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# ENERGETIC SUSTAINABILITY OF THREE ARABICA COFFEE GROWING SYSTEMS USED BY FAMILY FARMING UNITS IN ESPÍRITO SANTO STATE

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**ABSTRACT:** Three growing systems of Arabica coffee were evaluated under the energy perspective, in the state of Espírito Santo in Brazil. The systems are conventional cultivation (CC), cultivation with good agricultural practices (CGP) and organic farming (OF). It was made a comparison of the energy flows within these three systems to show sustainable levels of each one based on production average data of several family-farming units.  Therefore, we analyzed crop yield, total energy efficiency reverse (TEER), energy efficiency of ripe coffee (EERC) and non-renewable energy efficiency (NREE). OF system had values for TEER, EERC and NREE of 3.3 4.7 and 7.9 respectively. Yet CC showed values of 1.8, 1.9 and 1.6 for TEER, EERC and NREE respectively. Furthermore, CGP presented values for TEER, EERC and NREE of 0.7, 1.3 and 1.4 respectively. The highest yield was observed in CGP, reaching an amount of 1794 kg ha$^{-1}$ (17,455 MJ); however, this system expends more energy than it converts. Thus, over those points, OF is the most sustainable system.

**KEYWORDS**: agroecosystem, energy analysis, coffee, crop yield, sustainability.

# SUSTENTABILIDADE ENERGÉTICA DE TRÊS SISTEMAS DE CULTIVO DE CAFÉ ARÁBICA, EM UNIDADES PRODUTIVAS FAMILIARES NO ESTADO DO ESPÍRITO SANTO

**RESUMO:** Foram estudados, sob a ótica de seus fluxos energéticos, três sistemas de cultivo de café arábica no Estado do Espírito Santo: a - cultivo convencional (CC); b - cultivo com as boas práticas agrícolas (BPA), e c – cultivo orgânico (CO). A análise foi realizada para comparar os fluxos energéticos envolvidos nos sistemas de produção, a fim de apresentar os níveis de sustentabilidade de cada sistema, com base em dados médios obtidos em diversas unidades de produção de base familiar. Os indicadores analisados foram: Produtividade, Eficiência Energética Total Invertida (ETI), Eficiência Energética Café Maduro (ECC) e Eficiência Energia não Renovável (ENR). O sistema de CO apresentou valores para ETI, ECC e ENR de 3,3; 4,7 e 7,9, respectivamente. O sistema de CC apresentou valores para ETI, ECC e ENR de 1,8; 1,9 e 1,6; respectivamente. O sistema de BPA apresentou valores para ETI, ECC e ENR de 0,7; 1,3 e 1,4; respectivamente. A maior produtividade ocorreu no sistema de BPA, com 1794 kg ha$^{-1}$ (17.455 MJ); no entanto, o referido consome mais energia do que converte. Do ponto de vista energético, o sistema de CO é o mais sustentável.

**PALAVRAS-CHAVE**: agroecossistema, análise energética, café, produtividade, sustentabilidade.

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## INTRODUCTION

Espírito Santo State, in Brazil, has 183.400 ha with crop plantations of *Coffea arabica* and produces over 2.0 million bags of processed coffee (120,000 tons), which plays around 10% of the gross agricultural output of the State (ESPÍRITO SANTO, 2008) and contributes to national coffee production in 8% (CONAB, 2013). Coffee production in this area is spread over 20 thousand farming units, of which, some are family-based agriculture, and coffee generates 71% of the production income for each property. Most of these properties (97.3%) use a conventional system to grow coffee and only few of them (0.5%) are certified as an organic farmer (SCHMIDT et al., 2004).

In recent decades, agriculture has prioritized the implementation of increasing amounts of energy into production systems to increase crop yield. Yield is defined as production per unit of resource and is measured according to resource type. Each possible combination of products and resources can be used as a comparative measure of production efficiency between two or among various agroecosystems, or even set comparisons throughout time (MASERA et al., 1999).

Currently, the amount of energy demanded by production processes for transformations has often been higher than its return, in terms of product energy value; providing low efficiency and a negative balance (CAPELLESSO & CAZELLA, 2013; FURLANETO et al., 2013; SANTOS et al., 2011; SCHNEIDER & SMITH, 2009) regardless social costs associated with disruption of traditional economies.

In a context marked by high-energy dependence and inefficiency of agricultural systems, organic farming is seen as a feasible alternative in the sustainability scenario. Some authors as CLAUDINO & TALAMINI (2013), and SOUZA et al. (2012) asserted that comparisons among systems regarding energy is crucial to understand food chain energy efficiency and potential decreases in fuel consumption with consecutive reduction of greenhouse gas emissions. Also in this context, SOUZA et al. (2009) added that energy balance is a key to ascertain critical points when searching for energy-saving technologies, especially from fossil fuels; it is an important tool and is an indicator of sustainability in agroecosystems.

Given the importance of coffee and the need to verify peculiarities of the production processes with respect to sustainability, this study aimed to analyze, under the energy point of view, different Arabica coffee production systems in family-farming units located in the state of Espírito Santo, Brazil.

## MATERIAL AND METHODS

The study started on a census of organic coffee farms (OF) located within the established limits. It served to define the samples of cultivation systems with good practices (CGP) and conventional systems (CC). The areas were separated as follows: a – with similar soil and climatic conditions under organic production and neighbor; b - production data consistent with the state average (ESPÍRITO SANTO, 2008); c – meet CC and CGP production system characteristics (INCAPER, 2009) and d – areas that fulfill provisions of family-farming legislation.

Field data collection was performed between January of 2008 and March of 2010. Preliminary information on the cultivation techniques were obtained through interviews with farmers, being described and recorded for later evaluation. This part was undertaken with the help of the Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural - Incaper (Institute of Research, Technical Support and Rural Extension of Espírito Santo State – Incaper) and social organizations of the evaluated counties.

Collected information from 47 family-farming units, of which 11 are certified as organic (OF), 20 of them integrate good agricultural practices (CGP) and 16 adopt the conventional cultivation (CC). All OF units are already established, i.e., have already gone through a transitional period of at least three (03) years. The farms are located in the counties of Santa Maria de Jetibá, Afonso Cláudio, Brejetuba, Venda Nova do Imigrante, Ibatiba, Irupi, Iúna and Dores do Rio Preto.

## Energy balance and efficiency

The energy balance was carried out through energy equivalence by converting raw materials, work, processes, as well as machinery and equipment depreciation into energy coefficients scaled in megajoules (MJ), following recommended methodology found in literature (KHOSRUZZAMAN et al., 2010; CHECHETTO et al., 2010; PRUEKSAKORN et al., 2010; SALLA et al., 2010).

As input data, it was accounted the human labor, which consists on the amount of mean human effort in energy value (10 MJ.day$^{-1}$) or its hourly equivalent (1.25 hour$^{-1}$ MJ) (SOUZA et al., 2011). Chemical fertilizers were also taken based on information of AUDSLLEY et al. (1997), being 45 MJ.kg$^{-1}$ for N, 12.8 MJ.kg$^{-1}$ for $P_2O_5$ and 4.15 MJ.kg$^{-1}$ for $K_2O$. For urea, it was considered a coefficient of 63 MJ.kg$^{-1}$, while for dolomitic limestone was 553.67 MJ.ton$^{-1}$ (MACEDÔNIO & PICCHIONI, 1985). For organic fertilizers, it was regarded the mean cost of transportation and composting, since stock are derived from other system. Concerning the fuels, it was used an energy convertor equivalent to 35.4 MJ.L$^{-1}$ for each liter of diesel oil, 32.1 MJ.L$^{-1}$ for gasoline and one kilogram of liquefied petroleum gas (LPG) amounting to 46.3 MJ (BRASIL, 2007). For machinery and equipment, hourly rate was calculated as proposed by FRIGO et al. (2011), which considers machine capacity, load or performed work by time unit consumption. Agrochemicals had their energy accounted by kilogram of used commercial product, being 348.2 MJ.L$^{-1}$ for herbicides; 251.6 MJ.L$^{-1}$ for insecticides; 208.6 MJ.kg$^{-1}$ for fungicides and 269.5 MJ.kg$^{-1}$ for other pesticides, as average observed by PIMENTEL (1980) and SOUZA et al. (2011). Energy consumption estimated for coffee processing totalized 13.11 MJ.kWh$^{-1}$ related to power (electricity) and 12.9 MJ.kg$^{-1}$ referring to wood consumption (BRASIL, 2007).

As outputs, it was considered yield averages from 2008 to 2009 of each farm, being set as coffee production per hectare (kg.ha$^{-1}$). Energy input costs were achieved by means of 2007/2008 and 2008/2009 seasons. Brazilian coffee has an energy coefficient of 9.72 MJ.kg$^{-1}$ (FRANCO, 1999), which was applied in this study.

Once recorded input and output inflows per hectare and year, several energy efficiency indexes were found, pointing information on energy use in each of the coffee production systems. Among studied indexes, we may quote: a. total energy efficiency reverse (TEER) that matches inputs and outputs; b. energy efficiency of ripe coffee (EERC), which makes a relation of inputs and outputs up to the harvest of ripe or pulped cherries (without processing); and c. non-renewable energy efficiency (NREE) being the ratio of non-renewable inputs and outputs. Methodology used to calculate energy intake, as well as TEER, EERC and NREE, was based on literature findings (ARAUJO et al., 2013; VELOSO et al., 2012; GIANNETTI et al., 2011b; JASPER et al., 2010; ASSENHEIMER et al., 2009).

Data underwent descriptive statistics by means of analysis of variance (ANOVA). Averages were compared through Tukey and Mann Whitney tests at 5% ($p = 0.05$).

## RESULTS AND DISCUSSION

### Yield and energy inputs

Average yield of CC, OF and CGP systems for 2008-2009 season were 4,998; 2,667 and 11,499 kg, respectively. The highest performances of both evaluated seasons were observed for CGP system. Moreover, yield (kg ha$^{-1}$ MJ ha$^{-1}$) had differences among cultivation type ($F = 25.24$, $P = 0.0000$). Such differences draw a distinction between CC and OF against CGP, and there has been no significant variation between OF and CC (Table 01). CC values were similar to the averages of the Arabica Coffee Production Chain in Family-farming Agriculture (SCHMIDT et al., 2004).

TABLE 1. Yield (kg.ha$^{-1}$, MJ.ha$^{-1}$) reached by three systems of coffee production in Family farming agriculture of Espírito Santo State, in Brazil, from 2008 to 2009.

| Production system | Yield | | n |
|---|---|---|---|
| | Kg.ha$^{-1}$ | MJ.ha$^{-1}$ | |
| Conventional | 770.95±65.81 a | 7501.35±640.3 a | 16 |
| Organic | 839.35±122.41 a | 8166.88±1191.03 a | 11 |
| Good Agricultural practices | 1793.97±138.21b | 17455.29±1344.76 b | 20 |

Columns with different letters show statistical differences by the applied test (HSD post hoc $p<0.05$)

MALTA et al. (2007) evaluated conversion of organic coffee and observed significant differences in the second year, which was lower than conventional agriculture. INCAPER (2009) reported that local coffee average yield ranged from 600 to 840 kg ha$^{-1}$, compared to the period of 1995 to 2008.

Table 2 shows the mean energy consumption of each system regarding the used feedstock and exhibits the energy share of each material.

TABLE 2. Mean energy consumption of conventional cultivation (CC), organic farming (OF) and cultivation with good practices (CGP).

| Input | Cultivation systems and coefficients | | | | | |
|---|---|---|---|---|---|---|
| | CC | | OF | | CGP | |
| | (MJ) | (%) | (MJ) | (%) | (MJ) | (%) |
| Workforce | 402.50 a | 4.24 | 711.20 b | 20.66 | 649.30 b | 2.55 |
| Fertilizers | 6.258.80 b | 65.87 | 28.30 a | 0.82 | 12.089.80 c | 47.43 |
| Plant protection inputs | 1.558.30 a | 16.40 | - | 0.00 | 1.084.10 a | 4.25 |
| Machinery and Equipment | 1.282.40 a | 13.50 | 2.702.90 b | 78.52 | 11.669.00 c | 45.77 |
| Total | 9.502.00 a | 100.00 | 3.442.40 a | 100.00 | 25.492.20 b | 100.00 |

Means followed by the same letter do not differ from each other by the Tukey test (p = 0.05).
Obs.: Machinery and Equipment value is also composed by energy outputs by fuel and lubricant

In general inputs of the systems, there are significant differences (F = 28.56, P = 0.0000) related to production, with higher energy consumption in the CGP system. These differences are mainly due to higher use rates of machinery, equipment and fertilizers compared to the other two systems, corroborating information identified in Siqueira et al. (2011). These factors together account for 93.2% energy intake of CGP system (Table 2).

OF and CC did not differ statistically for total input values. Regarding OF, it might be related to organic fertilizer transportation, what has energetically encumbered this system, once it was used fossil fuel and lubricant. In this sense, it becomes important to produce an amount of biomass to serve as organic fertilizer, since it would decrease energy consumption and would present a greater number of renewable and local inputs, aside from lowering material energy flows.

Energy contribution referring to workforce differs significantly between CC toward OF and CGP systems, while the last two cropping systems do not differ from each other (Table 2). Despite not differing statistically CGP system, the largest labor force demand is given to the OF system (711.20 MJ), which had 20.66% of the total energy intake of the system. Whereas for the CC system, this contribution was only of 4.24% (402.50MJ). These findings meet values reported by Pimentel et al. (2005), who observed an average of 15% in workforce requirement on an organic farming system against conventional one; this value can assume percentages of 7-75% increased energy demand. SIQUEIRA et al. (2011) have also found similar result by assessing socioeconomic sustainability of conventional and organic coffee cultivation in Espírito Santo State-Brazil.

Energy intake related to fertilizer inputs had statistical differences among the three cropping systems (Table 2). CGP showed higher energy consumption (12,089.80 MJ), which accounted for

47.43% of inputs in this system. Therefore, it reveals that such system is marked by great fertilizer consume, followed by CC (6,258.80 MJ) and OF (28.30 MJ) that reached rates of 65.87% and 0.82% over total energy intake, respectively. The reduced contribution regarding fertilizer inputs of OF is justified by its distinctive nutritional management, which adopts organic fertilization as base of plant nutrition. On the other hand, the highest energy intake of CC (65.87%) is due to an intensive use of fertilizers, which is widely applied in conventional systems.

Concerning crop protection inputs, results showed no significant difference between CGP (1,084.10 MJ) and CC (1,558.30MJ), contributing with 4.25% and 16.40% of the total energy intake of each system, respectively (Table 2). For the OF system, energy intake was not observed regarding the use of pesticides, since it is not allowed in OF systems.

Energy spend of machinery and equipment showed statistical difference among systems (Table 2). OF accounted for the highest consumption, around 78.52% of the total amount, contrasting literature reports (TURCO et al., 2012; SOUZA et al., 2011). It emphasizes organic system lower energy expenditure on machinery and equipment. However, in this study, it was observed a significant need to purchase and carry organic fertilizers over long distances.

In addition, CC system had the lowest energy demand for machinery and equipment inputs (1,282.40 MJ), corresponding to 13.50% of total energy intake. Conventional farming systems have a greater reliance on mechanization (CAPELLESSO & CAZELLA, 2013); however, this is not observed in this study, since the farms are family-based and mechanization is not customary. Furthermore, even adopting conventional farming practices, family based agriculture has less dependence on energy inputs related to machines compared to corporate farming. CGP had the highest energy consumption (11,669.00 MJ), corresponding to 45.77% of all energy inputs. Moreover, mechanization was used in large proportions in the CGP system, especially in activities related to processing.

In respect of post-harvest and processing managements, OF and CC energy costs were predominantly low, since ripe coffee is prevalently dried using solar energy. While for the CGP, there has been a high demand for energy in drying and processing operations, which are performed by means of equipment that requires wood and electric power for process performance (Table 2).

Table 3 shows energy analysis strengthening for CC, OF and CGP, in MJ per ha.

TABLE 3. Energy analysis strengthening of the three studied Arabica coffee cultivation system in Espírito Santo State - Brazil.

| Input/ Output sources | Cultivation systems and coefficients (MJ) | | |
|---|---|---|---|
| | CC | OF | CGP |
| Input | 9502 a | 3442 a | 25492 b |
| Cultivation Total Energy (Ripe coffee) | 8562 b | 2111 a | 14407 c |
| Non-renewable energy | 8251 | 1491 | 13814 |
| Renewable energy | 1251 | 1951 | 11678 |
| Output | | | |
| Total outputs (Pulped coffee) | 7501 | 8170 | 17455 |
| Total energy efficiency reverse (output/input) (TEER) | 1.8 a | 3.3 b | 0.7 a |
| Energy efficiency of ripe coffee (EERC) | 1.9 a | 4.7 b | 1.3 a |
| Non-renewable energy efficiency (NREE) | 1.6 a | 7.9 b | 1.4 a |
| Energy contribution per kg of product (MJ/kg) | 12.4 | 4.0 | 14.3 |
| Renewable energy contribution rate (%) | 17.8% | 47.4% | 38.1% |
| Coffee yield Kg.ha $^{-1}$ | 771 | 839 | 1794 |

Means followed by the same letter do not differ from each other by the Tukey test (p = 0.05). Means were calculated from individual samples of replications taken at each studied system.

With regard to TEER, it was not observed any statistical difference between OF (3.3) versus CGP (0.7) or CC (1.8); and the last two had no statistical differences (Table 3). Confirming findings of GELFAND et al., (2010), who highlighted the advantage of OF in energy efficiency against conventional systems. Within the findings of VELOSO et al. (2012) and Souza et al. (2009), the lowest energy efficiency coefficient "one" (01) indicates a system that import virtually all energy consumed during production; it shows that for CGP, it should be reviewed aspects of energy conversion mainly about reusing local inputs, once this system imports more energy than produces it (Table 3).

EERC showed statistical difference between OF (4.7) towards CGP (1.3) and CC (1.9); while the latter two did not differ statistically to each other (Table 3). It also confirms the improved efficiency of OF systems, when analyzing energy intake until harvest stage of ripe coffee compared to other cropping systems. CGP and DC systems had EERC value of 1.3 and 1.9, respectively; it indicates that during growing phase, such systems import a greater amount of energy compared to OF one.

NREE, which was obtained through the ratio between total output and non-renewable energy for each system, presented statistical difference from OF (7.9) to CGP (1.4) and CC (1.6); nevertheless, CGP and CC were not statistically different (Table 3). The value observed for OF indicates lower use of non-renewable sources of inputs (PIMENTEL et al., 2005), before CGP and CC. The share of renewable energy, at 47.4%, 38.1% and 17.8% for OF, CGP and CC respectively (Table 3), reaffirms OF system primacy.

Working with the emergy accounting in a conventional coffee production, GIANNETTI et al. (2011a) and GIANNETTI et al. (2011b) found that even using relevant forms of renewable energy, such as organic fertilizers, the planting stage in CC showed higher energy consumption, such as chemical fertilizers and other non-renewable energy inputs, which actually committed the sustainability of this agro-ecosystem. This information can be extrapolated to CGP system that uses 38.1% renewable energy, but the energy sustainability of such cultivation system is compromised by other factors such as chemical fertilizers, machinery and equipment.

Table 3 also demonstrates values related to energy contribution per kg of product, corresponding to 12.4, 4.0 and 14.3 MJ.kg-1 of processed coffee for CC, OF and CGP, respectively. CC and CGP systems had higher energy requirements per unit of output, since the use of energy inputs, especially non-renewable, are common in such systems, occurring in greater proportion in CGP. The variable in question is presented with the best efficiency for OF, reporting the lowest energy requirement for conversion per product unit. MORA DELGADO et al. (2007), performing an energy analysis of coffee production in family-farming units of Costa Rica, noted that organic farming system showed the best efficiency. The authors observed that to produce one kg of cherries, it was invested an amount of 0.51 MJ, whereas for conventional and mixed farming systems, it was 1.06 and 0.97 MJ.kg$^{-1}$ cherry coffee, respectively.

Now, in this study, the energy consumption to produce one kg of coffee cherries was 0.50 MJ, 2.22 MJ and 1.61 MJ for OF, CC and CGP, respectively. Based on the findings of the above-mentioned authors, indexes related to one energy unit to produce one kg of coffee cherry from CC and CGP systems, in the current research, must be improved by reducing energy intake and/ or increasing energy conversion.

TURCO et al. (2012) evaluated the energy efficiency of organic coffee in Southern Minas Gerais State - Brazil, and found a value of 5.6. Whereas, in this study, we found a TEER of 3.3 (Table 3). The lower efficiency observed here is mainly due to transportation of organic fertilizers, which was evidenced when assessing machinery and equipment energy inputs.

OF energy analysis printed a higher level of sustainability of the CC and CGP systems, corroborating data from the literature (TURCO et al., 2012; ALLUVIONE et al., 2011; GABRIEL et al., 2011; MORA-DELGADO et al.; 2007).

Coffee production through the CC and CGP systems may have improved levels of sustainability, mainly by replacing non-renewable energy inputs such as chemical fertilizers, fossil fuels and lubricants for other inputs of lower energy cost as biofuels, organic fertilizers. Combining the energy aspects with plant nutritional requirements, there are a number of actions, which taken together, can improve coffee cultivation sustainability. One is to grow legume species for green manure, which promotes an increase of nutrients within the system, mainly nitrogen (N), which besides being a highly energy conversion limiting nutrient, most often is obtained by non-renewable sources. Alternatively, coffee processing byproducts would be properly used as energy source, such as coffee peel, which most of the time is used inappropriately.

Another important alternative would be to use more significantly and efficiently the solar radiation to dry coffee grain on terraces, greenhouses, or other alternatives that reduce an intensive use of mechanical dryers, which require great energy intake.

## CONCLUSIONS

Organic farming was the most sustainable system from the energetic point of view.

Cultivation with good practices presented the highest physical yield.

The most significant energy cost of organic system came from machinery and equipment. Yet for conventional cultivation, it was the use of chemical fertilizers. Finally, for cultivation with good practices, the highest costs came both from chemical fertilizers and from activities such as coffee processing and post-harvest.

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