 (see also supplementary material). The high share of annuals in Barreiras is also due to the recent implementation of Barreiras Block 2. Thus, experts assumed that the importance of perennials in Barreiras will increase within the next years even more. The drought in 2012 and 2013 caused high producer prices, especially of beans and banana. This lead to high values of production, especially in the schemes Icó-Mandantes and Barreiras (Fig. 2) (CODEVASF, 2013 and own data). 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 the perennials coconut and mango was less profitable compared to banana and 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.

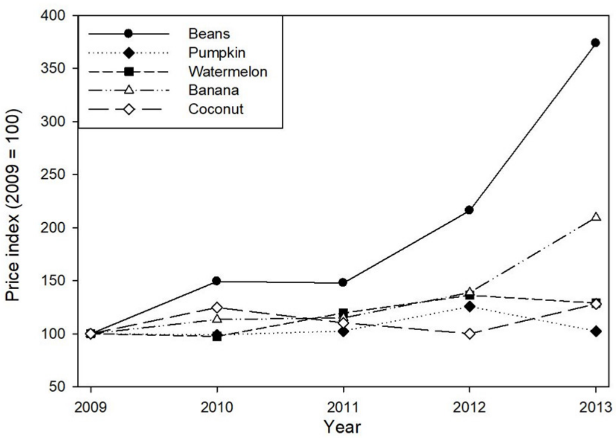

Fig. 2: *Price development of the main crops in the irrigation schemes of Petrolândia.*
Source: Own figure after CODEVASF (2013) for the period 2009-2012 and own data for 2013.

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 (nearly 1,000 ha estimated solely in Icó-Mandantes).

3.3 Major problems in the irrigation schemes

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. Salinisation occurred mainly in the early years favoured by high salinity of irrigation water and high evaporation rate. Installation of drainages solely reduced this problem. 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. Experts summarized the following factors as infrastructure relevant for agriculture: a) availability of land titles, b) access to credits, c) (physical) market access to purchase inputs and to commercialise products, d) availability of agricultural extension, and e) monitored provision of water for irrigation. 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 had practically no access to micro-credits. Consequently, they rarely invested in their farm, for instance in modern irrigation technologies or crop and site specific fertiliser. 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 prices.

Lack of access to markets hindered the successful commercialisation of agricultural products. The closest big producer market is located in Paulo Afonso and around 60 kilometres distant from Petrolândia and few smallholders possessed sufficient means of transportation. 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 farm gate. 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 paid the same price or less than the middlemen so there was 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-organised agricultural cooperatives in the study region (see also Hagel *et al.*, 2015).

Farmers in the irrigation schemes were not familiar with newly introduced cash crops, such as perennial fruit trees, and irrigation techniques. Especially in Icó-Mandantes and Barreiras, most smallholders were resettled subsistence farmers or former landless day labourers 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 caused by the involuntary character of the resettlement and by delayed provision of compensations provided justification to the illegally expanding farmers.

3.4 *Basic household information of the interviewed households*

The main socio-economic indicators of the analysed 107 established farms, categorised by irrigation scheme, are illustrated in Table 2. 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 of cattle, chicken, pork, quails, and draft animals. The high standard deviation was due to few farmers keeping big herds of small ruminants (80 to 120 animals equals 8 to 12 TLU) or some cattle (12-30 animals which equals 8.4 to 21 TLU). Main perennial cash crops were coconut and banana. Water melon, beans, and manioc were the main annual crops. Earnings from annual intercrops could not compensate the investments in perennial plantations, what led to negative agricultural income. The income distribution shown in Fig. 3 illustrates not only the different economic situation between the irrigation schemes but

Table 2: *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$)	19,848	12,924.1	11,760	12,045.6	8,033	9,388.6C
Profit by area (R$/ha)	3,374	1,871.3	3,188	2,553.3	3,645	3,834.7
Total 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)	7.88	2.91	4.26	3.13	4.99	3.24
Family labour (hrs/year)	6,731	2,660.4	4,946	3,952.7	3,249	2,931.6
Livestock (TLU)*	6.29	13.27	3.23	7.39	2.12	4.72

* A small ruminant equals 0.1 TLU, whereas a cow equals 0.7 TLU (after Chilonda & Otte, 2006)
(2013: 1 R$ ≈ 0.5 US$)

Table 3: *Income and socio-economic variables of the interviewed households by irrigation scheme*

					95% Confidence interval	
(I) Irr Scheme	*(J) Irr Scheme*	*Mean Diff. (I-J)*	*Std. Error*	*P value*	*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

Note: ** and * indicate statistical significance at the 1 % and 5 % probability levels, respectively.

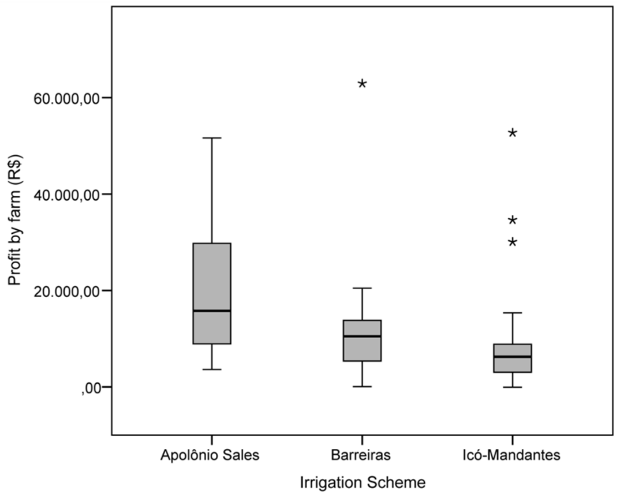

Fig. 3: *Distribution of farm income (R$ per farm) by irrigation scheme*

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. 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^{-1} against 23 t ha^{-1} as mean production). 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 ($p < 0.05$ and $P < 0.01$ respectively), whereas there was no significant difference between Barreiras and Icó-Mandantes as shown in Table 3. 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.

Interviewed farmers cultivated 21 different crops, which are illustrated in Table 4. New plantations, which did not provide yields yet, were excluded from the calculation. 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 perennials mango and guava. The gap between profits of the main annuals, banana, and coconut were due to the price situation (Fig. 2). Profits of the high-value fruits mango and papaya were unequally distributed in favour of the Apolônio Sales and Barreiras irrigation schemes.

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 5. Considering all integrated factors, 71 % of the total variance could be explained (R^2 0.710). 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. This can be explained by the fact that the few farmers who produced these crops were all among the ones with the highest income (see also Fig. 3). High producer prices of banana during the study period (Fig. 2) led to high impact of banana cultivation, which was nearly as high as the one of the cash crop water melon. Beans seem to have a high impact in relation to profits and area but were often cultivated as intercrop and

Table 4: *Distribution and economic performance of the assessed crops in the study area**

Crop	*No. of farms*	*Total area (ha)*	*Mean area per HH (ha)*	*SD*	*Mean profit (R$/ha)*	*SD*
Banana (*Musa* spp.)	33	47.9	1.452	0.8570	3,775.34	1,976.26
Beans (*Phaseolus vulgaris*)	22	44.5	2.023	1.2486	2,492.11	1,246.06
Capim (*Pennisetum purpureum*)	3	6.7	2.233	0.6807	1.269,10	927.06
Cashew (*Anacardium occidentale*)	1	0.8	0.800	–	691.05	–
Coconut (*Cocos nucifera*)	62	197.2	3.232	2.0128	1,970.96	2,028.64
Corn (*Zea mays*)	20	27.2	1.360	0.5789	905.41	552.55
Grape (*Vitis vinifera*)	1	3.5	3.500	–	12,645.12	–
Guava (*Psidium guajava*)	13	16.2	1.242	0.4291	5,536.02	5,040.15
Mango (*Mangifera indica*)	10	11.6	1.160	0.4624	3,954.25	3,433.25
Manioc (*Manihot esculenta*)	6	5.3	0.875	0.4937	4,002.72	2,430.24
Melon (*Cucumis melo*)	2	3.5	1.750	0.3536	4,974.49	438.38
Onion (*Allium cepa*)	4	5.5	1.375	0.7500	10,278.33	5,443.05
Papaya (*Carica papaya*)	4	4.6	1.138	0.1601	1,823.89	2,090.67
Paprika (*Capsicum annuum*)	3	1.8	0.600	0.3606	169.31	726.11
Passion Fruit (*Passiflora edulis*)	1	1.0	1.000	–	9,596.49	–
Peanuts (*Arachis hypogaea*)	3	2.5	0.833	0.2887	1,806.15	923.27
Pumpkin (*Cucurbita* spp).	8	10.6	1.319	0.2902	2,369.25	1,806.33
Tomato (*Solanum lycopersicum*)	2	2.3	1.150	1.2021	26,604.43	6,246.55
Water melon (*Citrullus lanatus*)	21	46.3	2.204	1.3314	3,099.44	1,545.30
Zucchini (*Cucurbita pepo*)	1	1.5	1.500	-	6,929.19	–
Fallow	50	75.9	1.520	1.0374	–	–

* Only lots with ongoing production were considered.

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. 3, the irrigation scheme had no significant impact on farm income. One reason for that might be the similar income situation in the Icó-Mandantes and Barreiras irrigation schemes, where 82 of the 120 household interviews were conducted. Another reason might be the presence of farmers with very high and very low income in all three irrigation schemes. Removing the outliers, which are shown in Fig. 3, may increase the effect of irrigation scheme. The socio-economic factors age, gender, job alternative, and available family labour had no significant impact on the farm income. In general, this can be explained by the dominant role of crop profitability on farm income. In addition, the sample seemed to be less diverse in respect to the chosen socio-economic indicators as it is in crop choice. An indicator for this explanation is the relatively low standard deviation of age of HH head, education of HH head, and available family labour compared to the high differences of profitability between the crops and the high standard deviation of farm income, as indicated in Table 2.

4 Discussion

4.1 *Insufficient infrastructure and unequal land distribution affect smallholders' livelihoods*

The main constraints for smallholders were insufficient infrastructure and unequal distribution of irrigable areas. Several studies (Naranjo, 2012; Rada, 2013; Untied 2005) underline the role of improvements of infrastructure for rural development. Low market power and the resulting high input costs and low producer prices negatively influence the smallholders' income. Although experts and several farmers mentioned that the situation had improved in recent years, the fundamental problem of low market power 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 6. Irrigable areas were unequally distributed between the irrigation schemes (Table 2). In addition, several farmers stated that 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 (Kenny, 2010; Bedran-Martins & Lemos, 2017). Naranjo (2012) identified limited access to

Table 5: *Test of between-subject effects, dependent variable profit by farm.*

Variable	*F*	*Significance*	*ETA-squ.*[§]
Age of HH head	1.692	0.197	0.023
Gender of HH head	1.252	0.267	0.017
Education of HH head	1.320	0.254	0.018
Alternative job	0.936	0.337	0.013
Available labour	0.036	0.850	0.000
Irrigation scheme	0.076	0.927	0.002
TLU*	0.096	0.757	0.001
Fallow	2.408	0.125	0.032
Banana	8.220	0.005*	0.101
Beans	22.054	0.000***	0.232
Capim	0.010	0.920	0.000
Cashew	0.039	0.845	0.001
Coconut	5.588	0.021	0.071
Corn	2.164	0.146	0.029
Grape	19.903	0.000***	0.214
Guava	0.873	0.353	0.012
Mango	6.333	0.014	0.080
Manioc	2.240	0.139	0.030
Melon	3.326	0.072	0.044
Onion	26.774	0.000***	0.268
Papaya	0.485	0.488	0.007
Paprika	0.647	0.424	0.009
Passion Fruit	2.526	0.116	0.033
Peanuts	0.254	0.616	0.003
Pumpkin	0.641	0.426	0.009
Tomato	29.490	0.000***	0.288
Water melon	8.963	0.004**	0.109
Zucchini	0.519	0.474	0.007

Number of observations: n=120; ANOVA: Type III SSQ=11226228777,988; df=33; Sign.=.000; R Squared = .770 (Adjusted R Squared = .579)
[§] Eta-squ. = proportion of variance in farm income explained by the independent variables. Values >.14 indicate large effects.
* Tropical livestock unit.
Note: ***, ** and * indicate statistical significance at the 1 %, 5 %, and 10 % probability levels, respectively.

land as an important determinant of the marginalisation of family farmers. 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.

Insufficient farm sizes increase the risk of resource overuse, as also mentioned by Sietz *et al*. (2006). Cline (1970) discussed the inverse relationship of farm size and productivity in Northeast Brazil. The risk of land degradation is also

Table 6: *Average producer prices of main perennial crops in the period from 2009 to 2012 in R\$ per 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] for prices of the irrigation schemes in the study area, and IBGE (2013)[b].

pointed out by Toni & 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. Insufficient access to credits due to lack of land titles, aggravates this problem. In addition, fear of debts deters poorer farmers from taking a loan to invest in their farm (Herwehe & Scott, 2017). Consequently, poor farmers were more susceptible to land degradation. Integrated nutrient management including aquatic and terrestrial sectors (Siegmund-Schultze *et al*., 2018) and the promotion of good agricultural practise (Cierjacks *et al*. 2016) may contribute to more sustainable production systems.

4.2 *Natural and economic developments increase pressure on irrigable areas*

Agricultural production focused on few crops, mainly coconut, banana, and beans. Especially owners of small areas with no capital available did not have sufficient opportunities to diversify their production and include, for instance, areas with a rotation of annual cash crops, such as beans, Cucurbitaceae, and vegetables. Low levels of diversification increased the vulnerability to price volatility which was a regular issue in the study region (Fig. 2). Volatile prices, as in the case of coconut during the study period, may reduce the low propensity to invest in farm infrastructure.

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. 3), 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 favour concentration of land ownership. Price shocks may reduce this relatively low attractiveness of agricultural activities in favour 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. According to interviewed experts, all rainfed areas were strongly affected by the severe drought in 2012 and 2013 and crops yielded solely on irrigated lots. As most yields of perennial crops in Petrolândia were produced on irrigated areas, the drought of 2012 and 2013 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) indicated positive effects of irrigated agriculture to off-farm income opportunities.

4.3 Determinants for farm income

Choice of highly profitable crops (banana, beans, grapes, onions, tomatoes, and water melon) had the highest influence on farm income, whereas socio-economic variables had no significant effect. However, 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. On the one hand, wealthier farmers seemed to be the ones with a better standing in the community, being better connected, and having off-farm income sources within the family. Consequently, those farmers had the capacity to grow more lucrative crops, such as mango, onions and tomatoes, or adapt to high producer prices as in the case of beans during the study period. On the other hand, poorer farmers seemed to be more risk averse. Consequently, they cultivated less economically lucrative crops, which provide secure and frequent yields, such as coconut, banana, corn, and beans. To support inexperienced farmers in regard to crop choice, cultivation methods, and business administration reintroduction of agricultural extension appears to be necessary (Hagel *et al.*, 2014), especially considering the preference of many smallholders towards traditional crops, such as beans, corn, and manioc (Scott, 2006).

Considering the historical background of involuntary resettlements, delayed provision of compensations, and lack of agricultural extension and land titles, it is also possible that farmers concealed the role of their own off-farm income. Off-farm income of family members was not captured by the questionnaire. Consequently, the relevance of additional stable income sources may have been underestimated in this study.

Employing day labourers was a common practise in the irrigation schemes, especially concerning the application of agrochemicals, manual fertilisation, and during harvest. Given the high farm income of wealthier farmers and potential off-farm income alternatives of family members, family labour might be substituted by hired labour. This might be one factor to explain the low impact of family labour on farm income.

Although there was no significant impact of TLU on farm income, several statements during the interviews indicated the economic importance of 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. Absurdly, the poor farmers who are more vulnerable to droughts would benefit the most from livestock production which is less susceptible to droughts (Coutinho *et al.*, 2013). De Oliveira *et al.* (2014) underlined the economic potentials of integrated crop-livestock systems in southern Brazil. By providing reliable feed sources, such systems may also reduce the pressure on the Caatinga vegetation, which is crucial considering the pressure of grazing of high intensity on the fragile biome (Schulz *et al.*, 2018).

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, such as grape, guava, and mango, with investments over more than ten years. De Lima & Lopes (2012) discussed the importance of education for economic independence, VanWey & Vithayathil (2013) underlined the role of education and social capital on agricultural productivity and off-farm activities, and Finan & Nelson (2001) argued that less educated farmers with small areas are the most vulnerable ones in the semi-arid region of Northeast Brazil. Due to limited time for each interview, the interviews focused on the head of each interviewed household. Thus, financial support provided by family members was not considered. 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 & Eduardo Del Grossi, 2001).

5 Conclusions

This study contributes to literature analysing the farm income of smallholders in irrigation schemes at the Itaparica reservoir in detail. Mean farm income was below the national minimum salary. However, smallholders in irrigation schemes appear relatively wealthy compared to marginalized peasants without access to irrigable land. Sufficient area of irrigable land seems crucial to provide sufficient income; an optimal land allocation of the scarce areas appears necessary.

Low producer prices, mainly due to limited market access, were a main constraint of profitable agricultural production. 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 susceptibility to salinisation and erosion of the soils in the study area, the fragile character of the Caatinga ecosystem, and the omnipresent water scarcity in the semi-arid 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. Joint purchases of inputs in the framework of cooperatives may increase the farmers' market power or even enable them to access more distant bigger markets where the input prices were lower due to higher competition between the retailers. In addition, joint sales of agricultural products may increase the producer prices, especially when cooperatives reach markets in the bigger cities, such as Santa Maria da Boa Vista, Petrolina, or Juazeiro, and do not depend on mobile middlemen who dictate literally farmgate prices, which were far below the northeastern average (Table 6). Value adding facilities, such as food processing units, might provide additional income sources in the region.

This study aimed at analysing the socio-economic aspects within the entirety of farmers in the investigated irrigation schemes. Further research could concentrate on more specific factors, such as yield levels and producer prices of the main crops in the area. Additionally, more research should be conducted on the role of off- and on-farm income alternatives in the study region. Soft socio-economic factors, such as standing in the community, business skills, and family cohesion, could be further investigated using a more qualitative approach to identify significant socio-economic key-indicators.

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Conflict of interest

Authors state they have no conflict of interests.

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