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Research Article

The Social, Ecological and Farming System Constraints on Organic Crop Protection in Puerto Rico

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Abstract

Puerto Rico, although well positioned to take advantage of growth in the North American organic produce market, is only a minor organic producer in the Caribbean. This is despite having a good national infrastructure, access to the organic markets in the U.S. and a significant amount of land lying outside conventional production. Using a linear programming model, a farming systems analysis was used to highlight the reasons behind this anomaly. Many of the reasons lie in the historical marginalization of agriculture in this five hundred year old colony. Without a strong agricultural sector, Puerto Rico's mixed economic developments of the 20th century and the U.S.'s response to rising poverty only exacerbated dependencies on colonial formulas. Cheap imports, food stamps and a comprehensive agricultural incentives program virtually ensure that farmers are not in a position to develop a significant organic farming sector. This is particularly true of the central mountainous region where most of the island's smallest farms are found. The farming system study and the linear programming model indicate that labor and poor markets are the biggest constraints to the producers of the central region. Organic crop protection strategies can often be labor intensive and, without a strong, dependable market, most farmers would not invest in the additional labor needed to develop organic production. On a more positive note, many of the crops grown in the central region of Puerto Rico are managed without pesticides. This is in part to do with producers choosing crops that have low labor requirements.

Keywords: Organic farming: crop protection: Puerto Rico: farming systems research: linear programming

1. Introduction

1.1. Background to organic farming in Puerto Rico

Countries in the Caribbean have begun responding to the seemingly inexhaustible demand for tropical organic products. The Dominican Republic, Costa Rica, and Guatemala are leading regional organic producers of both traditional tropical commodities like coffee, bananas, cacao, and sugar and nontraditional commodities like counter-seasonal vegetables [1, 2]. Organic products are also a small but growing part of the agricultural sectors of Belize, Cuba, El Salvador, Honduras, Nicaragua, Trinidad and Tobago, and Suriname. The rapid growth of organic demand together with premium world prices for organic products would seem to offer Caribbean countries an opportunity to take on a new and lucrative role in the emerging global food system.

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Among Caribbean islands, Puerto Rico is perhaps best suited for organics. First, Puerto Rico enjoys excellent infrastructure as well as unfettered access to U.S. markets where the consumption of organic and other "natural" products nearly tripled between 1993 and 1998 from $6 billion to $17 billion [3]. Second, the island's agricultural production declined rapidly after World War II, liberating extensive agricultural acreage and other resources from a conventional global commodity system. Third, ecological agriculture has been a consistent theme in environmental activism on the island since at least the late 1970s. In 2000-2001 there were five distinct organizations promoting ecological agriculture with a combined participation of about 100 activists.

Despite these successes, organic production in Puerto Rico is still negligible at best. There are at most 15 career growers that avoid agro-chemicals and depend on agricultural sales for at least 25 percent of their income. Another 20 or so retirees and other hobbyists own farms and are interested in organics but do not produce at a commercial scale or depend on farming for their livelihood (Guptill, forthcoming). The past decade has seen some successful organic agriculture projects, including a now defunct organic exporting company, a recently established consumer-producer cooperative sponsoring a twice-monthly farmers' market, and a line of natural grocery stores. Nevertheless, production has not grown in response to emerging demand.

The difficulties associated with organic crop protection in Puerto Rico are symptomatic of the greater problems faced by organic production on the island. The island seems to offer many of the necessities for the development of an organic sector but, as we will show, there are even more reasons for why this has yet to become a reality. This paper identifies the social, ecological and structural reasons that hinder the development of this sector and we use a farming systems approach to examine the interrelated causes. We chose the central region of Puerto Rico for this study in part because the agrarian way of life that embodies the area, can no longer sustain the people who live there and who would benefit most from the development of alternative agriculture, and in particular organic farming. The central region encompasses 20 municipalities [4], and is an area that is traditionally dominated by mixed, low resource farms. To the west of the region, coffee is the dominant crop. In the centre and in the east, the farms grow mainly plantain, banana and assorted root crops. In the 2002 agricultural census, the average size of the farms in this region was 25 acres, with 30% of the land being planted and harvested and 19% being used for pasture and grazing [5].

1.2. Historical legacy

The contemporary constraints on Puerto Rican agriculture largely reflect the historical patterns of Caribbean agriculture. Unlike Europe and the U.S., most countries of the modern Caribbean have never had a historic period in which the core of the population was made up of a "peasantry," i.e. independent small-scale farmers combining staple cash crops with products for home consumption. Rather, most Caribbean agriculture has been characterized by a combination of resource-rich plantations accompanied by marginal independent producers. Mintz explains [6] (p. 131):

"The fact is that Caribbean peasantries, practically without exception, have always grown in the crevices of their societies – before slavery, or after slavery, or in places where the plantation failed, or in places where the plantation never came. Such crevices have been both historical and ecological: *time periods* when European control faltered or was relaxed, when the political future was clouded, or when runaways and squatters were able to establish themselves 'outside'; *geographical spaces* where the plantation could not work because of soil or slope or aridity or distance from the sea or some other such reason."

In Puerto Rico, like in other Caribbean islands, the spaces for independent farming were primarily the steeply sloped and largely inaccessible lands of the central mountains. Under Spanish mercantilism, independent farming was largely illegal. In the late 19^{th} and 20^{th} centuries there were agricultural booms in coffee, sugar, and tobacco, but Puerto Rico, like other Caribbean islands, has always been highly dependent on imported food and never a major producer of staple food crops. Production for local markets has always been a sideline for export production operations: worker-sown subsistence plots around the edges of sugar plantations; bananas, plantains, and tree fruits interspersed with coffee bushes; and locally marketed root crops to supplement tobacco earnings [6, 7].

In response to the decline of the sugar industry in the middle of the last century and to the failed economic programs of the 1960s, the local government initiated an agricultural modernization program in the 1970s, which relied on the promotion of intensive farming techniques, government subsidies and the use of agrochemicals. Government subsidies were only offered to those producers that farmed on an appropriate scale [8]. The producers also needed to be in the right zoning area and to be using appropriately 'modern' techniques. While the program led to the establishment of large vegetable and fruit farms on the south coastal plain, it had more insidious results in the small mountain farms in the central region. These results will be discussed later in the paper to show how the program is a hindrance and a potential benefit to the prospects of organic agriculture in the central region.

1.3. Pesticide use

Pesticides have been an integral part of agriculture in Puerto Rico and have followed the general trend of pesticide evolution as witnessed in many parts of the world. The agrochemical products used before the World Wars were not entirely effective and resulted in innovative methods being used to control key pests. In sugarcane, for example, the citrus root weevil (*Diaprepes abbreviatus*) was hand picked by the millions in the 1920s and minute hymenopteran egg parasitoids were reared and released to control the lepidopteran stem borers, in an example of early biological control. With the development of organophosphate chemicals and other synthetic compounds during the war period, alternative methods fell away as the new and effective insecticides were adopted. Perhaps this adoption was aided by the influence of North American agriculturalists that brought 'modern' techniques to the sugarcane industry. The local agricultural research establishment also employed North American scientists who helped in the rapid dissemination of new compounds to the island.

In the latter part of the last century, incidences of insecticide resistance outbreaks and health worries led to the continued introduction of new chemistries in much the same way as had occurred in other parts of the world. This pesticide treadmill and forced dependence continues to this day. Two factors that influence pesticide use on the island are insecticide registration and insecticide costs. Because the local agricultural sector represents such a small market for the big agrochemical companies, these companies are loath to invest millions of dollars in registering compounds for specialty crop use in Puerto Rico. To alleviate this, the USDA's IR-4 program helps with registrations to bring the pesticides to the island. Nevertheless, many insecticide products are not registered for use in Puerto Rico. In addition, the small size of many of the farm operations on the island means that producers cannot afford the high costs of some of the newer compounds. This is especially true where the insecticides are packaged in commercial quantities at costs which are prohibitively expensive for an out-of-pocket purchase by a low resource farmer, such as those found in the central region. The government's incentives program has tried to help the small farmer with these problems by offering a service that provides the pesticides at a subsidized price. Such a service is another example of how the socioeconomic realities of Puerto Rico have unwittingly led to the promotion of pesticides and also how the agricultural sector, and the central region in particular, has not had the independence to find its own solutions.

1.4. Making changes

The introduction of alternative agriculture and organic production into Puerto Rico would require many changes to the existing conventional systems. Many of these changes pertain to the perception of agriculture's placement within the wider landscape and to how agricultural activities should be managed. Within this fits the attitude towards crop protection and pest control. The overlying management strategy in organic production is to ensure crop health and crop compatibility with the local environment. In this way the crop best competes with weed and pest species and also interacts with the local environment in a way that allows natural balances to emerge. This reduces the risks of catastrophic events that lead to heavy losses. The very nature of organic production requires a holistic approach to management, which is contrary to the prescriptive approaches taken in conventional agriculture. This is especially true when it comes to crop protection. In conventional systems, producers follow a defined agronomic management program for the planting and nutrition of the crop. Pesticides are then used as a fire-fighting tool – that is, when the surrounding environment responds negatively to the imposition of this artificial planting. These applications may be either preemptive or be in response to certain pest levels. Efforts have been made to minimize the use of pesticides and to increase their specificity (reducing non-target impacts and cost) but the incompatibility with organic systems lies at a more fundamental level. The crux of the issue is the one-dimensional placement of a monoculture and disregard of local conditions. This is what organic agriculture looks at first. How can the crop be most appropriately grown, given the nature of the local surroundings and the possible environmental responses to the crop?

If these factors are taken into consideration, along with the characteristics of the plants being cultivated, one is then looking at a systems approach. The focus is on the interactions between elements and on the introduction of flexibility into the system. In this way, site-specific production efforts can be developed that avoid the trap of being formulaic and prescriptive. In addition to the agricultural considerations, one also has to look at the sociological, ecological and economic influences. This is especially true in places like the central region of Puerto Rico. This is perhaps not so obvious in the large organic farms that one can find in North America, which in many ways mirror the more conventional production models. Looking to see how organic farming may serve a region comprised of relatively small farms and a plethora of external influences, one needs to be as inclusive as possible. In this paper we hope to show that in order to understand the constraints on organic crop protection and crop production in the central region, one needs to look at the factors that go beyond the farmer's field and which arise from Puerto Rico's history and socioeconomic situation. To examine the impact of these issues we used a linear programming model as a tool to assist in a farming systems analysis in the central region of Puerto Rico.

2. Farming systems research and the use of linear programming (LP) models

2.1. Agricultural research and the farming system

A farming system is defined by the FAO as "a population of individual farm systems that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate" [9]. Keating and McCown [10] identify two key components of farming systems, namely the biophysical 'Production System' of crops, animals, soil and climate together with certain physical inputs and outputs and the 'Management System', made up of people, values, goals, knowledge, resources, monitoring opportunities and decision making. Their review of six types of farming systems analyses concludes that the challenges and opportunities lie at the interface between the 'hard', scientific approaches used in the analysis of the biophysical system and the 'soft' approaches used in the study of social management systems. They also conclude that the use of models in farmer decision support systems has been disappointing and a way has to be found of making models relevant to real world decision-making and management practices.

Part of the scientific process in agricultural research is the deconstruction of problems so that individual elements can be identified, appraised, experimented on and understood. A weakness in the scientific process is that the deconstruction removes the elements from their natural position, and contextually, this can lead to misinterpretations and oversights. The place of an element in a particular system is as important as the intrinsic characteristics of the element itself. Importantly, the producers themselves see their environment as a system and evaluate new technologies by the way in which they interact with the other elements of their environment [11]. Success is based on a perceived overall betterment of the system. These considerations are particularly important in organic agriculture where the crops are more of a product of their interactions with the surrounding environment than in conventional systems. This is particularly true in tropical systems, which because of latitudinal biodiversity gradients and greater species numbers means that inter-specific interactions are greater than in temperate climates. Also, the biological processes which drive these interactions occur more rapidly in warmer climates, and so are more likely to impinge on the development of the crop species.

How can the totality of a system be understood? Participatory research methods are a good way of studying communities and understanding their characteristics. They also are an integral part of Farming Systems Research (FSR), and they serve as an important means of dialogue between participants and stakeholders. FSR is principally about technology generation and application, and its processes can be divided into four stages: descriptive (diagnostic), design, testing and extension [12]. Stakeholder feedback is crucial to all stages. The first stage is about understanding the livelihood system and generating research objectives based on identified problems or possibilities. The second stage determines how best the research objectives can be met by planning an effective and efficient set of research activities. The third stage is the execution of these activities. This stage is given validity by its inclusiveness, its relevance and its interactivity. The final stage disseminates results and implements new technologies.

2.2. Linear programming models

Linear programming is a form of modeling that uses an optimization matrix program that can be used to examine the utilization of resources to find 'best-fit' solutions based on predetermined objectives. Such a model can be constructed using Microsoft Excel, for example, and can be run using either default solvers found in the spreadsheet programs, or for bigger matrices, by using specific programs that contain the solver. In essence, each activity included in the matrix is an individual cost-benefit analysis, which is assessed alongside all the other activities within a framework of logistical constraints and finite resources. In farming systems analysis a linear programming (LP) model can simulate and analyze family farm livelihood systems by determining the optimal combination of feasible farm and non-farm activities, given a set of fixed constraints [13]. LP models are not as exact in their simulation of production functions as some crop models, and they are not as sophisticated as some economic models, but they do represent a robust and fairly simple means of characterizing farming systems. Disparate elements of the system can be assessed in a framework that allows for an appreciation of the various interactions and dynamics found within.

The use of LP models in farm planning has its origins in the late 1950s, when whole farm planning was being developed. In 1958, Heady and Candler [14] outlined the application of LP modeling to farm planning, and by 1963, its relevance to low-income agriculture had been demonstrated [15]. Since then, it has been widely used to examine supply changes and policy shifts in agriculture [16]. Its impact on improving livelihoods in developing countries, however, has never been great, in part due to the laborious data collecting process and to its lack of direct applicability [17].

How then does LP modeling fit into FSR? Its primary use is in the first stage (description/diagnostic phase) and second stage (research-planning) of FSR, but can also be used as an extension tool in stage 4. With disparate sets of community data or on-farm data, the LP model can be used to distill the information into a matrix representing the enterprise activities (resource requirements and production functions), the farm's constraints and resources (land, labor, capital, costs - on both spatial and temporal levels) and household objectives. Once a model has been validated, and it accurately reflects the farming systems under question, the designing of experiments (stage 2 of the FSR approach) can proceed. Alternatively, validated models can be used to assess already existing technologies to see if they would be worth implementing into the farming system under study. Used properly, LP modeling can be a very useful tool to FSR practitioners.

3. LP modeling of a farming system in the central region of Puerto Rico

A farming systems study was carried out in the central region of Puerto Rico to identify the characteristics and constraints of the system that would be compatible, or not, with the development of organic production in the region. The vehicle for this

Table 1: Farm characteristics, labor inputs and annual net income for the 16 study farms

Farm number	# of acres	# of acres (cultivated)	Farmer's # hours/week	# full-time workers	# part-time workers	Type of farm	Annual net income of farm
1	6	4	20		2 (12hrs/wk)	Mixed	$5-6,000
2	53	42	70	5 (40hrs/wk)		Mixed	$0-10,000
3	149	?	25	14 (40hrs/wk)	20 (coffee)	Mainly coffee	$0-10,000
4	27	24	30 (wife, 10hrs/wk - coffee)			Mixed	$0-10,000
5	90	29	30 (wife, 15hrs/wk - coffee)		1 (8hrs/wk)	Mixed	$0-10,000
6	43	25	35			Mixed	$20-30,000
7	40	12	35		3 (30hrs/wk - Oct & Nov)	Mixed	~$10,000
8	56	40	70 (wife, 30hrs/wk)	3 (40hrs/wk)		Mixed & poultry	$20-30,000
9	124	35	50 (wife, 15hrs/wk)	2 (40hrs/wk)	2 (for papaya harvest)	Mixed	$20-30,000
10	30	25	60	4 (40hrs/wk)	2 (4hrs/wk - Dec & Feb)	Mainly root crops	$0-10,000
11	100	60	65		6 (8hrs/wk)	Mainly plantain	$10-20,000
12	33	15	40	1 (40hrs/wk)	1 (20hrs/wk)	Mainly plantain	~$20,000
13	25	25	40	3 (40hrs/wk)		Mixed + fighting cocks	?
14	33	15	42	1 (40hrs/wk)	1 (24hrs/wk - 9 months)	Mainly plantain	$10-20,000
15	69	40	12	5 (40hrs/wk)	3 (coffee harvest, Oct.-Dec.)	Mixed	$10-20,000
16	70	40	40	5 (40hrs/wk)	2 (planting cabbage)	Mixed	$10-20,000

study was a linear programming (LP) model. The study was carried out in the three municipalities of Naranjito, Barranquitas and Orocovis, in the central region of Puerto Rico and was part of a doctoral study looking at the use of biological control in cabbage. The three municipalities were chosen because, in years past, they had collectively been the center of the island's cabbage production [18]. With their relative proximity to the metropolitan area of San Juan, and with the benefits of the cooler mountain climate, they had become important suppliers of cabbage to the local market. Most of the production of the cabbage is during the early months of the year, when North American production is restricted by the winter cold. Other reasons for choosing these municipalities were the homogeneity of the farming systems, the fact that family farms were the dominant farm type and the fact that the farms had a relatively low resource base as compared with the large coastal farms. They continue with more 'traditional' farming practices such as the use of bulls for preparing the land.

The interviews were performed with 16 farmers, and each interview was divided into three parts, given on different days. Each interview lasted one hour to two and a half hours and information was gathered on all aspects of the farm and family. Additional data was obtained from sociologists, extension agents, agronomists and economists from the University of Puerto Rico. Officials of the Puerto Rican Department of Agriculture and the U.S. Department of Agriculture were also approached for information on subsidies and incentive programs. Information that had been gathered for individual crops was compared with the technological packages produced by the University of Puerto Rico.

3.1. Characteristics of the farming system

From this work a detailed picture of the farms, the families and the area was obtained. Table 1 gives some basic information about the farms studied. The average size of the study farms was slightly higher than the average for the region and percent land harvested was also higher. They are family run farms, which also rely on the help of hired labor for the more laborious and routine tasks. Farm income is relatively low, and the farm is normally the main source of income. Table 2 gives the list of the crops grown and the information gathered for inclusion in the model. The crop harvests are usually sold to intermediates that come to the farms to buy the produce. There is also government assistance with the purchase of certain crops such as plantain and coffee. Farm sales are generally piecemeal and inconsistent in nature.

Table 2. Labor, costs and income per acre for the model's crops.

Crop activity	Labor (days)	Cash input ($)	Income ($)	Net income ($)
Banana (Yr 1)	41	$1,291	$1,600	$310
Banana (Yr 2+)	24	$848	$1,600	$752
Beans	26	$924	$1,226*	$302*
Cabbage	59	$1,888	$3,380	$1,492
Cassava	54	$916	$2,400	$1,484
Root celery, Celeriac	37	$1,109	$2,700	$1,591
Chayote	371**	$15,811**	$36,648**	$20,837**
Coffee	83+	$2,582+	$5,400+	$2,818+
Ginger	59	$1,315	$3,500	$2,185
Papaya, Pawpaw	78	$3,175	$7,560	$4,385
Plantains (Yr 1)	46	$2,087	$4,080	$1,993
Plantains (Yr 2+)	17	$1,471	$2,400	$929
Pumpkin	34	$1,170	$2,000	$830
Taniers	32	$869	$2,400	$1,531
Yam	43	$1,478	$4,800	$3,322

Note: * - half sold shelled, other half sold in their pods; ** - over 6 years; + - over 8 years

The extensive incentives program offered by the government is run by A.S.D.A. (La Administración de Servicios y Desarrollo Agropecuario) of the Puerto Rican Department of Agriculture, and it serves to promote and develop both crop and livestock production in the country. Possibly the biggest incentive in the program is the worker salary incentive, which guarantees a minimum wage of $4.50 per hour, of which the government pays $2.25. Farm workers are also given a government bonus at the end of the year, equivalent to 4% of their annual income. Another commonly utilized incentive is the provision of fertilizer. For example, with Arabica coffee, an incentive of two hundredweight of fertilizer (analysis: 12-5-15-3 N-P-K-Mg) is given for each hundredweight of green coffee beans produced, up to a maximum of 15 hundredweight per acre (1.7 tonne/hectare). Coffee receives more incentives than all other crops. New plantings of coffee are supported with a payment of $1,300 per acre to cover the cost of plants, fertilizer, lime and the application and costs of necessary herbicides and insecticides. Purchase of equipment is supported by payments of up to 50% of the costs, up to a maximum of $8,000. Other incentives include purchase of all coffee produced and the payment of transport costs for the farmer/worker to and from the farm. Another commonly used incentive is the subsidized agricultural machinery, which is used for clearing land and preparing the fields. Also popular is the crop protection and weed management assistance provided by A.S.D.A. Herbicides, insecticides and fungicides are applied by crop protection 'brigades' who provide the abor, equipment and chemicals so as to minimize accidents and the misuse of the agrochemicals. The services are offered for a wide variety of crops. Table 3 gives the crops included and the agrochemicals applied. Information on the incentives program was incorporated into the LP model.

3.2. The LP model

Once all the information was gathered and collated, the LP model was constructed. For the sake of accuracy, the model was extended to cover eight years, owing to the presence of multi-year crops such as coffee, plantain and chayote (christophine). In addition, each year was divided into quartiles so that within-year factors could be included. Various input tables were linked to the main matrix and included crop tables and individual farm data sheets. Using these tables, the researcher could examine the effects of the inclusion or exclusion of the government subsidies and incentives, for example. Output tables helped in the visualization and examination of the model's solution and by extension the farm system's functioning. One of the main objectives of an LP model is that it represents what is actually found occurring in the farming system. If enough care is taken and accurate data gathered then this simulation is possible.

When complete, our model gave the same crop mix (with plantain being the dominant crop) as found on the farms studied, although the amount of land used and therefore the income generated was higher in the model. Nevertheless, it proved to be a good platform from which to examine the system. One of the studies was to see how the incentive program influenced the make up of the farm activities. The LP model was run using three different scenarios and each scenario produced a different set of crops in the model's solution (Table 4). The first scenario simulated the full incentives program from A.S.D.A. The second scenario incorporated the removal of all agrochemical-related incentives and the third scenario included, in addition to the removal of the agrochemical assistance, the removal of the worker salary assistance. With the agrochemicals incentive

Table 3. Agrochemical products applied as part of ASDA's crop protection/weed control incentive program

Crop	Product name	Active ingredient	Type of agrochemical/use
Coffee	Di-Syston 15G	disulfoton	Insecticide
	Temik 15G	aldicarb	Insecticide/nematicide
	Roundup Ultra	glyphosate	Herbicide
	Goal 2XL	oxyfluorfen	Herbicide
Plantain and Banana	Horticultural mineral oils	petroleum-based	Fungicide against Sigatoka
	Manzate DF	mancozeb	Fungicide against Sigatoka
	Evik	ametryn	Herbicide
	Gramoxone	paraquat	Herbicide
	Roundup Ultra	glyphosate	Herbicide
	Vydate L	oxamyl	Insecticide/nematicide
	Mocap 10G	ethoprop	Insecticide/nematicide
	Nemacur 15G	fenamiphos	Insecticide/nematicide
Fruit crops	Fungicide mix		Fungicide
	(copper sulfate or Manzate +	mancozeb	
	Ditano + malathion 57% EC +	diethyl succinate	
	Volk oil spray)		
	Temik 15G	aldicarb	Insecticide
Cassava	M-Pede	potassium salts	Insecticide/miticide/nematicide
Yam	Temik 15G	aldicarb	Insecticide
	Copper sulfate + Manzate	mancozeb	Fungicide
Pumpkin	Copper sulfate	copper sulfate	Fungicide
	Sevin 80	carbaryl	Insecticide
	Lannate	methomyl	Insecticide
General	Amdro	hydramethylnon	Insecticide against fire ants
	Siege Pro Fire Ant Bait	hydramethylnon	Insecticide against fire ants

removed (Scenario 2), one farm model was unable to find a feasible solution. With all incentives removed (Scenario 3), there were five of the sixteen farms without feasible solutions. Aside from some farms not being able to achieve household income objectives, there was also a change in which crops were chosen by the model to best meet household objectives. Some of crops were never selected—banana, cabbage, coffee, papaya and yam. There was a steady decrease for all farms in the revenue ("maximized income") produced by the model from Scenario 1 through to Scenario 3. This is to be expected with the removal of the incentives.

3.3. Resource use in the farming system and potential constraints to organic production

In addition to simulating crop mixes, LP models also highlight the utilization of resources. Part of a model's solution shows which resources have been used in arriving at the optimum combination of activities. In our case, the three main resources included in the model were land use, labor and cash. These were distributed between the quartiles so that resource use could be followed more accurately through the year. From studying the model and from talking to farmers, labor was the main constraint to these farm systems. This was in part because of the additional costs associated with hiring labor but also because of problems of availability. As mentioned before, much of the repetitive labor is carried out by hired workers at around $30 a day (half of which is reimbursed by the government). Agricultural labor is not a job chosen by many as it pays poorly (where people can earn as much by not working, claiming benefits) and is physically demanding. There can be problems with acquiring labor, especially during coffee harvest. To remedy this, farmers often try and make it easy for the laborers. Many of the farmers collect the laborers from their houses and provide them with a breakfast. It is also common that the laborers only work a half-day, partly because of the midday heat but also so that they could use the afternoons to find additional work to supplement their wages.

As with many agricultural areas, farmers face relatively high labor costs whilst trying to reduce overall costs to compete with low market prices driven down by cheap imports. One way that the farmers seem to have dealt with this problem is by choosing crops that do not need large amounts of continuous labor. Many of the crops such as plantain and celeriac, only need one or two people to maintain the crop for much of the growing cycle. It is only at planting or harvest that additional labor is sought, which explains why the number of part time or temporary workers is relatively high on these. farms. The LP model

Table 4. The crops chosen by the 8-year LP model for the three different scenarios. The frequency of those choices is also given

Scenario	Crop	Number of farms with crop/ total number of farms
Full incentives (Scenario 1)	Plantain	16/16
	Chayote	14/16
	Celeriac	12/16
	Tanier	1/16
	Pumpkin	1/16
	Beans	1/16
	Cabbage	1/16
Agrochemicals removed (Scenario 2)	Tanier	15/15
	Beans	15/15
	Celeriac	14/15
	Chayote	13/15
	Pumpkin	8/15
	Ginger	7/15
No incentives (Scenario 3)	Celeriac	10/11
	Tanier	10/11
	Pumpkin	10/11
	Chayote	1/11
	Plantain	1/11

demonstrated in Scenario 3 (no worker wage incentives), that there are crops that require even less labor than those crops normally grown. This suggests that farmers plant crops that give the greatest returns and which have labor demands that are acceptably low, in part due to the help given by the government. These are not necessarily the crops with the lowest labor requirements.

The unstable markets are also a constraint on the system. Many of the sales from these farms are used to fill in gaps and remedy shortages from the larger suppliers to the island. Other avenues of sale are small, specific markets that only buy small quantities of produce. Many of the farmers did not know one year to the next, how their produce was going to be sold. For many crops, such as ginger and papaya, wasted surplus is common and it has prompted farmers to look to alternative avenues of sales such as local farmers' markets and small-scale processing facilities. This marketing reality puts an upper threshold on how much land can be put over to a crop, which goes some way to explain the discrepancies between the LP model's full use of land available and the reduced land use found on the farms. It also helps to understand the reluctance of investing in labor-intensive crops, when it is likely that any investment in labor is not going to be fully repaid. An additional consideration for farmers is that some crops like plantain and coffee have more secure markets due to government purchasing programs. This allows farmers to invest more acreage and labor in these crops than in others.

The Puerto Rican department of agriculture also supports an insurance program for certain crops, which include plantain, banana and coffee. This program covers catastrophic losses due to events such as hurricanes and helps minimize risks for these selected crops. One result of the poor markets is the common strategy of diversifying the mix of crops to maximize the likelihood of sales. This was true for most of the study farmers, although there were a couple of them who only grew plantain. This crop, with its many incentives and the protection afforded it by the government purchasing and insurance schemes, was not considered a risky monoculture by these farmers. A similar situation occurs with coffee in the western part of the central region, where zoning for coffee means that those farms receive maximum benefits.

Land is not a constraining resource and it was never fully utilized in the farms studied. As mentioned before, poor markets and labor costs preclude any increase in acreage. Interestingly, although much of the unused land was left for pasture or was not utilized, some farmers were deriving income from federal conservation programs. Federal programs for soil conservation and the payments for land under fallow have begun to be adopted in the central region to preserve the soils, waterways and forestland (via the USDA's Farm Service's Conservation Reserve Program, Environmental Quality Incentives Program and Stewardship Incentive Program). Notwithstanding these programs, underutilized or non-utilized land is common to the central region.

Money was never mentioned as a main constraint by the farmers, even though their lifestyles were fairly modest by American standards. Their main frustration was with the wasted effort of producing the crop but not selling it. They saw this more as a waste of their labor and energies rather than as lost revenue. Nevertheless, the model showed that at the end of the year there were higher financial requirements due to this being a more active time on the farm and due to it being the holiday season. Fortunately, this is a time when many of the crops could be harvested for sale. It also is a time where markets for local produce improve, with consumers having more time to prepare traditional dishes during the holiday season. The Christmas/Three Kings period is the time of the year when Puerto Ricans are most active in embracing their cultural heritage.

Most of the intermediary buyers paid on receipt of the produce, although money from sales from the government could be delayed for some months. The government reimbursements for worker salaries are paid to the farmer once every three months and the farmer has to cover the full costs during this time. Most of the farmers had some form of account in credit unions or banks. Most of the wives did not have formal work off the farm although they often made extra money looking after children or making food products, in addition to looking after the house, family and sometimes engaging in farm-related chores. Of all the 16 families studied, only two had children who worked full-time on the farms. Others helped on occasion, whilst others were too young, or were located off the farm and were unable to help. Generally, farming was not considered a viable career choice for many of the farmers' children, many of whom go on to tertiary education and professional jobs.

4. Discussion

It is not difficult to see why organic production has never had any sustained success in Puerto Rico. Not only has it not been supported by the government or consumers, but its existence and independence from the existing Puerto Rican food system is perceived as a threat to the status quo of an import-orientated economy. The marginality of the agricultural sector in Puerto Rico and its dependence on the government incentives scheme makes any change difficult. As it is, farmers in the central region of Puerto Rico do little more than make enough to live on and this is only made possible by the largesse of the incentives program. As shown by the failure of past organic projects, getting the farmers to invest resources in a venture that falls outside the farming norms and which does not come with the protection of any incentives, is a hard sell. This is especially true if production is aimed at the large external markets, which, by dint of their size, would mean significant commitments of land, money and time on the part of the producers. The local market at present is also not in a position to support any significant organic production on the island. Changes would need to be made by retailers and by the public who, with over twenty years of food stamps and large supermarkets selling cheap produce, would need some convincing.

Despite all these challenges, the development of an organic sector in Puerto Rico is not impossible. One of the main reasons for this is that the island, and the central region in particular, is primed for organic production. As mentioned before, much of the land lies in permanent fallow, free from agrochemicals. Also, despite the pesticide brigades and agrochemical incentives, few agrochemicals are actually used on the crops, in part because of the crop choices made in the light of labor constraints. Generally, crops that require continuous pesticide applications and other intensive management practices are not chosen by the farmers. The most commonly applied agrochemicals are the herbicides, which represent the greatest challenge to an agrochemical-free crop. Management of most of the root and tuber crops, coffee, plantain, banana and chayote use very little, if any, insecticide applications. The farmers in the study did not use any insecticides in the production of celeriac, cassava, ginger or tanier. In addition, none of these crops were exposed to fungicide treatments and tanier, ginger and cassava were weeded manually. There would not be need of any great changes to existing management strategies for many of the crops to be certified as organic. Most of the changes that are required exist at a different, more functional level. Producers need educating on the procedural points of what constitutes organic production. There is a need for consumer sensitization and promotion of organic products, in much the same way as has occurred for locally grown produce, marketed under the government supported label, 'Del Pais'. In addition there needs to be a support structure put in place, in the form of technical assistance, policy substantiation and the offering of appropriate incentives. Organic research efforts should be conducted by multidisciplinary groups using inclusive research methodologies. This present study has shown that a farming systems research approach can highlight factors that need to be accounted for by the research process. It seems that the cost and availability of labor constrains the producers in their crop choices and that the underlying insecurity of the system is the poor markets.

Only with such a technical support system could producers take a lead role in discarding the agricultural paradigm that has defined the central region for hundreds of years. Of the many perceptions that would need changing, is the idea that pesticides are the default option in resolving pest problems. Not only is this not true but it also curbs the freedom to look for the crop protection alternatives that exist. Many of these changes would take time and would involve many people. Nevertheless, a more sustainable, environmentally responsible and economically viable form of agriculture in the central region of Puerto Rico would be beneficial to the whole island.

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