Ecological Indicators 43 (2014) 281–287

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Short Communication

Energy balance and greenhouse gas emissions in organic and conventional avocado orchards in Mexico

Marta Astier[a,*], Yair Merlín-Uribe[b], Laura Villamil-Echeverri[c], Alfredo Garciarreal[d], Mayra E. Gavito[b], Omar R. Masera[b]

[a] Centro de Investigaciones en Geografía Ambiental, Universidad Nacional Autónoma de México, Antigua Carretera a Pátzcuaro No. 8701, Col. Ex-Hacienda de San José de La Huerta C.P. 58190, Morelia, Michoacán, Mexico
[b] Centro de Investigaciones en Ecosistemas, Universidad Nacional Autónoma de México, Antigua Carretera a Pátzcuaro No. 8701, Col. Ex-Hacienda de San José de La Huerta C.P. 58190, Morelia, Michoacán, Mexico
[c] Programa de Biología, Facultad de Ciencias Básicas, Corporación Universitaria Santa Rosa de Cabal, UNISARC Kilómetro 4 Vía Santa Rosa de Cabal – Chinchiná (Caldas) Santa Rosa de Cabal, Risaralda, Colombia
[d] Licienciatura en Ciencias Ambientales, Escuela Nacional de Estudios Superiores, Universidad Nacional Autónoma de México, Antigua Carretera a Pátzcuaro No. 8701, Col. Ex-Hacienda de San José de La Huerta C.P. 58190, Morelia, Michoacán, Mexico

ARTICLE INFO

Article history:
Received 29 May 2013
Received in revised form 16 January 2014
Accepted 3 March 2014

Keywords:
Avocado
Agriculture
Energy
GHG
Organic farming
Mexico

ABSTRACT

There is a worldwide growing awareness of the negative impacts of the increasing fossil fuel reliance and greenhouse gas (GHG) emissions from agriculture, in particular for intensive crop systems. We analyze the energy balances and greenhouse gas emissions from export-oriented avocado orchards in Mexico. Avocado is a very important export crop and one of the main drivers of land-use change in the country. We compared 12 avocado orchards under organic and conventional management during two production cycles (2010 and 2011) in a representative region of Central Mexico. Our analysis shows no significant differences in energy consumption and GHG emissions between organic and conventional systems with 55 and 56 GJ ha^{-1}, and 3.30 t CO_2 equiv. ha^{-1} and 3.57 t CO_2 equiv. ha^{-1}, respectively.

Organic systems show three times more use of renewable energy than their conventional counterparts. However both systems depend heavily on fossil fuel inputs, machinery and N-fertilizers (synthetic or organic). Also, there is a high heterogeneity in management practices and input application within both systems, which is reflected in a large variation of their energy-related parameters. Given that avocado production is rapidly expanding in Mexico, a move toward organic production without systematically changing toward less fossil fuel dependent agricultural practices would not be sufficient to ensure a sustainable production.

1. Introduction

Conventional agricultural systems face global challenges derived from the increasing degradation of natural resources (soil and water pollution by agrochemicals), intensive use of energy, and associated greenhouse gas (GHG) emissions. On a global basis, the food sector–which includes production, transportation, processing and preparation of food-accounts for 30% and 20% of the global energy use and global GHG emissions, respectively (FAO, 2012, 2011); agricultural production, including indirect emissions associated with land-cover change, contributes 80–86% of total food systems emission, with large variations across geographic regions (Vermeulen et al., 2012).

The development of agricultural systems with low fossil fuels inputs and low GHG emissions per unit of food produced could help reduce carbon dioxide and other GHG emissions at the global level (Dalgaard et al., 2001). Agriculture emits greenhouse gases through rice cultivation, livestock enteric fermentation and manure management (Burney et al., 2010), but also through the production and application of fertilizers and pesticides, operation of farm machinery and on-farm energy use (West and Marland, 2002).

The development of organic farming has been identified as an alternative to save fossil energy (Gomiero et al., 2008, 2011; Pimentel et al., 2005). Organic agriculture refers to a farming system that bans the use of agrochemicals, such as synthetic and pesticides, and is regulated by international and national bodies, which certify organic products from production to handling and processing

* Corresponding author. Tel.: +52 4433223876.
E-mail address: martaastier@gmail.com (M. Astier).

http://dx.doi.org/10.1016/j.ecolind.2014.03.002

Table 1
Main avocado producing countries, absolute and percentage avocado production in 2009, and mean annual growth rate of production volume between 1996 and 2009.

Country	2009 (Mg × 1000)	2009 (%)	MAGR[a] (%)
Mexico	1231	32.0	3.0
Chile	328	5.2	14.0
United States of America	269	6.4	3.4
Indonesia	258	6.3	4.6
Colombia	184	5.0	3.8
Brazil	139	4.3	4.3
Dominican Republic	184	4.8	4.8
Subtotal	2593	64.0	4.3
Others	1261	36.0	3.4
World	3854	100.0	3.9

Source: SE (2012).
[a] Mean annual growth rate between 1996 and 2009.

(Commission, 1999; IFOAM, 2009). Gomiero et al. (2011) showed that organic farms are more energy efficient due to use of less energy-intensive inputs, especially fertilizers and plant protection methods, than conventional farms. This is not so evident, however, when studying the fruit sector (Lynch et al., 2011; Gomiero et al., 2008).

Little is known about the carbon and energy footprint associated with avocado (*Persea americana*) production in Latin America. Avocado provides an interesting case study because it is an intensively managed crop that is expanding rapidly in several countries including Mexico (Table 1).

México is the largest producer, consumer and exporter of avocado in the world. As shown in Table 1, Mexico produced 1,231,000 Mg of avocado in 2009. This accounts for 32% of the global production. The United States (US), Indonesia and Chile are the next largest producers. Within Mexico, the state of Michoacán is the largest avocado producer with 950,000 Mg (86% of the total) (SE, 2012). In Michoacán alone, there are more than 153,000 ha under avocado, and the production area increases steadily – often at the expense of native forests – more than doubling in the last 6 years (Morales Manilla et al., 2012).

Avocado is mainly produced for the national market, but exports have been rapidly increasing at an average annual growth rate of 16.8% over the last eight years. By the year 2010, 833,000 Mg of avocado were produced for the national market, and other 398,000 Mg were exported (SE, 2012). Organic production has also been steadily increasing in Michoacán from 2850 ha in the year 2002, to more than 31,570 ha in 2009 (Gómez Cruz et al., 2011).

Understanding and comparing the energy balance and GHG emissions of conventional and organic avocado production has implications for the local and regional environment. Organic avocados, in particular, have been strongly promoted as a way to reduce the environmental footprint of production. However, despite their economic and environmental relevance, no studies have yet been conducted in Mexico to examine the energy and GHG implications of avocado orchards. Internationally, the few available studies were conducted in Spain and show inconsistent results, some organic systems showing higher or similar energy inputs when compared with conventional production (Alonso and Guzmán, 2010). Our study in a representative region of Michoacan State was therefore carried out to critically examine the energy and GHG balance of conventional and organic avocado orchards aimed at the export market.

2. Materials and methods

The study was conducted during 2010 and 2011 in the Cupatitzio Watershed, which is located within the main avocado producing region in the surroundings of Uruapan (19°25 N, 102°03 W) in the state of Michoacán in central México (Fig. 1). During these two years the mean annual precipitation, temperature and relative humidity in the study area were 888.1 mm (±280.4), 19.1 C° (±2.5), and 58% (±9.3), respectively (National Meteorological Service of México, 2011). The predominant soils in the region are humic Andosols (FAO/WRB soil group), sandy loams with low *P* availability and high Al content (Gutiérrez-Contreras, 2010).

Six organic and six conventional avocado orchards intended for export were selected randomly in four localities within the Cupatitzio Watershed. These orchards were selected using four criteria: (1) to be representative of their management system (organic or conventional); (2) to have 6 to 12 years since its establishment; (3) to be approximately 20 ha in size, and (4) the farmers had to be collaborative. All the orchards were planted with *P. americana* 'Hass' trees, the most important avocado cultivar in the region and in the State, and were irrigated in the dry season for approximately six months every year. Data were collected for two production cycles (2010 and 2011) through personal interviews and the farmer' working and input schedules. The main agricultural practices conducted in the organic and conventional avocado orchards during the study period are presented in Table 2. Data were subjected to analysis of variance (ANOVA) using a randomized complete block design combined over locations (Gil and Lara, 1990). Means were compared using Fisher's least significant difference (LSD) test.

The quantity of inputs and time devoted to each practice were calculated on a per hectare basis. These data were multiplied by their respective energy equivalents to determine the energy use per practice (Table 3). References from the international literature and direct field measurements were used to determine the energy equivalents for each input and output. A Mexican study was used to determine the energy equivalent of gasoline and diesel (Castillo-Hernández et al., 2012). Field measurements were conducted to determine the energy invested (labor and machinery) in the manufacturing of organic fertilizers (such as compost, and the foliar fertilizers BIOL and SUPERMAGRO) and organic pesticides (such as squash soap). The total energy used per system per hectare is calculated by summing the energy use of each input for all inputs (Table 4). Energy efficiency was calculated using the conventional energy ratio, as follows:

$$\text{energy ratio} = \frac{\text{energy output}\,(\text{MJ ha}^{-1})}{\text{energy input}\,(\text{MJ ha}^{-1})}$$

The greenhouse gas emissions (CO_2, CH_4 and N_2O) of avocado production were computed according to Michos et al. (2012) and Kavargiris et al. (2009). The emissions factors used were: for CO_2 emissions from fuel (gasoline and diesel) consumption, we used IPCC (2008); for N_2O emissions from nitrogen (synthetic and organic), Penman et al. (2000) and for the CO_2-equivalent factor we used the Global Warming Potential for 100 years estimated by Forster et al. (2007).

3. Results

The total average energy use at the farm level is 55 and 56 GJ ha^{-1} for organic and conventional orchards, respectively (Table 4). The total amount of direct energy is similar (27 and 22 GJ ha^{-1}) in organic and conventional systems, respectively (Table 5). Fuel use constitutes the largest energy input in both systems (47% of total energy use for organic and 39% for conventional systems). In avocado orchards fuel is used extensively for weed mowers, cultural practices, harvesting, fertilizing and pest control. Fertilizers, minerals, nutrients, biological agents, pesticides and adherents (synthetic or organic) are sprayed over the trees using water trucks. Tools, machinery and fertilizers were the largest indirect inputs for organic systems (17%, 17% and 16% of total,