Energy flux analysis in fruit agroecosystems

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Abstract

Industrial production systems use subsidies that accelerate energy flux and nutrient cycles increasing entropy. This is visualized in the contamination and loss of diversity. Energy flux analysis assess agricultural practices, identify processes to be improved and give tools to develop agroecosystems with a degree of entropy compatible with life. The objective of this work was to determine how different energy sources affect a fruit crop and to propose strategies to improve the sustainability of agroecosystems. Energy flux was done for a crop obtained from an organic-biodynamic apple orchard of Red Delicious cultivar 'Top Red'. It was considered that the production responded to a "superior" quality for fresh consumption. Cultural Biological energy was determined with labor costs data used in the orchard and industrial energy through the consumption of oil and electricity. The production system studied had industrial direct energy values of 24,106.57 MJ ha^{-1} and cultural biological energy values of 449.56, equivalent to 98 and 2% of the total energy input to the orchard, respectively. Dependence on energy subsidies that increased industrial energy can be reduced with the application of different strategies that will be discussed. In the fruit-growing system, total energy revenues are largely retained in the agroecosystem for the structure and maintenance of the "fruit deciduous forest" that sequesters carbon. This could determine lower efficiencies compared to other crops so, not only harvested fruit should be counted in the analysis. Agricultural sustainability is reached by adequate knowledge of ecological processes at farm and regional levels and through socio-economic changes that promote sustainability in all sectors of the food system. The agriculture system should allow appropriate levels of production with the conservation of natural resources considering social, spatial and temporal asymmetries and inequalities in the human use of resources.

Keywords: cultural biological energy, industrial energy, energy subsidies, sustainability, fruit deciduous forest

INTRODUCTION

Studies conducted reflect the negative impacts that industrial agriculture has caused in recent years on the environment (Foley et al., 2011). This is due to the high use of energy subsidies, which has accelerated the rate of biodiversity loss, climate change and the alteration of the nutrient cycle. All these human-induced changes put the survival of ecosystems at risk, since they have exceeded the limits of the Earth (Rockström et al., 2009). Among the serious causes of alteration to the ecosystem, we can mention eutrophication, soil acidification and greenhouse gas emissions (Conley et al., 2009). In this context, authors such as Godfray et al. (2010) and Foley et al. (2011) resurface the idea that one of the greatest challenges of the century is to satisfy the growing food needs of society and at the same time reduce the environmental impact of agriculture.

As an alternative to the above, the agroecological approach considers agricultural ecosystems as the fundamental units of study. In these systems, mineral cycles, energy transformations, biological processes and socio-economic relationships are investigated and analyzed as a whole (Altieri and Nicholls, 2000). Agroecology presents concrete strategies of resistance and resilience to climate change, based on agroecological principles, solidarity and

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innovation (Dussi and Flores, 2018).

The use of energy in the agricultural sector depends on the size of the population dedicated to agriculture, the amount of arable land and the level of mechanization. According to Gliessman (2002), different types of energy income in agroecosystems can be classified in energy from solar radiation, called ecological energy to cultural energy, from anthropogenic sources. In turn, cultural energy can be subdivided into biological and industrial. Biological cultural energy is any energy input that has a biological basis under human control or management. This includes human work, animal work handled by humans and byproducts of animals such as manure and compost among others. Cultural biological energy is renewable and efficient by facilitating the production of harvestable biomass. The industrial cultural energy is that which derives from oil, from radioactive fission and from geothermal and hydrological sources, among others.

Energy balances are the instruments to analyze the use of energy in agrarian systems (Fernández, 1995). Its main objective, through energy indicators, is to calculate the total amount of energy needed to obtain a product and the relationship between the energy input compared to that extracted from the system (Tabatabaeefar et al., 2009). Energy income is represented by the biological and industrial energy used in the production process and the energy outputs by the energy contained in the harvested product. Energy efficiency is a robust indicator in the analysis of energy use in agroecosystems (Díaz Ambrona and Gregorio, 2013), which is measured by relating the energy input and output flows of the agroecosystem (Tieri et al., 2014). It is expressed as the relationship between the amount of energy contributed to the system per unit of product (MJ kg^{-1}) and the amount of energy obtained by the system per unit of product (MJ kg^{-1}). The value of energy efficiency represents the energy cost of agricultural products (Corré et al., 2003) and is related to the intensity with which resources are used and which type of production is carried out (Redondo and Pérez, 2006).

Greater diversity in the agroecosystem increases the complexity and therefore the resilience of the system, thus increasing its sustainability (Racskó et al., 2008; Dussi et al., 2011, 2012; Flores et al., 2015).

Fruit growing is the main economic activity in the Upper Valley region of Río Negro, Argentina, contributing 20% of the Geographical Gross Product of Rio Negro province. Likewise, agricultural activity occupies, directly and indirectly, 35% of the economically active population. According to the national agricultural census (CAR, 2005) the area of apples exceeds 26,000 ha., with an approximate production of 750,000 t out of which about 212,000 t are exported. At present, the apple fruit value chain, based on the industrial agriculture model, faces a loss of profitability with a marked process of decapitalization of small producers (Elosegui et al., 2017). Climate of the Upper Valley is continental, temperate arid with an average annual rainfall of 200 mm. Incidence of late spring frosts is controlled in different ways among them using water spray (active control).

The objective of this study was to analyze how different energy sources affect a fruit crop, determine energy efficiency and propose strategies to improve the sustainability of agroecosystems.

MATERIALS AND METHODS

Cultural practices carried out during the growing season between August 2015 and February 2016 on a 20 ha fruit agroecosystem, with pip fruit trees, located in the province of Río Negro, Patagonia Argentina, (39°LS), under organic management and biodynamic certification were analyzed.

Energy was calculated for the production obtained from 1 ha of Red Delicious apple cultivar 'Top Red' (30 years old) trained as a palmette trellis system. Plants, have a planting frame of 4 m between rows and 3 m between plants, with vegetation cover in the alleyway (space between two fruit trees rows). Harvest is semi mechanized with a self-propelled agricultural platform and apples are harvested into wooden bins with a capacity of 480 kg. A net yield of 25,000 kg ha^{-1} was obtained with 5% discarded low quality, which yielded a net yield of 23,750 kg ha^{-1}. Energy contained in the product is made up of the energy extracted (MJ ha^{-1}) from the system. To calculate it, a table of caloric content published by the National

University of Lujan (2010) was taken as a reference, in which for every 100 g of raw apple, 64 kcal are due, or that per kilo of apple produced 2.68 MJ are extracted.

To collect the information of the energy input (MJ ha^{-1}) to the system, interviews with the technical manager of the production unit and field notebooks of the orchard were consulted. Cultural practices, supplies used and workforce requirements were detailed, which represent the flow of income of 1 ha during 2015-2016 growing season. Study did not include energy provided by the sun, agricultural infrastructure of fruit orchard and its maintenance. Energy management analysis was extended until the moment apples transposed the physical limits of the orchard, thus excluding packaging, storage and transport procedures to consumers.

To determine the industrial and biological-cultural energy, fuel, electric power and labor data were considered for all the activities that were carried out in the productive unit during the established period.

Calculation of energy contribution of human work depends on duration and intensity of the work carried out by humans. It was estimated that labor with a high duration and intensity called "strong" equals 96.28 kcal h^{-1} and "weak" labor is 64.28 kcal h^{-1} according to Campos and Naredo (1980) which is equivalent to 3.22 and 2.50 MJ $workday^{-1}$, respectively. Workday represents 8 h of daily work. For fuel consumption of gas-oil type fuel, the value of 35.86 MJ L^{-1} was used (Funes Monzote et al., 2006, 2009).

The orchard has a tractor of 185 HP and a sprayer of 2000 L, with a gasoline consumption of 7 L h^{-1}. In addition, the agroecosystem has a self-propelled agricultural platform used in harvesting, pruning and thinning.

For the calculation of indirect energy, tractor and sprayer data were taken. Indirect energy consumption was represented by the energy incurred in the equipment manufacture; at this point the energy costs derived from the production of summer oils and carpovirus were not considered. To establish the indirect energy (Table 1) Equation 1 was used (Bridges and Smith, 1979) which was applied by Doering (1980) and Fluck (1992). It determines the cost in MJ h^{-1} and adds the energy sequestered in construction materials including manufacturing and transportation, fuel, lubricants/filters, repairs/maintenance.

$$\text{Indirect energy} = \text{Equipment weight} * \text{Energy per unit mass} / \text{Equipment lifetime} \quad (1)$$

where indirect energy is measured in MJ ha^{-1}; equipment weight in kg; energy per unit mass in MJ kg^{-1} and life time of the equipment in hours.

Table 1. Value of cultural biological energy and direct and indirect industrial cultural energy contributed in the production of 1 ha of Red Delicious cultivar 'Top Red' apple trees during 2015-2016 growing season.

Cultural practices	Renewable energy	Non-renewable energy		
	Cultural biological energy (MJ ha^{-1})	Direct industrial cultural energy (MJ ha^{-1})	Indirect industrial cultural energy (MJ ha^{-1})	Total energy of each cultural work (MJ ha^{-1})
Soil fertilization	145,41	2565,06	0,00	2710,47
Foliar fertilization	0,48	450,45	0,00	450,93
Agroecological pests management	31,75	5705,70	0,00	5737,45
Irrigation	21,61	0,00	0,00	21,61
Pruning and thinning	202,86	681,39	0,00	884,25
Spring frosts control	13,13	13513,50	0,00	13526,63
Harvest	34,32	1190,47	0,00	1224,79
Machinery	0,00	0,00	68,12	68,12
Sub-Total (MJ ha^{-1})	449,56	24106,57	68,12	24624,25
Total energy entered into the system (%)	2	98		100

Values for the equipment weight (kg) were obtained from manuals of the machinery; for the energy per unit mass (MJ kg^{-1}) Fluck (1992) was consulted; and for the life time of the equipment (h), Solari and Quintana (1979) were taken as reference. Once the value of indirect energy expressed in quantity of MJ consumed per hour was calculated, it was multiplied by the hours of use in the analyzed hectare and the indirect energy value was obtained.

Late spring frosts control was carried out by sprinkler irrigation that work with a gasoline pump. In productive terms, these frosts are the most important in the study area. During the analyzed season, there were 5 days of frost that justified the use of the sprinklers during 41 h. During the apple production cycle, dispensers were used for codling moth control and traps for pests monitoring.

To calculate energy efficiency, Equation 2 was used.

$$\text{Energy efficiency} = \text{Energy output (MJ kg}^{-1}\text{)} / \text{Energy input (MJ kg}^{-1}\text{)} \qquad (2)$$

RESULTS AND DISCUSSION

Of the total energy subsidies that enter the orchard analyzed (Figure 1), 54.93% corresponds to the control of spring frosts, 23.29% to the agroecological pest management (APM), 11% to the elaboration and application of compost in soil fertilization, 4.97% to harvest, 0.3% corresponds to indirect energy represented by the machinery used, and 5.51%, corresponds to fruit trees irrigation, foliar treatments, pruning and fruit thinning.

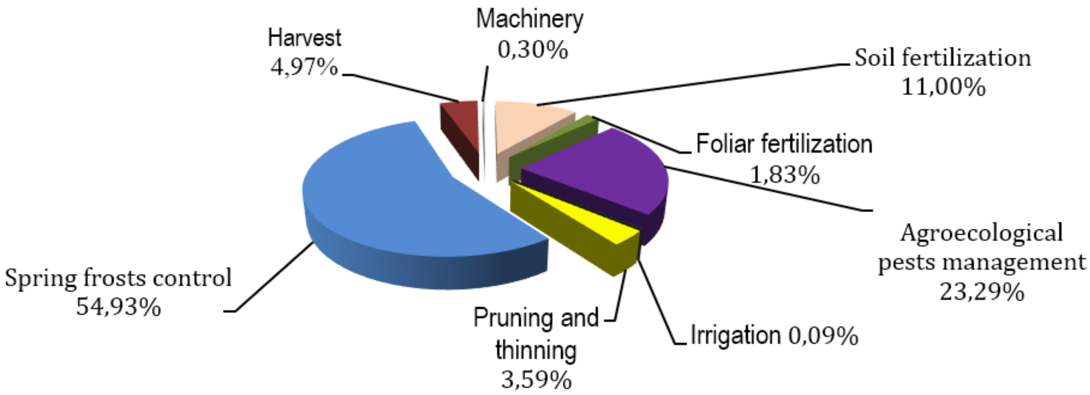
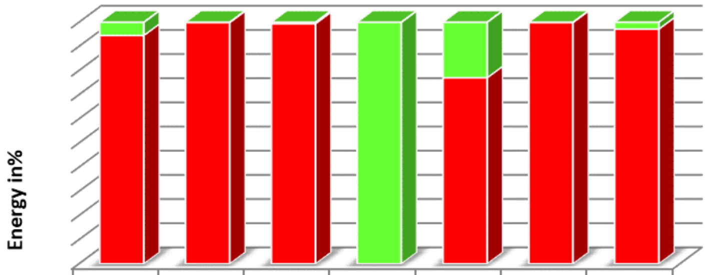


Figure 1. Energy values (%) contributed to the different activities carried out on one hectare of Red Delicious cultivar 'Top Red' apple trees. Season 2015-2016.

During the analyzed season, for frost control, sprinklers were used for 41 h, equivalent to an industrial energy value of 13,513.50 MJ ha^{-1} and a cultural biological energy of 13.13 MJ ha^{-1} (Table 1).

Activities that recorded, in proportion, a greater contribution of industrial energy were, late spring frosts control, APM, soil fertilization and harvest. While irrigation only consumed cultural biological energy (Figure 2).

In the production system studied, 449.56 MJ ha^{-1} of cultural biological energy and 24,106.57 MJ ha^{-1} of industrial energy were used. The share of renewable energy is equivalent to 2% while of the non-renewable was 98%. This difference was also observed by Aydın et al. (2018), who estimated a percentage contribution of 8.99% renewable energy and 91.01% non-renewable for the production of apples produced with good agricultural practices. A value of 68.12 MJ ha^{-1} was the input of indirect industrial cultural energy in the agroecosystem analyzed (Table 1).



	Fertilization to the soil	Foliar fertilization	Agroecological Management of Pest	Irrigation	Pruning and thinning	Control of spring frosts	Harvest
Biological cultural energy (MJ/ha)	147.41	0.48	31.75	21.61	202.86	13.13	34.32
Indirect industrial cultural energy (MJ/ha)	2565.06	450.45	5705.70	0.00	681.39	13513.50	1190.47

Figure 2. Percentage share of energy contribution to the different cultural labors performed on 1 ha of Red Delicious cultivar 'Top Red' apple trees. Season 2015-2016.

Manual labors that involve more energy by the workers are those related to the preparation of compost, pruning, thinning and harvesting. Those practices where intervention of workers is limited to the management of a machinery involve less energy.

Table 2 shows that 50% of the workforce was classified as strong. Labors that involves weak workforce was mechanized and the non-mechanized labors used strong workforce. In none of the work carried out in the productive unit under study, the workforce exceeded 6% of the total energy contributed by cultural work. These results coincide with those of Strapatsa et al. (2006), who state that cultural labor whose driving force is manual labor, are those that involved the least energy expenditure and in those mechanized work they only represented a small fraction (less than 8%).

Table 2. Labor classification in MJ $workday^{-1}$, applied to the agroecosystem, related to the energy expenditure of the different cultural labors carried out[a].

Concept	Type of workforce: Weak (2.50 MJ $workday^{-1}$)	Type of workforce: Strong (3.22 MJ $workday^{-1}$)
Labor for collection and selection of herbaceous material	X	
Labor for compost tumbling		X
Labor for compost irrigation		X
Labor to sift the compost		X
Labor to place dispensers with pheromone	X	
Labor to place traps for Codling moth	X	
Labor for reading codling moth traps	X	
Labor for monitoring pests and predators	X	
Compost application labor	X	
Labor for biodynamic preparations	X	
Labor for fruit trees irrigation	X	
Labor for ditches cleaning and conditioning		X
Labor for fruit thinning		X
Labor for pruning material storage and conditioning		X
Harvest labor		X

[a]Own elaboration based on Campos and Naredo (1980).

Energy efficiency obtained by the evaluated agroecosystem was 2.60 (Table 3). This implies that more energy was extracted in the form of harvested fruit than that received in the form of energy inputs during production. Although energy efficiency indicator showed a favorable value, the agroecosystem has a high energy income per hectare, with a large share of energy from non-renewable sources.

Table 3. Energy efficiency value for the production obtained from 1 ha of Red Delicious apple trees in the Upper Río Negro Valley. 2015-2016 growing season.

Energy output (MJ kilo^{-1})	Energy input (MJ kg^{-1})	Energy efficiency (energy output/energy input)
2.68	1.03	2.60

Energy efficiency value was higher than those obtained by Strapatsa et al. (2006) and Rafiee et al. (2010) who indicated values of 1 and 1.6, respectively; doubled the value obtained by Aydın et al. (2017) who pointed out that the conventional production of pears under good agricultural practices had a value of 1.20; and similar to the one obtained by Neira (1996) for apple production in Chile, who reported an energy efficiency value of 2.18.

The main reason why the energy efficiency values found are higher than those of Strapatsa et al. (2006), Rafiee et al. (2010) and Aydın et al. (2017) is that their energy income per hectare were larger (50,700, 49,857.43 and 30,046.64 MJ ha^{-1}, respectively) and their yields per hectare were similar to those obtained in this study (21,501 and 20773,93 kg ha^{-1} for Strapatsa et al. (2006) and Rafiee et al. (2010), respectively) or even lower (15,000 kg ha^{-1} for Aydın et al. (2017). This makes their relation energy output-energy input lower and therefore these agroecosystems are less efficient than the one analyzed in this study. In the case of Neira (1996), who carried out his research in agroecosystems with conventional management with a high dependence on fertilizers and synthetic biocides, the efficiency found by the author was similar to that of the present study. However, it can be observed that their average energy income for red apple cultivars amounted to 46,605 MJ ha^{-1}, which almost doubles the value found in this study. The yields declared were higher, reaching 43,152 kg ha^{-1}, which almost doubles the 22800 kg ha^{-1} obtained in the Argentinian organic-biodynamic apple agroecosystem evaluated. Higher yields improve mathematically the energy efficiency equation, yielding a better value of the indicator, but to establish a fruit production respecting the environmental standards, not only energy indicators should be improved by increasing yields, but also energy subsidies per hectare, especially those from non-renewable sources must be reduced.

When comparing the evaluated organic-biodynamic agroecosystem with a conventional one typical of the region (Leskovar et al., 2010) in terms of energy efficiency, differences are also observed. The energy efficiency in the organic-biodynamic system is 2.60 and in the conventional 1.44; this implies that in the organic orchard to obtain the same unit of product, less energy is consumed. The conventional system is half as efficient as the organic system, despite having obtained a net production of 6000 kg more per hectare. This implies that although the outputs increase, that is, more kilograms of apples are obtained, the system is less efficient because more units of energy must enter per unit product than in the organic model. Strapatsa et al. (2006) point out that a better energy efficiency could be obtained, without affecting yields, mainly through the reduction of fertilizers (especially nitrogen).

CONCLUSIONS

The high percentage of industrial energy used in the fruit agroecosystem under analysis, reflects a high dependence on energy subsidies. To reduce this dependence, it is essential to regulate different activities that are carried out in the productive system through the application of appropriate technologies, that is, reduce the use of industrial energy, especially the one that comes from non-renewable or polluting sources, such as oil. Using tillage systems that require less use of machinery, water efficiently, use alternative sources of cultural-industrial energy, such as photovoltaic systems and wind turbines is recommended.

For the control of late spring frosts an alternative is to change toward the use of an electric pump driven with energy from renewable sources. In addition, passive frost control systems could be used, maintaining a low alleyway vegetation cover with a humid soil to produce greater heating during the day and nocturnal release of energy to attenuate frost. Likewise, the use of plants as windbreaks reduces the entrance of cold air and slows down the intensity of the breeze that causes greater evaporation and cooling. It is essential to design agroecosystems resilient to climate change, cultivating species resistant to low spring temperatures.

Additionally, it is necessary to increase the knowledge of agroecological pest management, trophic networks and farm-level interactions in order to reduce external inputs and increase the use of biological control through cover crops or intercrops and the use of trap plants.

As regards marketing, the regionalization of production and the link between consumers and producers to understand the value of the organic and biodynamic products to reach a fair trade must be put in place.

One aspect to be considered for the energy analysis of deciduous fruit trees is that if only harvested fruit is accounted as energy output, the analysis is underestimated, because of the total input much is retained in the agroecosystem as a plant structure and maintenance. Fruit trees sequesters carbon so these type of agroecosystems acts as "fruit deciduous forests" giving to these systems other functions toward the environment that is beyond producing fruits.

Energy flow analysis allows the evaluation of agricultural practices, and identifies those aspects to be improved. Agricultural sustainability is achieved, among other factors, through adequate knowledge of the ecological processes that occur at farm level and in their context. With these bases, socio-economic changes that promote sustainability in all sectors of the agri-food system can be made.

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