Mathematical Programming Models to Increase Land and Water Use Efficiency in Semi-arid NE-Brazil

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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.

1. INTRODUCTION

Since the 1970s, several dams and reservoirs were constructed on the São Francisco River to provide energy to the growing economy and cities of northeast Brazil. One of those projects is 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 local agricultural production. Intensive irrigated vegetable and fruit production replaced extensive traditional systems, which had consisted mainly of dryland farming along the riverside and livestock keeping on large areas in the interior (World Bank, 1998). Resettled smallholders received areas in irrigation schemes equipped with sprinkler systems and free irrigation water as compensation for their flooded land. However, sandy soils in many areas 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 extension, and limited market access (Untied, 2005). Inappropriate irrigation practices, inaccurate use of agrochemicals, and low producer prices persist (Hagel et al., 2012). In contrast to other regions along the São Francisco River, farmers at the Itaparica reservoir still do not pay any fee for irrigation water (Untied, 2005).

This study aims at analyzing current production systems and identifying ideal crop composition of small farms at the Itaparica reservoir. Farm analysis is conducted using a cost-benefit calculation. Effects of changing production conditions are analyzed using a linear programming model.

2. MATERIAL AND METHODS

2.1 Study Region

The Itaparica reservoir is located in northeast Brazil (*Sertão*) as shown in Figure 1. The reservoir is bordering to Pernambuco state in its north and to Bahia state in its south. This study concentrates on the Apolônio Sales irrigation scheme near the town Petrolândia in Pernambuco, which is presumed to be a model for successful implementation of irrigated fruit production on the small scale.

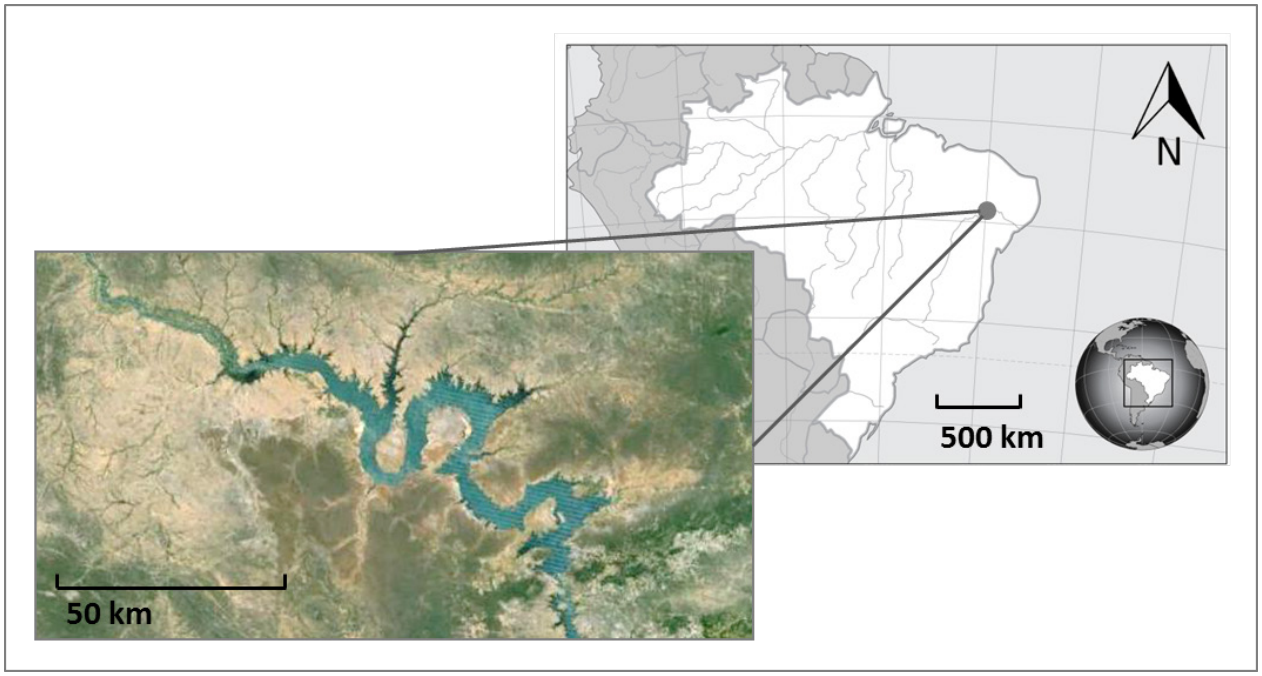

Figure 1. Location of the Itaparica reservoir. (Source: Own figure after Google Earth, 2014 and National Geographic, 2014)

Climate in the study region is semi-arid, characterized by average annual rainfall of around 300 mm and an average temperature of 25° C. According to the Köppen-Geiger Climate Classification, the climate type is BSs´h´. Natural vegetation is the shrub and thorn forest Caatinga (Parahyba et al., 2004). 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 the main income source (Ferreira Irmão et al., 2013).

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 of 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. 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 using farmers' preferences determined from twenty semi-structured on-farm interviews. Data for the analyses were collected from smallholders in a random sample of 191 structured on-farm interviews. According to these and secondary data received by local authorities, an LP model of a representative farm in the irrigation scheme Apolônio Sales nearby the city of Petrolândia was formulated.
As farmers mentioned in the interviews that they were mainly interested in profit maximization, the objective function of the model was formulated to maximize the farms' gross margin (GM, income less variable costs):

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

GM	=	Gross Margin
X	=	Cultivated area
i	=	1,…,n 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:

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

To spread the risk of low prices or yield loss of one specific crop, farmers of the chosen irrigation scheme 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 1 in the next chapter.

3. RESULTS

According to interviewed experts, data of local decision makers (CODEVASF, 2013), and secondary literature (Ferreira Irmão et al. 2013), perennial fruit cultivation dominates in the irrigation scheme. Coconut (*Cocos nucifera*) is the dominant fruit cultivated on nearly 60% of the irrigated area. The other relevant perennials are banana and mango. 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 1 illustrates the average GMs of the main crops within the irrigation scheme. Whereas mangos are harvested once per year, coconut and banana plantations provide yields through the whole year. Due to this and high tree care requirements of the farmers, mango is cultivated on relatively small areas, despite its high GM.

Table 1. 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, 2013

Due to a long-lasting drought from 2012 to 2013 and combined with heavy rainfalls in the south of Brazil, prices for annual crops increased strongly. Beans are one of the main subsistence crops and are cultivated mainly rather extensively in a rainfed system. Without irrigation opportunities, the drought caused severe crop failures in annual crop cultivation, which led to extremely high prices. Figure 2 illustrates the price development of the main annual (watermelon, pumpkin, beans) and perennial crops (coconut, banana) in the irrigation schemes.

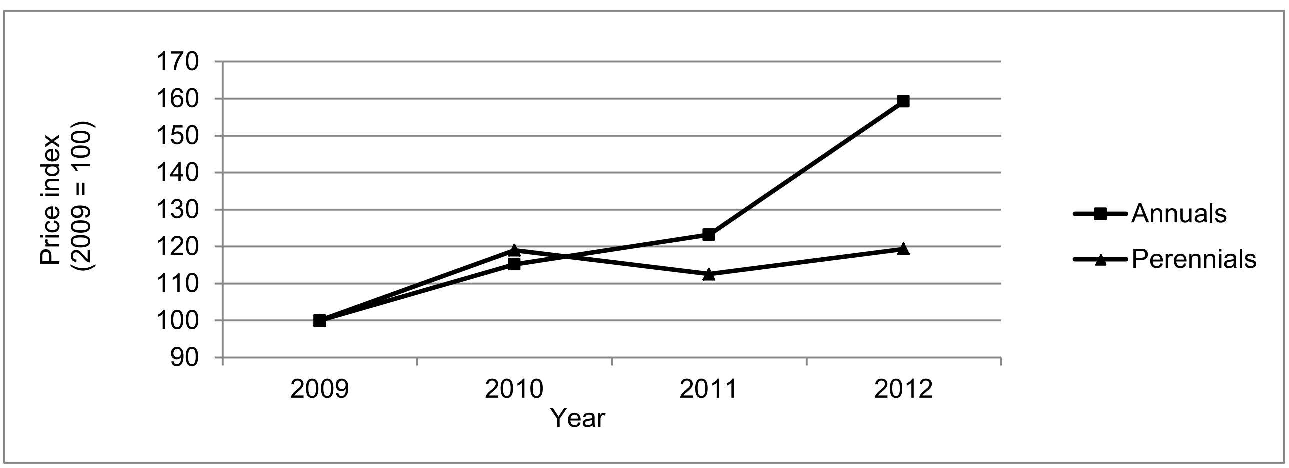

Figure 2. Price development of annual and perennial crops (Own figure after CODEVASF, 2013)

3.1 Dependency 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 1. During the study period the average daily wage of a day laborer was 30 Brazilian Reais (R$), equal to the legal minimum wage. In adjacent regions with higher labor scarcity, the average wage was 40 R$ per day. As shown in Table 2, such an increase of daily wages could strongly affect the GM and therewith the smallholders' income.

Table 2. 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

3.2 Susceptibility Towards Changing Production Conditions

A fee for irrigation water is not yet included in the low GM for the irrigation scheme. Consequently and in addition to high implementation costs, most farmers use old sprinkler systems on coconut and mango plantations. Due to higher plant densities in banana cultivation, micro-sprinkler systems are used. The low returns of the current production systems, especially in the water intensive coconut cultivation, could reduce or become negative in a period of low prices or with the implementation of a water fee.

3.3 LP Model Approach to Increase Farm Productivity

To quantify the role of labor availability and free irrigation water, the LP model was developed as shown in Table 3. Results will provide the basis for policy recommendations to improve the farmers' livelihoods and implement resource efficient production methods.

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 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. Improved market access and higher producer prices are crucial to provide secure farm income. However, provided agricultural extension services, moderate water pricing may lead to implementation of more efficient irrigation technologies and water saving techniques. 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.

Table 3. Illustration of LP model with area and labor constraint

Decision	Coconut (1 ha)	Banana (1 ha)	Mango (1 ha)	Employ day laborer (8 hours)	Goal
Variable	X_1	X_2	X_3	X_4	
Objective					
GM (R$/ha)*	2,400	2,700	7,500	-30	Max
Constraints					
Area (ha)	1	1	1		≤ 8
Area coconut (ha)	1				≥ 4
Area alternative crops (ha)		1	1		≥ 1
Family labor (h/ha)	1,208	1,104	1,768	-8	≤ 5,000

* Excluded hired labor costs

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