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COMPARING ENERGY EFFICIENCY AND GREENHOUSE GAS EMISSIONS IN CACAO PRODUCTION SYSTEMS

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Abstract: High dependence on non-renewable energy and greenhouse gas (GHG) emissions are a clear symptom of unsustainability in food production systems. We compared the energy use and efficiency, the productivity and GHG emissions per ha and per kg of products harvested of 4 cacao production systems, i.e., agroforestry systems and monocultures under organic and conventional management during 5 years in a newly established experimental plantation. Our results showed that agroforestry systems and organic management reduced the demand of non-renewable energy and GHG, and increased the energy efficiency. In addition, the return of energy per unit of labour invested was higher in the agroforestry systems. Organic agroforests were the most sustainable systems according to the indicators analysed. Organic sector should discuss considering agroforests as part of the requirements for certification, since, in addition, they contribute to reduce deforestation and increase farmers' livelihood and food security.

Introduction: Increasing demand for cacao has led to the replacement of agroforestry systems by monocultures and management has been intensified. Labour and locally-produced inputs are being replaced by a large number of external inputs and machinery. This increases the productivity of the target crop at the cost of reducing energy efficiency and incrementing dependence on fossil energy, while contributing to other environmental impacts (Giampietro et al. 1999). Organic agriculture can reduce energy consumption and balance long-term productivity and ecological sustainability. Agroforestry systems have been proposed as an alternative to monoculture due to their potential role in curtailing the loss of biodiversity and soil degradation and climate change mitigation. On-farm production is the most energy-demanding and GHG-emitting phase in the life cycle of chocolate (Pérez-Neira 2016).

We compared the energy use and efficiency of 4 cacao production systems, i.e., agroforestry systems and monocultures under organic and conventional management during 5 years in a newly established experimental plantation.

Material and methods: Data, i.e., cacao and banana/plantain yield, labour time, inputs (fertilization, herbicides, etc.), petroleum derivates and tools used, were collected during 5 years (2010-2014) in a newly established long-term trial in Bolivia (https://systems-comparison.fibl.org/) comparing cacao agroforestry systems and monocultures under conventional and organic farming. Each production system was replicated four times in 48 m × 48 m plots. In the

agroforestry systems, the main shade trees were *Inga* spp. and *Erythrina* spp., complemented by timber, fruit and palm trees.
The energy analysis was performed at four study levels i) output, i.e., edible biomass, ii) energy consumed directly at the farm, which included organic fertilization, labour and diesel, iii) energy cost of producing the inputs used during the production process (NPK fertilizers, crop protection, diesel, oil and tools) and iv) energy amortization of the tools used on the farm.
According to this, different energy indicators were calculated for each production system: cumulative energy demand (CED) and non-renewable CED (NR CED), the energy return on investment (EROI) and non-renewable EROI (NR EROI). These indicators were calculated per ha (CED ha^{-1}) and both considering only cacao production (CED kg^{-1}) and all the products harvested (cacao and banana/plantain). In addition, the energy returns on labour (Labour EROI) were also estimated. Renewable energy includes human labour, organic fertilization and the proportional share of renewable energy (mainly wind, hydraulic and solar) used in the production of agricultural inputs.
Life Cycle Analysis (LCA) software SimaPro version 8.2.5.0 was used to estimate the direct (on-farm) and indirect (external inputs) emissions of GHG (kg CO_2-eq). Direct emissions associated to fertilization (N_2O) have been estimated from IPCC emission factors.

Results: Monoculture systems produced approximately 42% more energy in the form of cacao than the agroforestry systems due to the latter's lower yield per hectare. In addition, while the energy output of cacao in conventional monocultures was higher than in organic monocultures, there were no significant differences found between the conventional and the organically-managed agroforestry systems. The total output of the agroforestry systems was three-fold higher than that of the monocultures due to the banana/plantain and other accompanying crops.
The cumulated energy demand per hectare (CED ha^{-1}) was almost 2-fold higher in the monocultures than in the agroforestry systems (Figure 1a). The organic systems reached a higher CED ha^{-1} than the conventional systems, but up to 93% of the total CED came from renewable sources, while it was only about 25% in the conventional systems.
No significant differences were found in the CED per kilogram of cacao produced between the agroforestry and monoculture systems, meaning that the higher inputs used in the monocultures were compensated by their larger cacao production (Figure 1b). CED per kilogram of organic cacao was higher compared to that of conventional cacao due to the lower productivity per hectare of the organic monoculture compared to the conventional one, and greater reuse of biomass for fertilization (compost). This led to lower energy efficiency, i.e. the energy return on investment (EROI) was lower in the organically-managed systems (Figure 2a). However, when considering non-renewable and renewable energy separately, the organically-managed systems presented lower values of non-renewable cumulate energy demand (NR CED) and higher values of non-renewable energy efficiency (NR EROI) when compared to the conventional ones.
When by-crops (bananas, plantains) were taken into account in addition to the cacao output, the energy demand CED kg^{-1} was 8.6 times higher in the monocultures than in the agroforestry systems (CED MJ kg^{-1}, Figure 1c) and the energy efficiency (EROI) of the agroforestry systems increased up to 5.5 times in contrast to that of the monocultures (Figure 2b). When only non-renewable energy was considered the organic production systems had a lower energy demand and higher efficiency than the conventional ones, with values even more favourable for the organic production than when only cacao production was considered (Figure 1c and 2b).
Agroforestry systems had a higher demand for human labour mainly due to works associated with the management of agroforestry trees and the harvest of by-crops. However, the time of human labour invested in the agroforestry systems was more efficient to produce food. Considering the different management systems, there were no differences in the

demand for labour between organically and conventionally-managed agroforestry systems, but the demand was higher in the monoculture under organic management. The agroforestry systems produced larger energy outputs per energy unit of human labour invested (Labour EROI).

GHG emissions per ha, per kg of cacao and per kg of total products harvested were higher in the monocultures compared to the agroforestry systems, and also higher in the conventionally managed systems compared to the organic ones. This was mainly related to the use of chemical fertilizers and herbicides in the conventional systems compared to the organic ones, and lower use of petroleum derivatives and less fertilizers in the agroforestry systems compared to the monocultures.

Discussion: Agroforestry systems and organic management are two key elements that allow improving the energy efficiency of cacao production while reducing their dependence on fossil fuels and GHG emissions. Despite the higher yield per hectare of cacao grown under conventional systems and monocultures, organic management makes it possible to reduce the non-renewable energy demand per kilogram of cacao produced and, when considering as well the by-crops, the agroforestry systems were more efficient than monocultures, especially when organically managed. In addition, agroforestry systems have a higher energy return on labour.

To reverse the current scenario of systems with low energy efficiency, high demand for non-renewable energy and GHG emissions, stakeholders should promote the adoption of organic agroforestry, which can better ensure the sustainability of the plantations than the organic monocultures. Moreover, agroforestry systems improve farmers' livelihood, food security and ecosystem services.

Disclosure of Interest: None Declared

Keywords: agroforestry, energy demand, monocultures, climate change

Figure 1. Annual mean from 2010 to 2014 of the Cumulative Energy Demand (CED) classified into renewable and non-renewable CED per a) hectare, b) kilograms of cacao harvested and c) total system yield in: conventional agroforestry (Afc), organic agroforestry (Afo), conventional monoculture (Mc), and organic monoculture (Mo). Different letters indicate significant differences between production systems. Capital letters refer to the compared agroforestry and monoculture systems.

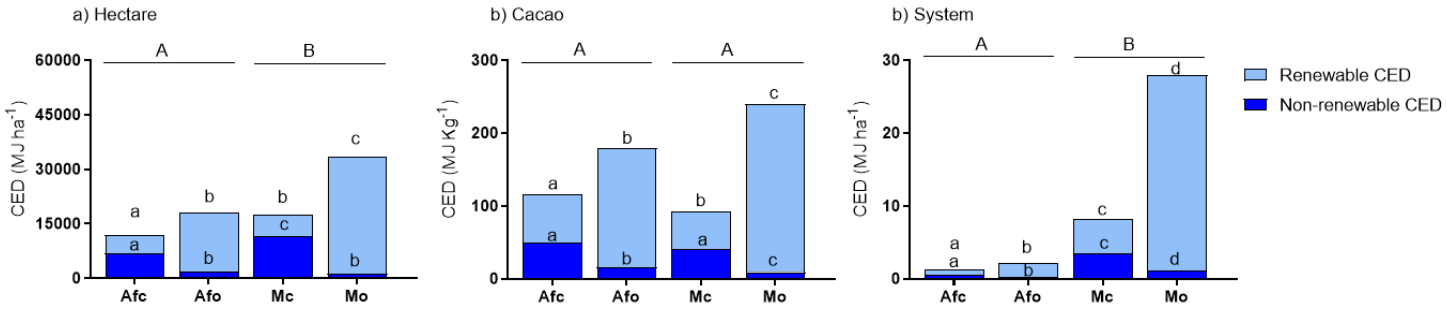
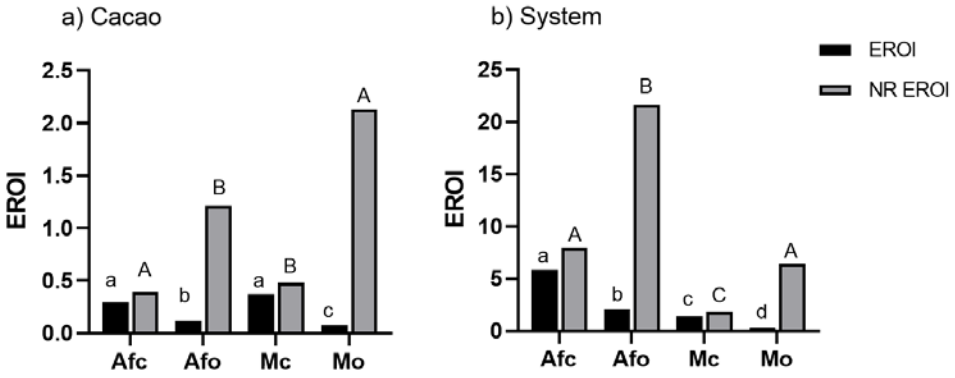


Figure 2. Annual mean from 2010 to 2014 of the Energy Return on Investment (EROI) classified into renewable and non-renewable EROI per a) kilograms of cacao harvested and b) total system yield: conventional agroforestry (Afc), organic agroforestry (Afo), conventional monoculture (Mc), and organic monoculture (Mo). Different small letters indicate significant differences between EROI and capital letters between NR EROI.



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