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PRACTICE BRIDGE

How to make prosperous and sustainable family farming in Cuba a reality

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A number of factors in Cuba today contribute to the urgent need to develop family farming based on agroecological practices across the island. These factors include: soil deterioration, high external dependence for inputs and food, damaging effects of climate change, loss of farmer traditions, and the next generation's disinterest in a farming lifestyle, coupled with the essential contribution that family farming makes to supplying food for the country, often in small spaces, together offer the real possibility of repairing the damage caused by conventional farming practices. Given this urgent need and possibility, it is important to identify and share successful experiences built on innovative practices. The study presented here aims to do just that by sharing the experiences of a farm representative of the cooperative sector in Cuba. This is a longitudinal study of the agroecological transition that occurred in one farm's socio-ecological system between 1995 and 2015. In particular, the study evaluates the socio-ecological resilience of the family farm during three periods of transition, which are considerably different from one another given the strategies of the family and the design and management of the socio-ecological system. We define socio-ecological resilience as the capacity of agroecosystems to adaptively change in its socio-ecological structure and interactions in order to withstand and overcome disturbances, stress and change, and to maintain production levels in harmony with the culture, social organization, and satisfaction of the needs and capacity of ecosystems, in an ecologically possible and socially desirable context (Altieri et al., 2012; Casimiro Rodríguez, 2016; Koohafkan et al., 2011). We used the Evaluation Methodology of the Socio-ecological Resilience of family farms (MERS in its Spanish acronym) (Casimiro Rodríguez, 2016), based on the evolution of an array of indicators of efficiency and indexes of food, technological and energy sovereignty, as well as from the transformation process from conventional farming practices to agroecological practices. Based on the results of the study, we show a set of elements that address the need to transform Cuban agriculture by implementing an agroecological base, the importance of family farming, as well as aspects that can come into play in the socio-ecological resilience of other family farms in the country. *Please refer to Supplementary Materials,* DOI: https://doi.org/10.1525/elementa.324.s1, *for a full text Spanish version of this article.*

Keywords: Agroecology; Socio-ecological resilience; Family farming; Cuba; Agroecologia; Resiliencia socio-ecologica; Agricultura familiar

Bajo la situación actual en el país con el deterioro de los suelos, la dependencia externa, los efectos del cambio climático, la pérdida de tradiciones campesinas, el desarraigo y desinterés de los jóvenes por hacer vida agrícola, unido a la participación de la agricultura familiar en el abastecimiento de alimentos en el país y el aprovechamiento de los pequeños espacios, la posibilidad real de resarcir los daños causados por la práctica de la agricultura convencional, entre otros, son elementos que demandan en Cuba, el desarrollo de una agricultura familiar sobre bases agroecológicas. Lo anterior resalta la importancia de identificar experiencias exitosas construidas a base de prácticas novedosas y su difusión a otros lugares y agricultores familiares, por tanto la presente investigación se realizó en una finca campesina representativa del sector cooperativo cubano, a partir de un estudio longitudinal de la transición agroecológica ocurrida en este sistema socioecológico, que abarca en el tiempo el período comprendido entre 1995 y 2015. El estudio se centró en la evaluación de la resiliencia socioecológica de la finca familiar en tres períodos del proceso de transición, los cuales se diferenciaron considerablemente uno del otro teniendo en cuenta la proyección estratégica de la familia y el diseño y manejo del sistema socioecológico. Definimos la resiliencia socioecológica como la capacidad de los agroecosistemas de llevar a cabo cambios adaptativos en sus estructuras e interacciones socioecológicas para sobreponerse a las perturbaciones, situaciones de stress o cambio, y mantener una producción agrícola en armonía con la cultura, la organización social, la satisfacción de necesidades y la capacidad de los ecosistemas, en un contexto ecológicamente posible y socialmente deseado (Altieri et al., 2012; Casimiro Rodríguez, 2016; Koohafkan et al., 2011). Para ello se utilizó la metodología MERS (Metodología de Evaluación de la Resiliencia Socioecológica de fincas familiares (Casimiro Rodríguez, 2016)), a partir de la evolución de un conjunto de indicadores de eficiencia e índices de soberanía alimentaria, tecnológica y energética, así como de los procesos de transformación llevados a cabo. A partir de los resultados de la investigación se exponen un conjunto de elementos que abordan la necesidad de la transformación de la agricultura cubana sobre bases agroecológicas, la importancia de la agricultura familiar, así como aspectos que pueden incidir en la resiliencia socioecológica de otras fincas familiares en el país. *La versión en español de este artículo se puede encontrar en Materiales Suplementarias,* DOI: https://doi.org/10.1525/elementa.324.s1.

Palabras clave: Agroecologia; Resiliencia socio-ecológica; Agricultura familiar; Cuba; Agroecologia; Resiliencia socio-ecologica; Agricultura familiar

Introduction

From its early history, Cuban agriculture was characterized by monocultures, dependence on export markets and the overexploitation of natural resources. This model intensified with the Green Revolution and its use of conventional[1] agricultural practices, and an increased dependence on external inputs has caused negative impacts on the soil, on biodiversity and on forests, leading to extensive deforestation, high production costs, among other problems (Funes, 2013; CPP, 2014; García et al., 2014). Widespread use of this agricultural model resulted in low levels of self-sufficiency, inefficient use of energy, and the shift and loss of values and traditions related to family life on the farm and with small-scale agricultural production (Funes-Monzote, 2009). Cuba has not been able to fully supply itself with food produced in-country since it was a Spanish colony (Casimiro González, 2014).

At the height of the Green Revolution in Cuba (1970s and 80s), the country received a massive influx of tractors, harvesters, large scale water irrigation systems, hybrid seeds, and a renewed emphasis on large extensions of monoculture crops. Additionally, 48% of the fertilizers and 82% of the pesticides were imported. Moreover, many of the components of the fertilizers manufactured in the country came from other countries. As documented by Machín et al. (2010), direct imports of food represent approximately 57% of the total calories of Cuban families' diets. In 1989, 78% of cultivated land belonged to the State; 10% belonged to the Agricultural Production Cooperatives (CPA)[2] and the remaining 12%, to Credit and Services Cooperatives (CCS)[3] and individual farmers. The latter maintained traditional farming practices and conserved their farming systems to a higher degree. (Machín et al., 2010).

With the collapse of socialist countries in Eastern Europe and the Soviet Union, as well as the loss of the main markets with which Cuba maintained commercial relations during the previous 30 years, imports fell from 8,100 million USD in 1989 to 1,700 million USD in 1993. This represented an 80% decrease (Funes and Funes-Monzote, 2001) and provoked an immediate decline in production, more accentuated in the big farming and livestock companies than in the smaller farms and revealed the vulnerability of systems that rely on high external inputs in Cuban agriculture (Machín et al., 2010). Farmers with small and medium scale operations, who were more independent and able to manage their farms' natural resources, were able to overcome this disruption more quickly (Funes and Funes-Monzote, 2001; García et al., 2014; Ríos, 2015). The composition of their farming systems – in general diversified – and the continuation of agroecological practices were factors that deflected the impacts of the "Special Period" (i.e. the term given by the Cuban government to the period following the fall of the Socialist Bloc) and guaranteed a growth in production that buffered the blow of the food crisis. A key factor in this was the advancement of the Peasant-to-Peasant or Farmer-to-Farmer Agroecological Movement (Movimiento Agroecologico Campesino a Campesino, MACAC in its Spanish acronym), which started in Cuba in1997 and reached more than 100,000 Cuban farmer families in ten years (Machín et al., 2010).

Despite the fact that agroecological practices and diversification of small-scale family farms in Cuba produce much more food per hectare than commercial exploitation of industrial farming, and that family farms generate more than 65% of the food produced in the country (Rosset et al., 2011), interest in systems with high external inputs and expensive technological packages persist because of the assumed increase in food production and decrease in imports. But with these methods, the agroecosystems stay dependent on external inputs and are energetically inefficient (Altieri and Funes-Monzote, 2012); and they impose high environmental costs. All this adds to the fact that many Cuban farmers, who don't have a methodological base for the transition into agroecology, substitute inputs due to their needs, and prefer to use synthetic agrochemicals when they are available, even though they recognize their negative effects healthwise and on their economy (Wright, 2005; Funes-Monzote, 2009).

These and other factors indicate that, in Cuba, it is necessary to solve an array of problems related to the annual importation of 2 billion USD in food (García, et al., 2014), including learning how to: mitigate the effects of more frequent natural disasters due to climate change and the high vulnerability of certain agroecosystems across the island, slow the degradation of the soil that affects more

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than 76% of the Cuban farming area (CPP, 2014), and diminish the negative health effects of synthetic agrochemicals which also increase the costs of farm products (Machín et al., 2010; CPP, 2014; García et al., 2014). These issues demonstrate the need for a change in the current farming model in the interest of achieving socio-ecological resilience. Research in various countries and in Cuba show that small and medium sized family farms are much more productive than those with a greater surface area, if total production is considered instead of yields of each crop or animal species (Toledo, 2002; Pretty, 2008; Altieri, 2009; Machín et al., 2010; De Schutter, 2010; Funes-Monzote et al., 2011; Ikerd, 2016).

In response to the many challenges of agriculture in Cuba, family farms are responding with local innovations. It is important to identify successful examples of agroecological farms, or "agroecological lighthouses", that showcase innovative practices and share their experiences with other family farmers in order to organize them in the processes (van der Ploeg, 2013) that favor the socio-ecological resilience of family farms and food soverignty in the country. The objectives of this paper are to share the experience of a 20 year long transition from a conventional farm to an agroecological family farm, to demonstrate how this change can achieve high indexes of socio-ecological resilience, and to offer criteria and proposals that can contribute to obtaining similar results in other family farms around the country.

Materials and methods

This research was carried out on *Finca del Medio* (Del Medio Farm), which began as a tobacco growing and subsistent family farm in 1942. The farm used traditional, low-input practices typically implemented by peasant farmers before the Green Revolution. These practices are based on the use of local resources, farmer's labor and animal traction. By 1975, Green Revolution technologies were introduced to the farm whereby tractors substituted animals and most of the labor, and synthetic fertilizers, pesticides, herbicides and fungicides were used. Finca del Medio is a family farm of 10ha located in the municipality of Taguasco, at 22° 01′ 03, 75″ of northern latitude and at 79° 18′ 17, 34″ of western longitude, in the province of Sancti Spiritus, Cuba (**Figure 1**).

The farm land has an average height of 96 meters above sea level (MASL) with an average annual rainfall of 1292 mm, 92.9% of this falling from May to October, and has an average temperature of 28°C[4] (**Figure 2**). The soil is predominantly Brown Siliceous (Hernández et al., 1999) which is related (according to Hernández et al., 2015) with the Cambisol Order (Soil Survey Staff, 2003); and is characterized by undulating topography or slightly hilly, of a brown color, with low or medium organic material, and occasionally slightly acidic, with good superficial and internal drainage and, in general, affected by erosive processes. This is the most common soil in Cuba (27%) and is represented in all of the provinces, although more so in the Central and Eastern part (Instituto de Suelos, 1999; ONEI, 2015). The principal limiting factors of these soils are undulating landforms, little effective depth, compactness, hydromorphic soil in the lower areas and stoniness.

Data was collected through a survey and through the review of detailed records kept by the farmer and analyzed during three key periods of transformation. Data analysis was framed by the concept of socio-ecological resilience (RSE is the Spanish acronym) using different indicators and indexes of food, technological, energy sovereignty (**Table 1**) and economic efficiency.

We used the Evaluation Methodology of Socio-ecological Resilience (MERS, by its Spanish acronym) (Casimiro Rodríguez, 2016) to measure and assess the socio-ecological resilience in each period. This methodology was created and validated as a result of a doctoral study on the farm (Casimiro Rodríguez, 2016). In consultation with a panel of experts we used the Delphi methodology (Horrillo et al., 2016) and different statistical tools that validated and made this method realiable (see details in Casimiro Rodríguez, 2016). The weight of each indicator in the calculation of the corresponding index and the scale that analyzes the value for that mathematical calculation was also determined (**Table 2**).

The farm study site, Finca del Medio, has the following characteristics, which are representative of other farms in Cuba:

- It belongs to the Cuban cooperative sector (this sector manages 71% of the farmlands in Cuba (MINAG, 2015a).

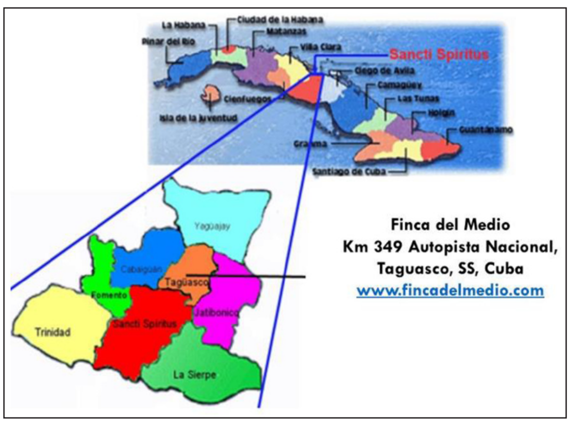

Figure 1: Geographic location of Finca del Medio Farm. DOI: https://doi.org/10.1525/elementa.324.f1

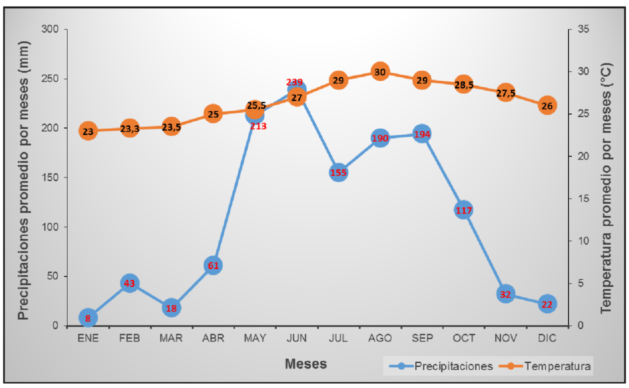

Figure 2: Average rainfall and monthly temperatures on the Finca del Medio (period from 2004–2015). DOI: https://doi.org/10.1525/elementa.324.f2

Table 1: Theory and practice of different sovereignties on a family farm. DOI: https://doi.org/10.1525/elementa.324.t1

Sovereignty	Literature	Family Farm
Food	The right of people to nutritious and culturally appropriate food, accessible, produced in a sustainable and ecological manner, and the right for them to choose their own food and production system (Rosset, 2003; 2007).	Agroecological production and consumption of the most food possible by the family from their own farm, including food from livestock. The surplus is distributed nearby in an ecologically sustainable and efficient manner.
Technological	The right of farmers to produce without external inputs, by using the environmental benefits derived from the biodiversity of the agroecosystems and the management of resources available at a local level, and by applying agroecological technology (Altieri and Toledo, 2011).	Efficient agricultural production of food and services, designed and managed in an agroecological way, the management of knowledge, farmer innovation and experimentation. Low or zero use of external inputs and the contextualization of appropriate technologies for the maximum use of renewable energy. Availability of technologies and the possibility of obtaining them on a local level. Permanent access to technical services.
Energy	The right of peoples, cooperatives and rural communities to have access to enough energy within the ecological limits (Altieri and Toledo, 2011).	Maximum energy efficiency, making use of the necessary energy for agricultural production sourced fundamentally from renewable energies.

Source: Casimiro Rodríguez (2016).

Table 2: Calculation method for assessing the Socio-ecological Resilience Index on a family farm. DOI: https://doi.org/10.1525/elementa.324.t2

Indicator (i)	Weight (Wi)	Scale (Pi)	Index (%)
People fed/ha-yr, for protein intake (Pp) (Funes-Monzote et al., 2011; Altieri et al., 2012).	0.33	Pp > 7; 5 7 >= Pp >= 5; 4 5 > Pp >= 3; 3 3 > Pp >= 2; 2 2 > Pp > 0; 1	Food Sovereignty $SA = \frac{\sum_{i=1}^{n}(Pi \times Wi)}{5\sum_{i=1}^{n} Wi} \cdot 100$
People fed/ha-yr, by energy intake (Pe) (Funes-Monzote et al., 2011; Altieri et al., 2012).	0.001	Pe > 10; 5 10 >= Pe >= 8; 4 8 > Pe >= 6; 3 6 > Pe >= 4; 2 4 > Pe > 0; 1	
Percentage of food produced by the family on the farm (AF) (Altieri et al., 2012).	0.66	AF > 75%; 5 75% >= AF > 60%; 4 60% >= AF > 45%; 3 45% >= AF > 30%; 2 30% >= AF = 0; 1	
Index of land use (IUT) (Altieri et al., 2012; Funes-Monzote et al., 2011).	0.005	IUT > 1,5; 5 1,5 >= IUT >= 1,3; 4 1,3 > IUT >= 1; 3 1 > IUT >= 0,7; 2 0,7 > IUT > 0; 1	Technological Sovereignty $ST = \frac{\sum_{i=1}^{n}(Pi \times Wi)}{5\sum_{i=1}^{n} Wi} \cdot 100$
Percentage of external inputs used for production (IE) (Altieri et al., 2012).	0.201	20% > IE = 0; 5 20% <= IE < 35%; 4 35% <= IE < 50%; 3 50% < = IE < 70%; 2 70% <= IE < 100%; 1	
Diversity in the production using the Shannon index (H) (Funes-Monzote et al., 2011; Altieri et al., 2012).	0.281	H > 2; 5 2 >= H >= 1,5; 4 1,5 > H >= 1; 3 1 > H >= 0,5; 2 0,5 > H > 0; 1	
Index of the use of renewable energy potential associated with appropriate technologies (Casimiro Rodríguez, 2016).	0.401	IAFRE > 75%; 5 75% >= IAFRE > 50%; 4 50% >= IAFRE > 35%; 3 35% >= IAFRE > 20%; 2 20% >= IAFRE = 0; 1	
Innovative intensity of the farm; adaptation from Suárez (2003) and Hernández (2010).	0.111	IIF > 80%; 5 80% >= IIF > 70%; 4 70% >= IIF > 50%; 3 50% >= IIF > 30%; 2 30% >= IIF = 0; 1	

(Contd.)

Indicator (i)	Weight (Wi)	Scale (Pi)	Index (%)
Energy efficiency (EE) (Funes-Monzote et al., 2011; Altieri et al., 2012).	0.402	EE > 3,5; 5 3,5 > EE >= 2,5; 4 2,5 > EE >= 1,5; 3 1,5 > EE >= 1; 2 1 > EE 1	
Percentage of energy injected to the farm coming from the exterior (EFE) (%) (Altieri et al., 2012).	0.110	30% > EFE = 0; 5 30% <= EFE < 40%; 4 40% <= EFE < 60%; 3 60% <= EFE < 80%; 2 80% <= EFE < 100%; 1	
Percentage of energy used from the farm (human, animal, FRE) (EF) (Altieri et al., 2012).	0.282	EF > 70%; 5 70% >= EF > 60%; 4 60% >= EF > 50%; 3 50% >= EF > 30%; 2 30% >= EF = 0; 1	Energy Sovereignty $SE = \frac{\sum_{i=1}^{n}(Pi \times Wi)}{5\sum_{i=1}^{n} Wi} \cdot 100$
Energy balance (BE) (Funes-Monzote et al., 2011).	0.201	BE > 10; 5 10 >= BE >= 7; 4 7 > BE >= 4; 3 4 > BE >= 1; 2 1 > BE > 0; 1	
Energy costs of production of protein (CEP) (Funes et al., 2011).	0.003	30 > CEP = 0; 5 30 <= CEP < 60; 4 60 <= CEP < 90; 3 90 <= CEP < 120; 2 120 <= CEP; 1	
Ratio between costs/benefits (RCB) (Astier et al., 2008; Sarandón et al., 2014).	0.1	0,35 > RCB; 5 0,35 <= RCB < 0,50; 4 0,50 <= RCB < 0,75; 3 0,75 <= RCB < 0,95; 2 0,95 <= RCB; 1	Economic efficiency $EEco = \frac{\sum_{i=1}^{n}(Pi \times Wi)}{5\sum_{i=1}^{n} Wi} \cdot 100$
Index of dependency on external resources (IDIE) (Astier et al., 2008; Sarandón et al., 2014).	0.9	20% > IDIE = 0; 5 20% <= IDIE < 40%; 4 40% <= IDIE < 60%; 3 60% <= IDIE < 80%; 2 80% <= IDIE < 100%; 1	

Index of socio-ecological resiliency (%)

$$IRS = \frac{SA + ST + SE + EEco}{4} \cdot 100$$

IRS: 0–20% Not resilient
IRS: 21–40% Slightly resilient
IRS: 41–60% Moderately resilient
IRS: 61–80: Resilient
IRS: 81–100% Very resilient

Source: Casimiro Rodríguez (2016).

- It is a family farm (rural family farms provide more than 65% of the country's food (Machín et al., 2010; MINAG, 2015a; ONEI, 2015)).
- More than 70% of Cuban soil is degraded (CPP, 2014). Since its beginning this farm cultivated tobacco and maize, high extractors of nutrients from the soil which lead to soil degradation; furthermore, the system presented very low crop and livestock diversity.
- The average area of family farms in Cuba is 11.5 ha, including the area where the house is located (Fernández et al., 2012), and this farm has an area of 10 ha.
- The majority of family farms in Cuba present a mix of traditional and conventional practices (Vázquez, 2009). This farm has passed through the different typologies.
- In general, family farming is practiced by farmers who are associated with Credits and Services Cooperatives (CCS); this farm belongs to the Rolando Reina Ramos CCS.

Results and discussion

Periods of agroecological transformation of the farm

The agroecological transformation of Finca del Medio is characterized by three periods from 1995 to 2015. In the beginning (1995), the family decided to leave urban life with the interest of producing their own food and sustaining a farmer's life that would allow them to survive the food crisis of the moment. They received the farm in a severe level of deterioration due to 20 years of exploitation from conventional agricultural methods and intensive tobacco farming. There were several drawbacks: soil compaction due to the use of heavy machinery, loss of topsoil, invasion of pests and unwanted plants, poor infrastructure and technological resources, lack of internal and perimeter fencing, and lack of water sources. The house was in terrible condition, with no electricity and no economic resources for the initial investments.

The conventional practices acquired from the previous family, and the requirement of carrying out their contracts with the state, led to a focus on growing the following crops: tobacco (*Nicotiana tabacum* L.), rice (*Oriza sativa* L.), bean (*Phaseolus vulgaris* L.), maize (*Zea mayz* L.); and raising livestock (cows, chickens and pigs), which included cultivating yucca (*Manihot esculenta* L.), and sugar cane (*Saccharum sp.*) to feed the animals.

Period I (1995–2000): Agricultural management based on conventional agricultural practices and technological packages that use synthetic agrochemicals and the development of specialized monocultures

The processes of farmer innovation and experimentation were present along the timeframe of this study, from the onset of the initial years to help face the problems caused by the scarce rural work force (Figueroa, 2005; García et al., 2014). On this farm, the multi-implement use of animal traction known popularly as JC21A was invented, designed and manufactured. This innovative farm tool received the Certified Invention Patent 2006-0096, given by the Cuban Office of Industrial Property.

The JC21A is an animal traction multi-implement farming tool that can carry out 28 growing and harvesting tasks, with highly efficient and effective production and labor outputs, especially when facing harvests. This equipment has an array of tools that are interchangeable and adjustable depending on the kind of labor, planting, seeding provisions, size of operator, etc., with a versatility that opens an array of options and variations, avoiding having to acquire a large amount of equipment for the same activities.

The conventional management of the agroecosystem during this period provoked the degradation of soils and economic benefits, to the point that the farm was exposed to receiving even more negative impacts when faced with an extreme climatic event or the impossibility of accessing any kind of external input markets.

In 1996 the farm was hit by a hurricane that was classified as category 3 on the scale of hurricanes Saffir-Simpson, due to the wind speed, which brought in internal tornadoes that affected the farm system, as well as torrential rains that caused flooding and landslides. Due to uncovered soils, a lack of protective barriers and windbreaks, among other factors, the farm was highly vulnerable.

The family's experience through this first period on the farm made them realize the unsustainability of the conventional productoin model and the need for change. These included the high level of vulnerability when faced with extreme climatic events, the dependency on external inputs, the high production costs, the scarce and inefficient day labor that could be hired for agricultural work and the level of deterioration of the soil that was more and more evident. These problems created the basis to move towards the use of a new model of management based on the introduction of agroecological practices that improved the general state of the socio-ecological system; and, thus, the farm entered the second period of analysis and evaluation.

Period II (2001–2005): Change in mentality, agriculture focused on introducing agroecological practices, production diversity and the use of organic fertilizers

During this period, the implementation of agroecological practices was notable, including: the production and use of organic fertilizers like compost and worm humus from animal excrements and crop residues; reforestation with fruit trees and establishment of leguminous plants associated with the perimeter hedge and in areas around the house and pastures; production diversification, crop rotation and intercropping, furrows perpendicular to the steepest slope; and the continued use of JC21A improving the compaction and moisture balance of the soil. All of the above enhanced the flow and connections of the productive subsystems by using waste from one as an input to another (i.e. animal excrement used as fertilizer or energy).

Nevertheless, as can be observed in the results in **Table 3** for this period, practicing agroecology with the conditions of the farm was more costly than conventional agriculture. This can also occur on other farms, because of the high amount of work and hours a year that is necessary. For example, producing worm humus, entails periodically collecting manure so that it ferments, transferring it to the worm bed, which has to be watered every day for numerous months, after which the process is reversed (sifting to separate out the worms, putting them in sacks, taking them to the field) for the fertilization of a small garden; and this takes up much more time and energy than what is needed to apply, in a single day, synthetic chemical fertilizers on a planting area.

A tractor driver can prepare 10,000 m^2 (one hectare) of land with 50 CUP[5] in petro and 200 CUP in wages. In other words, with 250 CUP, in whatever state the soil is in, in one day a tractor driver carries out the work of a man and his team of oxen in 15 days, that in wages would add up to 1,500 CUP. A windmill can extract 10,000 liters of water a day but is technologically much more costly due to its maintenance than a diesel turbine, that can pump out that same quantity in 10 minutes.

If we were only to look at the economic aspect, opting for agroecology in Cuba would not be the appropriate choice. It is viable, however, as a way to enhance degraded soil, or in areas where mechanization is not possible due to steep slopes which are continuously eroded and burned each year during the dry season. When it is not competing with conventional agriculture, agroecology allows for a *repeasantization* (increasing the number of farmers) of vacant spaces, and the development of an independent and sovereign rural culture. All of this requires public policies that support the development of cultured peasant families, or farming families, that live in harmony with nature's patterns. It is important that these families do not become a social weight to the State and that they fulfill their goal of producing a variety of products made in the most humane, enjoyable and dignified way possible.

Research carried out during this period found that agriculture based on agroecological techniques may be more costly than conventional agriculture, but in turn, has implicit improvements in the environment including significant aspects like the protection of the soil through practices that avoid soil compaction and favor moisture balance and improvements in soil fauna, as well as minimizing dependence on external resources. The latter objective resulted in the need to introduce more appropriate technologies that allowed improving economic and energy efficiency, which represents the goal of Period III.

Period III (2006–2015): Agroecological management and design, use of appropriate technologies for the maximum use of renewable energy sources and of locally available resources

This period began by implementing an agroecological design and management strategy with the goal of becoming self-sufficient in resources, food and energy, by maximizing the use of locally available resources and reducing or eliminating the need to import external. This strategy included diversifying the farm's production and becoming more efficient, by increasing the flow and interrelations between each element of the socio-ecological system (**Figure 3**).

During this period, the family increased their capacity by periodically participating in workshops, courses and scientific events. This allowed for greater technological change, for each member to take on various jobs, and resulted in a high Index of Innovative Intensity (see **Table 3**). This supported a high level of innovation, experimentation, adoption and validation of adequate technologies that enabled an increase in efficiency in each process and improved the farm's results for the indicators and indexes used to assess its socio-ecological resilience (**Table 3**).

Table 3 shows a summary of the values of the indicators and indexes evaluated for each period. The evolution of each indicator is perceived throughout the research longitudinally and provides elements to value the agroecological transition process in Finca del Medio. The energy efficiency (EE), which was at 2.7 and 8.2 in the first and second period respectively, arrived at 17.26 in the third period, reducing the energy cost of production and the intensity of the work force per hectare (730 hours/ha/year),[6] and these results corroborate those obtained by Rodríguez (2009). Rodríguez (2009) carried out a comparison of energy efficiency for maize production between Finca del Medio and a neighboring conventional farm. The study found that Finca del Medio's energy efficiency for maize production was 6.3 kcal whereas the neighboring farm was at 0.75 kcal. This demonstrates the energy inefficiency of the conventional system, highlighting proposals by Pimentel et al. (1989), Funes-Monzote (2009), Funes (2013) and Nicholls et al. (2016), regarding the use of technological packages based on Green Revolution approaches which has contributed considerably to the decrease of energy efficiency in production systems.

The cost-benefit ratio improved through the transition periods moving from 0.78, to 0.9, to 0.34. Furthermore, the farm achieved an index of external dependence of 1.81%, much lower than the first period (71.39%) and with profits 11 times higher than the second period.

The conventional agriculture developed in period I, with scarce agroecological practices and lack of diversity in species and crops, despite its high productivity (9.9 t/ha/year) and the possibility of feeding 13.69 people in protein per hectare a year and 11 in energy, did not favor socio-ecological resilience because it provoked damage to the soil by how the different crops were managed. Moreover, it required an intense labor force per hectare 2336 hrs/ha/year, as well as having to import 80% of inputs at a high cost, which in turn provoked, despite the considerable amount of income, less profits per year and a high index of external dependence.

In contrast, the production yields for period III (6.7 t/ha/year), a period characterized by more diversity (H = 2.15), was higher than the second period

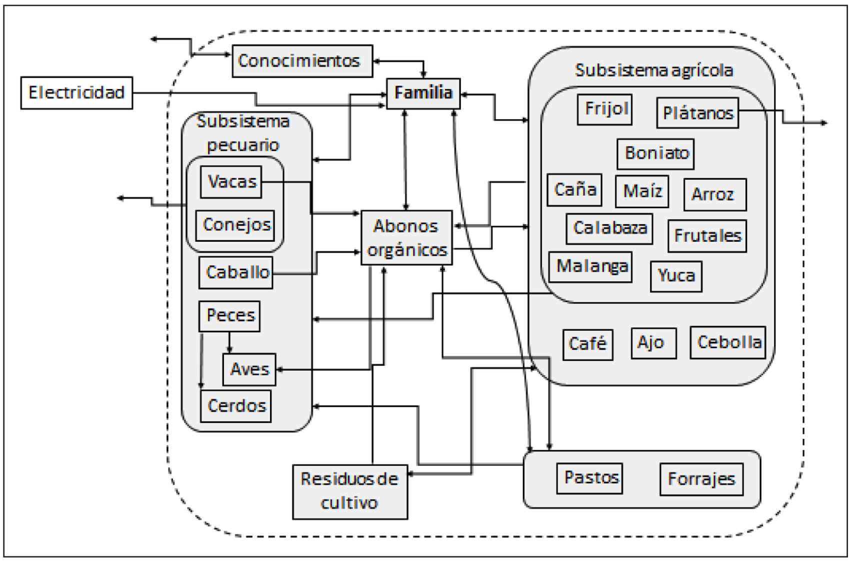

Figure 3: Productive subsystems and resource flows between them in Finca del Medio, Period III (2006–2015). The arrows represent inputs and outputs for each subsystem or element. During this period, the diversification of production, the use of crop residues and animal manure for organic fertilizers and for biogas, all enriched the systems interactions and increased the overall productive, energy and ecological efficiencies of the system. DOI: https://doi.org/10.1525/elementa.324.f3

Table 3: Summary of indicators evaluated at Finca del Medio for each period during 1995–2015. DOI: https://doi.org/10.1525/elementa.324.t3

Indicator	Finca del Medio		
	Period I (1995–2000)	Period II (2001–2005)	Period III (2006–2015)
People fed, by protein content, pers./ha/year (Pp).	13.69	8.27	8
People fed, by energy content, pers./ha/year (Pe).	11.20	4.02	6.11
Percentage of food for the family produced on the farm, % (AF).	98	98	98
Index of the land use (IUT).	2.18	3.35	2.74
Percentage of external inputs used for the production, % (IE).	80	50	10
Diversity in the production (H).	1.64	2.01	2.15
Index of the use of potential sources of renewable energy (FRE) associated to appropriate technologies (%) (IAFRE).	0	0	83.61
Innovative intensity of the farm, % (IIF).	52.66	78.77	95.44
Percentage of the energy used from the resources of the farm, % (EF).	5.23	30.05	84.94
Energy efficiency, MJ produced/MJ inputs from outside the farm (EE).	2.7	8.2	17.26
Energy cost of the production of protein, MJ/kg (CEP).	1.67	0.49	0.58
Total of energy inputs imported to the system, MJ/year.	180,951.64	22,147.65	24,078
Intensity of the work force, hrs./ha/year	2,336.00	1,168.00	730.00
Production yield, t/ha/year (R).	9.94	4.18	6.72
Cost-benefit Ratio (RCB).	0.78	0.90	0.34
Index of external dependence, %	71.39	35.83	1.81
Profit (CUP)	55,986.00	12,500.00	143,509.73
Index of Food Sovereignty	98	98	0,99
Index of Technological Sovereignty	0,42	0,54	1
Index of Energy Sovereignty	0.48	0.72	1
Economic Efficiency	0.4	0.76	1
Index of Socio-ecological Resilience (IRS)	57.54	75.37	99.98

Source: Casimiro Rodríguez 2016.

(4.182 t/ha/year). This suggests that the more time agroecological practices are in place the more productivity for each unit of cultivable area, and more productivity for the total area of the system in general, which leads to the possibility of feeding more people per hectare and to greater energy efficiency. It should be noted that the family was self sufficient for food, since the beginning, from their own farm production by 98%, but gradually improved in nutritional quality due to increased variety of foods produced on the farm during the whole transition process.

In periods II and III, the biodiversity was considerably greater. Biodiversity improved along with the rest of the agroecological management processes and the relationship between each component: the state of the soil, the quantity and optimal use of water, no incidence of pests and the gradual increase of productivity. This confirms the research carried out by Funes-Monzote et al. (2011) and Koohafkan et al. (2011), that support the notion that the diversification of agricultural systems, in and of itself, is not a factor that determines the increase in productivity but is rather the design of functional biodiversity in terms of the use of resources like nutrients, water and energy. According to Altieri (2009), Vázquez (2015) and Vázquez et al. (2014) the importance of biodiversity for agricultural systems consists in restraining homogenization and simplification of agroecosystems, providing a greater resistance to shocks, less vulnerability to diseases and pests, as well as the benefits in preventing soil erosion.

The innovative intensity in Period I was limited, due to its development based on technological packages, which prescribed what had to be done. This left little space for creativity and for innovating to improve the processes and to make them more efficient from an ecological, technological and economic point of view. Therefore, the analysis in this period shows the unsustainability of the conventional agriculture model on this farm, that was very vulnerable when faced with extreme climatic events.

Period II, focused on introducing and developing agroecological practices, which led to less productivity per hectare with a continued high demand of the labor force. During this period, the increased cost was enough evidence to see the need to use available resources more efficiently, and to develop appropriate technologies for maximum use of renewable energies (FRE) and to improve the economic and energy indicators. Nevertheless, the system improved its Socio-ecological Resilience Index (IRS) when it decreased its dependence on external resources, increased its ecological efficiency based on innovative agroecological processes, and improved the foundation of natural and human resources.

During period III, the introduction of appropriate technologies and the use of renewable energy resources supplied 83.61% of the energy needed for the socio-ecological system (**Table 4**). Also, the intensity of the work force needed was significantly less (730 hrs./ha/year), achieving a yield of 6.7 t/ha/year (**Table 3**).

Due to a focus on agroecological design and management, soil and landscape restoration were prioritized, and the energy efficiency was six times higher than in period I. Furthermore, the external dependence index decreased from 71.39 to 1.81% and production costs considerably decreased and profits increased by 256%. The challenge in this period was to increase productivity to be able to feed more people per hectare in energy, without depleting or overloading the fundamental elements that it depends on, nor compromising its resilience. In this regard, Funes-Monzote et al. (2011) show that a high productivity comparable to high efficiency in the use of energy can be achieved.

Lessons learned

In the Finca del Medio, the transition from conventional family farming to an agroecological farm focused on maximizing socio-ecological resilience, which allowed for achieving a better relationship with the environment through the following: protecting and recuperating the soil, efficiently using the available local resources, multiplying the efficiency and productivity of family labor, and obtaining economic advantages much higher than those previously obtained with conventional agriculture. Moreover, these results were helped by structural elements of the farm, in which each element carries out various functions, corroborating what Cruz and Cabrera (2015) pointed out (see **Table 5** for examples).

The energy efficiency on the farm is supported by the design of the spaces and the location of its components,

Table 4: Percentage of generated and used energy on the farm, in one year during period III, with renewable energy resources and the use of appropriate technologies (IAFRE), measuring its equivalent in Megajoules (MJ) and the energy cost in kWh, if this energy was supplied from imported electricity. DOI: https://doi.org/10.1525/elementa.324.t4

Appropriate Technology	Uses	Description	Consumption resulted in kWh/year	Equivalent MJ[1]
Efficient wood-burning stove	For cooking and drying food, heating water.	At a daily rate of 50 kWh[2]	18,250	65,700
Anaerobic digestor	Production of organic compost and biofuel for cooking and drying foods, refrigeration, electricity	Daily consumption of 6 m^3 of biofuel is equivalent to approximately 6 kWh (Hilbert, 2003; Cepero et al., 2012)	13,140	47,304
Hydraulic ram	Water supply	At a daily rate of 12 kWh during seven months of the year, 24 hours a day (June to December).[3]	2,568	9,244
Wind Mills	Water supply	At a daily rate of 1 kWh a day during the remaining five months of the year; four hours average/day (January to May).	151	543.60
PAFRE	Water supply, energy for cooking drying foods, refrigeration and light.	Potential used from the renewable energy (FRE) with the appropriate technologies	34,109 (9,45 kWh/day)	122,792.40
Consumption of external energy.	Electricity of the home	This refers to the energy imported in this period, equivalent to the consumption of electricity in the house.[4]	6,660 (18,25 kWh/day)	23,976
DES	PAFRE + Consumption of energy outside the system	Total demand of energy in the system (DES), having in mind the consumption in kWh that would imply supplying the energy that is used on the farm with the FRE and appropriate technologies (PAFRE) and the external consumption.	40,769	146,768
IAFRE		IAFRE = (PAFRE/DES) × 100	**83,66%**	**83,66%**

[1] One kWh is equivalent to 3,6 MJ (Funes-Monzote, 2009).

[2] The calculation was based on four 1500 watt burners that were used ten hours a day on average for carrying out all the tasks, that the efficient wood-stove built on the farm does, cooking, drying, oven use, heating water, among others.

[3] In the case of the hydraulic ram and windmills, the calculation was based on the energy in kWh that an electric turbine with (500 watt) horsepower would use to supply the amount of water presently supplied with those technologies.

[4] The consumption per capita of the members of the family of the Del Medio farm is of 2.28 kWh/day, that is equivalent to 39.1% of the average daily consumption per capita kWh/of Cuban clients in their homes (5,8027 kWh/día (ONEI, 2015)).

Table 5: Examples of elements of the system and the functions they carry out. DOI: https://doi.org/10.1525/elementa.324.t5

Element	Function*
Hedgerows	· Defines the spaces. · Food resource for people and animals since the hedgerows include fruit trees and fodder crops. · Windbreak. · Retention barriers to control erosion. · Refuge for wild fauna. · Rainwater harvesting. · Improvement of the landscape and the microclimates. · Diversifies production. · Hosts natural enemies of pests.
Reservoir	· Collects water and makes it available for irrigating. · Serves as a trough for domestic animals and natural wildlife. · Regulates the humidity in a positive way for the immediate surroundings. · Fish farming for the family farm and for the animals. · Deposit(sink) for organic fertilizers. · Resource of pastures rich in nutrients during the dry season. · Space for family recreation.
House	· Comfort and family security. · Rainwater harvesting. · Walls with the possibility of planting medicinal plants; vertically to take advantage of the space.

* Likewise, the function of the water supply is supported by the reservoir, water holes, rainwater harvesting; therefore, it is guaranteed by various elements.

Table 6: Assessment of the average outputs or contributions, direct and indirect, that a dairy cow gives in Finca del Medio. DOI: https://doi.org/10.1525/elementa.324.t6

Outputs/Contributions	Unit of measure	Amount (yearly)	Value in CUP
Milk	L	1,200	5,280
Yearling (a)	Unit	1	1,000
Fertilizers[1]	Kg	1,095	17,793.75
Biofuel[2] (0,5454 daily m^3 per cow is equivalent to 3,2724 kWh/day that has a cost of 0,211 USD for Cuba for each one or 5,275 CUP)	m^3	199.07	6,300.57
Emission reduction of CH_4[3]	m^3	119,442	
Reduction of the increase of the CO_2[4] concentration.	m^3	76,628	
Total			**30,374.32**

[1] This calculation was based on the effluents of the anaerobic digester. The cow manure deposited at nighttime (15 kg per cow) is collected and mixed with 1 kg of manure: 1.5 of water, to put it inside the anaerobic digester, the anaerobic digestion and the production of biofuel and effluents used for fertigation and the improvement of the soil and crops. (7.5 kg of effluents equal 1 kg of fertilizer (Suárez et al., 2012). QUIMIMPORT pays $650 USD for one ton of fertilizer 1USD = 1CUC[7] = 25.00 CUP.

[2] This value is calculated following the daily biofuel production in the Finca del Medio, 6 m^3 and 11 cows that, on average, deposit the manure at night time that is then collected the next day to feed the anaerobic digestor.

[3] 60% of 1 m^3 of biofuel is equivalent to methane (Cepero et al., 2012).

[4] 40% of 1 m^3 of biofuel is equivalent to CO_2 (Cepero et al., 2012).

by how frequently components are used or by the need to work with them, so that there is no energy loss. The house is built so that it is cooled down by air circulation and uses natural light for illumination, its' design also conserves human energy by not having to walk unnecessary distances in accordance with what Cruz and Cabrera (2015) showed. Also, respecting the nature's cycles supports the resilience of the system, as it influences the flexibility and the capacity of adaptation to changes in external or internal situations. The use of harvest residues, the renovation of landscapes, the addition of organic material to the soil and the agroecological management, are part of this principle.

Similarly, the farm family processes and conserves food products in order to maximize their value. For example, Finca del Medio makes its own flour for bread and cakes, cheeses, makes yogurt and butter from the milk produced on farm, makes molasses from the sugar cane to make wines, desserts; and extracts oil from the coconuts, apart from other uses, like to make soap. The cow manure has different uses (**Table 6**), which contributes a great deal by adding nutrients to the soil in an organic and energy efficient way.

Another principle is to not produce wastes which could contribute to closing the natural cycle of nutrients and to the recuperation of the soil (Cruz and Cabrera, 2015). As an example, the grey waters are filtered through natural filters, so they come out clean from the system and the black waters, with a designed pipeline, are brought to the anaerobic digester to use them and transform them into bio-fuel and bio-compost.

The farm is designed following the key principle of not overloading the ecosystem with each practice that is carried out. The goal is to protect the soil and natural resources as much as possible and to recuperate what has been lost, conserving as much water and energy as possible. The desire is for the farm to function permanently with the capacity to adapt and develop new states in response to perturbations while preserving its essential social and ecological attributes. For example, the increase in prices or absence in the market of synthetic chemicals, the lack of or high prices of petrol, the impossibility of having electricity, among others, do not directly affect the socio-ecological evolution of farms like Finca del Medio, because the farm can continue evolving in a positive way despite these perturbations. Furthermore, as a way of life for the family, such farms can generate resources that offer well-being, abundance and prosperity to the whole society. If farms like Finca del Medio were scaled-up to the million hectares that have recently been declared idle (MINAG, 2015b), half of the Cuban population could be fed in protein and energy, according to the energy efficiency studies by Funes-Monzote et al. (2011).

The Finca del Medio is an example of the importance of Agroecological Family Agriculture (AFA). In this context, various authors have discussed their assessments of AFA, among which it is worth mentioning the following:

- Small scale farms are one of the main sources of food production on a global level, and a main source of work and income for the rural population (ETC, 2009).
- Contrary to industrial agriculture, which is highly dependent on external inputs and susceptible to the volatility and control of agro-export markets, agroecology represents diversified production systems that subsidize their own fertility and production, with conservation practices and improved soil, poly-culture and silvo-pastoral systems, less dependence on petrol and its byproducts. It is more resilient and plays an important role in the mitigation and adaptation to climate change (Pengue, 2005; Altieri, 2009; Rosset and Martinez Torres, 2013).
- Agroecological family farms are energetically more efficient, producing up to 20 times more energy than they consume (SGCA, 2011; Funes-Monzote et al., 2011).
- It is the alternative rural development model where human capital and capacity, rather than financial capital, are its center; it is inclusive (Pengue, 2005).
- It aims to guarantee its self-reproduction by creating an environment that is attractive to the next generation of young, new farmers. It can produce enough for self-consumption and for the market in a diversified way and transmits training, cultural and educational knowledge from parents to children, as pillars of an integrated rural development process (Pengue, 2005; Casimiro, 2007; van der Ploeg, 2013).
- It manages and conserves an important diversity of seeds and of cultivated varieties (genetic resources), where each one responds to particular ecological conditions, to specific technologies and to attributes valued by people (Casas and Moreno, 2014).
- Agroecological techniques act upon the biological fertility of the soil, the conservation of traditional varieties, respect of the natural cycles and maturation periods of crops, and the farming family has the possibility of offering their crops fresh to local consumers. It favors the production and consumption of food with a higher concentration of nutrients, antioxidants, organoleptic qualities, favoring a healthy diet for consumers. (Baranski et al., 2014; Ugás, 2014; Raigón, 2014).[8]

In order to foster socio-ecological resilience on family farms, public policies and concrete actions are required to bring a culture of agroecology to all levels, as well as the creation of expectations with families that gain the capacity and preparation to initiate a move towards farming.

After having analyzed the different periods of transformation from conventional to agroecological agriculture on Finca del Medio, we would like to bring light to the following lessons learned, that could influence the resilience and technical assistance of other farming families in Cuba as well as policy recommendations:

- A continuous and permanent education in agroecology for the whole society focused on the knowledge, values, abilities, and acquired capacities, that promote the innovation processes and adoption of technologies towards the resilience of socio-ecological systems.
- The permanence of the family unit on the agroecological farm contributes to the enrichment of the agroecological culture of each place and a large part of the work force needed for production.
- The size of the farm should be adjusted to what the family can handle; small farms will benefit the development of more family farms in the countryside.
- Maximum priority is given to the protection, conservation and improvement of the soil.
- Assurance that the water supply, energy and fertilizers are resourced from a farm's own system.
- Genetic types of crops and animal species adapted to the culture of the place, family and resources of the system.
- Maximum functional relationship between the components and functions of the socio-ecological system.
- Design of houses and infrastructures that offer the family comfort, saves energy, recycles resources and avoids the possibility of damage due to extreme climatic events.
- Existence of a market of inputs and services where the farming families can acquire what they need at fair prices with the possibility of soft loans.

- Existence of policies, programs and funds that incentivize families to root themselves in their farms, to validate the extension of innovations and agroecological technologies.
- Consolidation of a market or organic inputs and production assets, in the opportune moment and at adequate prices, that correspond with the prices received from production (Casimiro, 2007; García et al., 2014).
- A pricing policy that is in tune with agroecological production costs (Casimiro, 2007; Nova, 2013) and one that stimulates the best prices for the products that substitute imports, which are currently being paid at high prices (Nova, 2013).
- Favor short marketing channels that lower the transportation and storage costs, and at the same time offers quality and freshness to the products sold at the local market.
- Awareness, inclusion and participation by the consumer in the decisions around the market of agroecological products.
- Guarantee the adequate frame for granting soft credits to the families that choose an agroecological development of their farms, the use of appropriate technologies and renewable energy sources.
- Promote agroecology by stimulating farmer families through honorary, economic and legal resources.
- Promote lifestyles in the town that help resolve their current and future necessities with the resources available.
- Create and develop a national program that promotes agroecology in local development, that contributes to food security and sovereignty and to the development of a new culture of living in the countryside on farms and in rural communities, where one can value that living there and off the farmlands is a pleasure that improves human well-being and carries out an important contribution to the construction of a prosperous Cuban society.

Conclusions

The transition of conventional to agroecological family farming in Finca del Medio focused on maximizing socio-ecological resilience with the use of diverse sources of renewable energy and appropriate technologies. As a result, the farm established a healthier relationship with the environment, through soil conservation and improvement, the efficient use of available local resources, as well as respecting and working with nature's cycles. Through all this the productivity and efficiency of the family multiplied and improved their economy. The transformation processes that occurred on Finca del Medio shows that it is possible to obtain high indexes of food, technological and energy sovereignty in the Cuban context. The positive results of shifting from conventional to agroecological practices on Finca del Medio offers an approach that can be brought to other family farms.

Notes

[1] Conventional agriculture is based on intensive production systems, normally large-scale monocultures, that use synthetic chemicals based on technological packages. This is opposed to the principles of agroecology which are based on methods and practices that use ecological systems and functions using local resources for soil and pest management, which supports autonomy.

[2] CPA: Agricultural Production Cooperatives, whose patrimony is made up of lands and other assets given by farmers, the decisions are made by the majority of members in the General Meetings.

[3] CCS: Credit and Services Cooperatives. Cooperatives comprised of small-scale farmers who are owners of their farms and make the decisions on them; the cooperative is based on the collaboration and management of credits and services.

[4] This information was obtained from the rainfall and temperature records that already existed on the Finca del Medio.

[5] CUP: Cuban pesos.

[6] The decrease in the intensity of the work force per hectare was determined by the increase in the productive efficiency with the use of appropriate technologies, among them, the JC21A that decreased by 60% the labor needed for farming and 50% the labor needed for obtaining water for irrigating.

[7] CUC is the convertible Cuban peso which is pegged in value to the USD.

[8] According to Davis (2009), the deterioration of the soil, the use of commercial varieties, the long-term storage of crops that don't ripen naturally, the transport and use of synthetic agrochemicals, in the course of the last few years, have negatively affected the composition of fruits and vegetables, which have lost considerable amounts of vitamins and minerals, ranging for example, from a 12% loss of calcium in bananas, to a 87% loss of vitamin C in strawberries.

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Competing interests

The authors declare no competing interests.

Author contributions

- Contributed to conception and design: LCR, JACG
- Contributed to acquisition of data: LCR, JACG
- Contributed to analysis and interpretation of data: LCR, JACG
- Drafted and/or revised the article: LCR, JACG
- Approved the submitted version for publication: LCR, JACG

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