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Analysis of the Energy Balance in the *Morus alba-Bombyx mori* System in Cuba's Sericulture

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Abstract: The National Sericulture Project in Havana, started in 2011 to establish silkworm (*Bombyx mori*) rearing at a large scale in order to generate products to be used in the cosmetic, biomedical, biotechnological and pharmaceutical industries. The feeding of *Bombyx mori* L. exclusively depends on mulberry (*Morus alba* L.), so turning this system into a sustainable one for its development in the country requires an efficient use of the energy mainly based on the energy input-output relationships, on having mulberry cultivars of a high photosynthetic efficiency, on increasing agroecological practices and introducing other agricultural activities to diversify the intensive mulberry production system. The analysis of the energy balance used the software Energía 3.01, designed to estimate the energy of agroecosystems. The management of the area was characterized by identifying conventional agroecological practices developed on it. The results of estimating the energy efficiency indicate a mean efficiency for a specialized system depending on very few external outputs. These results were compared to 2019 the energy balance made in 2017. The introduction of new productive activities leading to increased energy efficiency and the generation of new products with a favorable impact on the environment and on the energy balance of the system, were proposed.

Keywords: *Bombyx mori*, *Morus alba*, Agroecology, Energy Balance

1. Introduction

Sericulture is a set of cultural and economic activities developed around silk and its by-products [1]. It is defined as the combination of growing a perennial plant and rearing insects from the lepidopterous order that produce silk and can be used by man. The combination of mulberry (*Morus alba* L.) and the silk worm from the *Bombyx mori* L., specie worldwide, is the most developed one through rearing, selection and breeding programs [2].

Sericulture is a branch of agriculture in some tropical and subtropical countries in which it has a historical and economic significance. This activity has existed for several centuries, mainly in Asia. Until the XX century it was focused on the textile industry and since the end of that century and early XXI century, it started its most scientific development period focused on what has been called functional silk [3].

Even when agriculture is one of the branches of the economy resting upon a high use of fossil resources and electricity, sericulture is an activity that requires very low energy inputs for its development compared to other agricultural systems; however, alternatives to make this activity more energy-efficient with the development of agroecological models [4]. In so doing, it is necessary to design multifunctional agricultural systems able to adapt to natural environmental and socio-economic changes [5].

Late in 2011, the National Sericulture Project started in Havana to develop a sustainable large scale technology of silkworm rearing and generate products for the cosmetic, biomedical, biotechnological, pharmaceutical, textile and other industries, taking advantage of the strengths of different scientific and productive institutions with a large experience and prestige in the country [6].

That is why a challenge to make Sericulture in Cuba sustainable is to achieve an efficient use of available energy sources within the integrated agricultural system *Morus alba-Bombyx mori*, by making an adequate balance between energy, productive and economic efficiency and the human wellbeing, through innovations, the introduction of new scientific results that contribute to mitigate the effects of climate change and increase agroecological practices in the system to make it more efficient energy wise.

Based on experiences developed by China's sericulture looking for a more efficient sericulture model [7], since 2017 energy efficiency assessments are made in Cuba.

In this sense, the present study targeted to evaluate the energy efficiency of the Integrated System *Morus alba-Bombyx mori* at the Production Unit.

The results of this study contribute to the scientific and methodological basis for the sustainability of sericulture in the country and expand the possibilities of this activity as a source of income, bringing in new products to the national market that can be linked to other national industries, replace imports and penetrate into the international markets.

2. Materials and Methods

2.1. General Characteristics of the Experimental Areas

The studies described in this article were made at the farm "Los Mangos" with an area of 92 hectares (ha). The Unit holds the following crops: mulberry (26 ha), mango (8.88 ha), tropical cherry and silkworm rearing facilities (2.88 ha), pastures (2 ha), moringa (1 ha), medicinal herbs (4 ha), rabbits rearing facilities (4.47 ha), forests and mangrove (39.77 ha) and socio-administrative facilities (3 ha). Mulberry cultivars mentioned in Table 1 are planted in such plot, they were brought from China in 2012 and the descendant of cultivar Gui SangYou 62, was named Cuba 1 [8].

The planting density in the studied selected areas averaged 16 thousand plants per hectare which is the recommended one to produce enough biomass to feed silkworms. [9].

These mulberry plots are rainfed and are planted on yellow lixiviated ferralitic soils, according to a technical report from the Cuban Soil Institute. The fertilization used was the one indicated to manage mulberry plots for sericulture [10]. In the rest of the cultures the fertilization dose of 9:13:17 (N, P, K), was used.

The main products in the areas are: mulberry biomass, silkworm cocoons, cherries and mangos, fodder plants and pastures to feed rabbits, rabbits meat and medicinal herbs for making tea and dry fruits.

Table 1. *Mulberry cultivars established at the experimental areas of "Los Mangos" farm.*

Origin	Cultivars	Area (Hectare)	No. of plants
China-Cuba	Gui SangYou 62	41	64 000
	Gui Sang You 12	1	16 000
	Guangdong 11	1	16 000
	Cuba	20	320 000
Total		26	416 000

2.2. The Main Characteristics of the Rearing of the Silkworm (Bombyx Mori L)

The biological cycle of the silkworm (*Bombyx mori* L) in Cuba is approximately 45 to 50 days depending on the breed and climatic conditions. The larval stage is the most active cycle of the insect that has 5 ages or instars with a duration of 21-23 days.

This research was made with the silkworm race Quifeng x Bayue from China, that classified for showing good behavior under Cuba's tropical conditions [10]. The rearing cycle of 14 boxes of silkworms, with 25 thousand eggs per box. The first one rearing is made with the tray technology, from the 1st 3rd age (Figure 1) and then, they are transferred to the rearing facilities called Tunnels, (Figure 2) where the rearing cycle ends with the 4th and 5th age. These facilities have a rearing capacity of 14 boxes per tunnel.

Figure 1. *Tray technology where the first ages of the silkworm rearing take place.*

Figure 2. *Facilities named Tunnels where the rearing cycle of the silkworm is completed.*

2.3. The Energy Balance

The energy evaluation was made for the year 2019 and was compared to the results from 2017 [10] using the software Energía 3.01, designed to estimate the energy functioning in agroecosystems [11]. The input the software were: human work (h), animal work (h), seeds (kg), chemical and organic fertilizers (kg), concentrate for animal feeding (kg), pastures and forage and (kg), mulberry for silkworm feeding (kg), machinery, diesel (L), electricity (kW) and values of products from crops and related animals (kg).

A comparative analysis of the characteristics of conventional and agroecological models were made according to Funes (2009) to classify the system based on its approach [5].

The output variables included in the software Energía 3.01 were: energy balance and nutritional contribution. The energy balance is a measure of the efficiency in energy terms of the activity. Its calculation means to have the coefficient between the total amount of energy produced in megajules (MJ) and the total amount of invested energy in (MJ), in terms of human, animal work and inputs (Equation 1).

$$\text{Energy balance} = \frac{\text{Total energy produced at harvest (MJ)}}{\text{Total invested energy (MJ)}} \tag{1}$$

3. Results and Discussion

3.1. Characteristics of the Morus alba-Bombyx mori Integrated Agricultural System

Table 2 shows the main features of the *Morus alba-Bombyx mori* Integrated Agricultural System evaluated at "Los Mangos" farm.

Table 2. *Characteristics of the Morus alba-Bombyx mori Integrated Agricultural System.*

Conventional Approach	Agroecological Approach
Varieties of a high productive potential	
	Biodiverse system (plants, animals and wild life)
Import of external inputs for the productive process	
Chemical fertilizers	Organic fertilizers
	Conservation and management of soil fertility
	Use of biological controls
Mechanization	Animal-draft power
	Intensification of available natural and local resources
Energy dependent	

Among the features of the conventional approach, the use of highly-productive mulberry cultivars can be found.

Studies made at the Extension Sericulture Station of Guangxi, [12, 13], with mulberry cultivars Gui Sang You 12 and Gui Sang You 62 refer to them as cultivars of big fast-growing leaves, solid stems, with a high density of branches, with intensive regenerative qualities (they can be pruned 4 or 5 times per year) and have a high recovery capability to water stress; which confers them a good behavior for sericulture and good use of sum energy because of a bigger leaf area (Figure 3).

Figure 3. *Mulberry fields at "Los Mangos" farm.*

The Cuban cultivars propagated from Chinese parents (Cuba 1) shows the same behavior according to studies made by García B. in 2019 who refers that this cultivar maintain the genomic features of its selection [8].

What has already being said on the mulberry cultivars planted at "Los Mangos" farm, coincides with Funes-Monzote in 2009, who stated that industrial agricultural practices have made major emphasis in capture available energy in all possible forms with the increased photosynthetic active surface and the productive cycles by developing more efficient plant cultivars in capture solar energy [5].

No economically important pests have been reported in the mulberry plots, except outbreaks of the pink scale (*Maconellicoccus hirsutus* G) at certain periods of the year. The control of this pest is made with biological agents like *Anagyrus kamali* M. y *Cryptolaemus montrouzieri* M. [10]. The use of biological controls is an important experience in the transition to sustainable agricultural productions [21].

Cultural practices are made with machinery using diesel which makes the system energy-dependent. However, the system also employs animal-draft power as alternative.

From the agroecological approach, the system can be classified as a biodiverse one, that combines the use of plants, animals and wildlife present in the forest and mangrove areas. This feature has had a positive expression compared to the study made in 2017 [10], relative to the increased biodiversity of plots and productions, the elimination of the single intensive mulberry crop and the incorporation of small cattle.

The latter has been positive, because as Monzote and Funes-Monzote (1997) state, animals produce protein, vitamins, fats and mineral sources, services and other valuable resources for industry. They also consume agricultural byproducts and fibrous foods that cannot be directly used for human consumption so they use them before being incorporated into the soil. Hence, they perform important recycling functions of nutrients within the conception of integrated systems [20].

3.2. Energy Balance of the Integrated System Morus alba-Bombyx mori

Figure 4 shows a scheme of the energy model for the *Morus alba-Bombyx mori* Integrated System of "Los Mangos" farm.

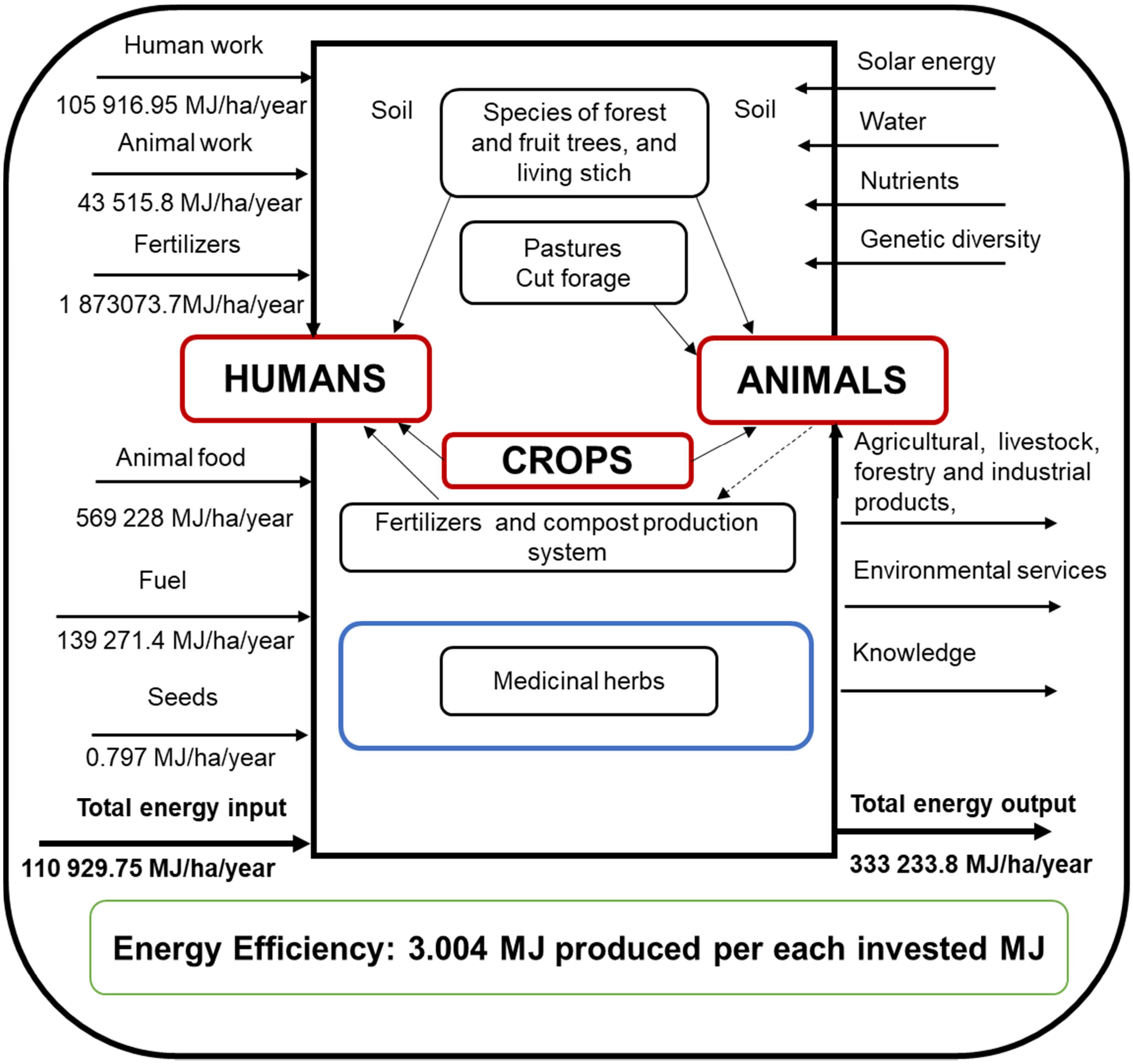

Figure 4. *Energy model adapted for the Morus alba-Bombyx mori Integrated System in "Los Mangos" Production (5).*

The result of the energy efficiency rate for the Integrated System *Morus alba-Bombyx mori* from "Los Mangos" farm is 3.004 MJ produced per each invested MJ. If the sustainable energy model for food production and energy from Funes, F., (2009) (Energy efficiency rate: 6.000) [5] is compared to the achieved model, it has an intermediate energy efficiency.

It is good to state that silkworms have a feeding cycle of 21-23 days in which they increase 10 thousand times is initial size, being more efficient than other animal species energy wise [9].

The studied system produces 4 314.5 kg of proteins per ha. The quantity of persons that can be fed from the system with energy is 77.9 persons per ha, and the quantity that can be fed from the system with proteins is 169.2 persons per ha. Reached values are higher than reference values for agricultural systems of 11 to 15 persons per ha that can be provided with enough energy and proteins respectively [22].

Such values are also higher than those reported for other integrated systems of food and energy production in Cuba. In these systems, values range from 0.3 to 21.1 persons that feed from the system with energy and from 1.25 to 38.4 persons fed from the system with proteins [23, 24].

The combined analysis of diversity, productivity and efficiency allows to include the studied system into the classification of the four contrasting agricultural models established by Funes-Monzote in 2009 [5], as a specialized system using very low external inputs with average efficiency and productivity, but with high integration levels.

Figure 5 shows a graphic summary of the energy evaluation of the *Morus alba-Bombyx mori* Integrated System.

The diversification of the Integrated System *Morus alba-Bombyx mori* can include intercrops with vegetables and mushrooms taking advantage of the rearing wastes, aquaculture, the combination of poultry and small cattle. It is the ideal ecological model with a circular economy value chain, the integration of *Morus alba*, *Bombyx mori*, livestock and methane production, plus the use of renewable energy sources to reduce energy consumption [4].

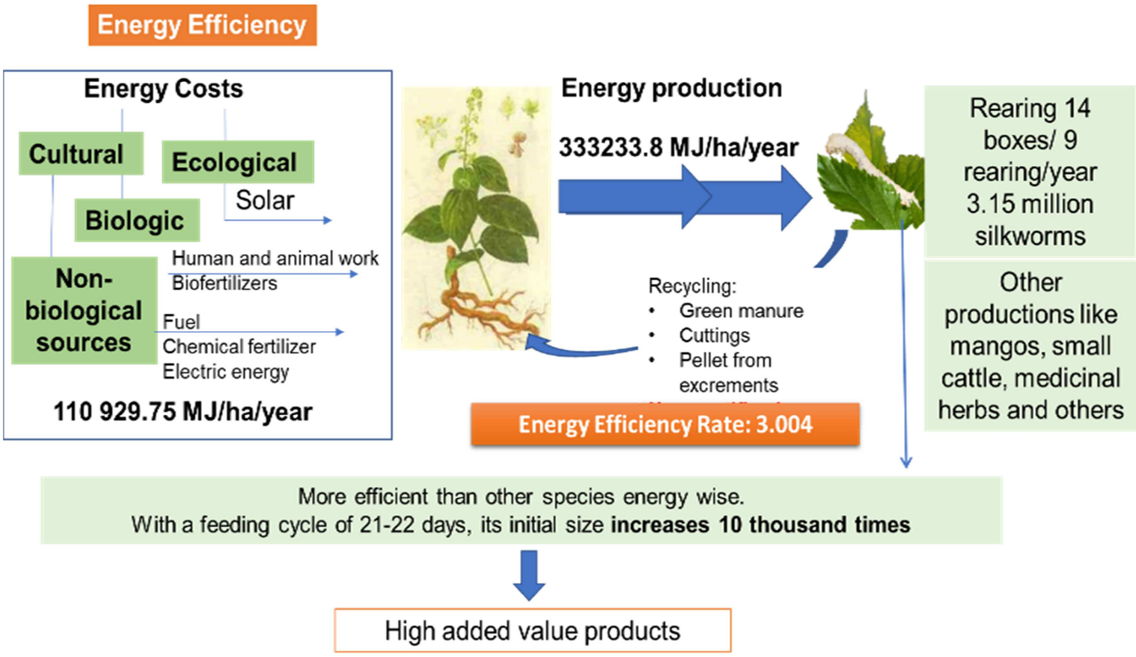

Figure 5. *Graphic summary of the energy evaluation of the Morus alba-Bombyx mori Integrated System.*

Based on the above-mentioned reasons, the proposal consists in the introduction of new productive activities leading to an increased energy efficiency of the Integrated System *Morus alba-Bombyx mori* at "Los Mangos" farm, and get new products with a favorable impact on the environment and on the energy efficiency of the system.

The future goal of the Integrated System *Morus alba-Bombyx mori* for the 2020-2022 within the National Sericulture Project, includes the integration of mushrooms and ornamental fish feeding using silkworm rearing wastes and methane production by the combined use of silkworm rearing wastes and those of small cattle.

4. Conclusions

The energy efficiency in the *Morus alba-Bombyx mori* System in Cuba's Sericulture was based on its integration to biodiverse agricultural systems where agroecological practice prevail.

The greater complexity of the biodiversity of the system improved energy efficiency, where the most important flow of energy income was the production of mulberry itself.

One of the symbols of the rapid progress of scientific researcher in agricultural ecosystems is energy balance. Information generated by this study showed the improvement capacity of *Morus alba-Bombyx mori* system, this allowing the projection for value chain with a circular economy.

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