Comparative study of the environmental impact of models of conventional agricultural and agro-ecological agriculture in the agricultural phase of tomato cultivation [version 1; referees: 1 approved with reservations]

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Abstract
Background: In this study, the water footprint and the carbon footprint were calculated during the activities of the agricultural phase of tomato cultivation, comparing agro-ecological production systems with conventional production systems.

Methods: We examined with six plots in total: 3 agro-ecological plots and 3 conventional plots in La Esperanza and Tabacundo, Pedro Moncayo canton, Ecuador. The water footprint was calculated according to Hoekstra’s method. For the greenhouse gas emissions calculation, due to the production of fertilisers, the activity data was multiplied by the emission factor. Phytosanitary emissions were calculated using the factor given by BioGrace.

Results: For the conventional system the most representative footprint is that of blue water with 44.19 litres of water/kg of tomatoes, followed by the green water footprint with 14.42 litres of water/kg of tomato whilst the lowest value is 0.96 litres of water/kg of tomatoes for the grey water footprint.

Conclusions: The results obtained show that an agro-ecological system is the most efficient in terms of consumption of resources. Its produce also have an added value for promoting sustainability, responsible consumption and a healthier diet. The generation of eco-labels can encourage the consumption of these by expanding markets for this production system.

Keywords
life cycle assessment, food systems, agriculture, environmental impacts
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Author roles: Taipe Velasco CM: Methodology, Visualization, Writing – Original Draft Preparation; Lizano Acevedo RX: Conceptualization, Investigation, Methodology, Supervision, Writing – Original Draft Preparation; Mátyás B: Formal Analysis, Methodology

Competing interests: No competing interests were disclosed.

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Introduction

Greenhouse gas emissions from agriculture continue to rise on a global scale, although not as fast as emissions from other human activities. Having better information at a national level on emissions from agriculture, livestock, fisheries and forestry can help countries identify opportunities to reduce them, whilst pursuing objectives of food security, resilience and rural development and gaining access to global financing for implementation. The agricultural sector is the sector that uses the most water, globally representing around 69% of all extraction, with household consumption at approximately 10% and industry at 21%. The water footprint of a product is the total amount of water used to produce the goods or the service we use. In this study we calculated the green, blue and grey water footprint. The green water footprint is the amount of water in the root zone of the soil and evaporated, transpired or incorporated by plants. The blue water footprint is the amount of water that comes from surface or groundwater and is evaporated, incorporated into a product or taken from one body of water (for example irrigated agriculture have a blue water footprint). The grey water footprint “is the amount of fresh water required to assimilate pollutants to meet specific water quality standards” (see Water Footprint Network website). The agro-ecological agriculture is farming that “centers on food production that makes the best use of nature’s goods and services while not damaging these resources” (see More and Better report on a viable future). It links ecology, culture, economics and society to create healthy environments, food production and communities in order to maintain the sustainable development (see Groundswell international page on agroecological farming). While the conventional agriculture also known as industrial agriculture, “refers to farming systems which include the use of synthetic chemical fertilizers, pesticides, herbicides and other continual inputs, genetically modified organisms, concentrated animal feeding operations, heavy irrigation, intensive tillage, or concentrated monoculture production. Thus conventional agriculture is typically highly resource and energy intensive, but also highly productive” see USDA factsheet on conventional farming. In this study, emissions and water requirements for tomato cultivation in conventional production systems and agro-ecological production systems were calculated in the La Esperanza and Tabacundo parishes, Pedro Moncayo canton.

Methods

The present study examines the carbon and water footprint of product during the activities of the agricultural phase of tomato cultivation (between 2nd June and 5th of September 2017) in La Esperanza and Tabacundo, Pedro Moncayo canton, Ecuador. The average temperature was 20 °C, the humidity was 66% and the total precipitation was 320.8 mm in the examined period (https://en.climate-data.org/location/719640/). Three agro-ecologically managed plots (GPS decimal degrees: Plot 1: Latitude: -0.811193, Longitude: -78.6955; Plot 2: Latitude: -0.809214, Longitude: -78.6362, Plot 3: Latitude: -0.811429, Longitude: -78.6318) and three conventionally managed plots (GPS decimal degrees: Plot 4: Latitude: -0.809021, Longitude: -78.6273; Plot 5: Latitude: -0.805316, Longitude: -78.6114; Plot 6: Latitude: -0.805312, Longitude: -78.6114) were analyzed in this study. For information about the size of the experimental areas and the applied fertilizers please see Dataset 1. The water footprint was calculated as established by Hoekstra et al. (2011). For agro-ecological production systems, the green water footprint and blue water footprint were calculated. They lack a grey water footprint since they do not incorporate synthetic fertilisers, whereas for the conventional system the green water footprint, blue water footprint and the grey water footprint were calculated. Agro-ecological systems:

Water footprint = Green Water Footprint + Blue Water Footprint (m³/ton)

Conventional case:

Water Footprint = Green Water Footprint + Blue Water Footprint + Grey Water Footprint (m³/ton) (Hoekstra et al., 2011)

For the Carbon Footprint calculation, the equation given by greenhouse gases (GHG) Protocol, World Resources Institute and wbcsd (2011)'y' was used:

\[ kgCO_{2eq} = Activity\ Data \times Emission\ Factor \times GWP \]

For the (GHG) calculation in the conventional plots, due to the use of fuels, the equation given by the IPCC belonging to the all-terrain category was used. This equation allows one to obtain CO2 emissions according to the type of fuel- be it diesel or petrol- as applicable for each case.

\[ Emission = \sum_j Fuel_j \times EF_j \]

Source: IPCC (2006a)

where:

Emission: total emissions expressed in KgCO₂eq
Fuel: fuel consumption TJ
EF: Emission factor (KgCO₂eq TJ)

j: fuel type

For the greenhouse gas emissions calculation, due to the production of fertilisers, the activity data was multiplied by the emission factor. Phytosanitary emissions were calculated using the factor given by BioGrace. Regarding greenhouse gases, due to direct emissions of N₂O, the contributions of nitrogen in managed soils were taken into account and for the study the equation given by the IPCC was adapted so that for the case studies it was applied as follows.

\[ N_{2}O - N_{Contributions} = (FgN + FgR) \times EF_i \]
And for the agro-ecological systems:

\[ N_{2O} - N_{\text{Contributions}} = (F_{NN} + F_{CR}) \times EF_{1} \]

The calculation of indirect emissions of N\(_2\)O for managed soils was carried out by means of adapting equation 11.9 of the manual (IPCC, 2006c)7 to the case study, thus the applied equation was:

**Conventional systems:**

\[ N_{2O}(\text{ADT}) - N = (F_{SN} \times \text{Frac}_{GASF}) \times EF_{4} \]

**Agro-ecological systems:**

\[ N_{2O}(\text{ADT}) - N = (F_{ON} \times \text{Frac}_{GASM}) \times EF_{4} \]

For the calculation of greenhouse gas emissions due to the use of fertilisers, the results of direct and indirect emissions of N\(_2\)O were taken into account. Regarding the emissions from applying phytosanitary products, this section was considered only in the conventional plots since they apply pesticides for the prevention of pests, such as fungicides and insecticides. To perform the calculation, the amount employed in kg/hectare (ha) and the emission factor given by BioGrace\(^8\) were taken into account.

### Results

#### Water footprint

Figure 1 shows the water requirements for each plot. Regarding the conventional system, the highest values of green and blue water footprints corresponded to plot 5 with 34.42 and 87.54 litres of water/kg of tomatoes, respectively. For the agro-ecological systems, the plot with the highest green and blue water footprint was plot number 1 with 16.46 and 42.54 litres of water/kg of tomatoes, respectively. In relation to the grey water footprint, the highest value was found for plot 5 with 2.59 litres of water/kg of tomato.

In relation to the green water footprint, on average an agro-ecological system requires 9.07 litres of water/kg of tomatoes. For the blue water footprint, it requires 32.04 litres of water/kg of tomatoes (Figure 2). For the conventional system the most representative footprint is that of blue water with 44.19 litres of water/kg of tomatoes, followed by the green water footprint with 14.42 litres of water/kg of tomato whilst the lowest value is 0.96 litres of water/kg of tomatoes for the grey water footprint.

These results show that conventional cultivation consumes 18.45 litres more water for every 1 kg of tomatoes in the La Esperanza and Tabacundo parishes of the Pedro Moncayo canton (Figure 3).

#### Carbon footprint results

Table 1 shows that the highest generation of emissions was in plot 2 for the agro-ecological system and plot 4 for the conventional

![Figure 1. Results of water footprint per plot.](image-url)
Figure 2. Averages Water Footprint per component: conventional or agro-ecological system.

Figure 3. Total water footprint based on a conventional system or agro-ecological system.

Table 1. Carbon Footprint Results (GHG - green house gases).

<table>
<thead>
<tr>
<th></th>
<th>Agro-ecological system</th>
<th>Conventional system</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg CO(_2)/ha</td>
<td>Plot 1</td>
<td>Plot 2</td>
</tr>
<tr>
<td>Fuel (diesel or petrol)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>GHG fertilisers (production)</td>
<td>184.61</td>
<td>767.60</td>
</tr>
<tr>
<td>GHG fertilisers (use)</td>
<td>546.98</td>
<td>584.63</td>
</tr>
<tr>
<td>Phytosanitary control</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total kg CO(_2)/ha</td>
<td>731.59</td>
<td>1352.23</td>
</tr>
</tbody>
</table>
system. The average emissions for the agro-ecological system in the study area was 757.83kg of CO₂/ha whilst it was 830.96kg of CO₂/ha for the conventional system. In the agro-ecological system, the greatest generation of emissions is due to the use of biofertilisers with an average of 426.68kg CO₂/ha, whilst for the conventional system it is due to the use of fuel with a 552.32kg CO₂/ha on average.

As a whole, an agro-ecological system emits on average of 757.83kg CO₂/ha whilst a conventional system emits on average 830.96kg CO₂/ha. In the latter system, the greatest generation of emissions corresponded to the use of fuel, with an average of 552.32kg CO₂/ha whilst for the agro-ecological system the greatest generation of emissions corresponded to the use of biofertilisers with 426.68kg CO₂/ha.

The results obtained show that an agro-ecological system is the most efficient in terms of consumption of resources. Its produce also have an added value for promoting sustainability, responsible consumption and a healthier diet. The generation of eco-labels can encourage the consumption of these by expanding markets for this production system.

**Dataset 1. Experimental setup**

http://dx.doi.org/10.5256/f1000research.14334.d203750

Area of the lands, total crop production (Kg), fertilizer application rate on total crop production, concentration of NPK in each solid fertilizer, mount of NPK (Kg), Liquid fertilizer application rate on the total crop production, Concentration of NPK in each liquid fertilizer, Amount of NPK in liquid fertilizer (Kg), GPS coordinates.

**Dataset 2. Calculated water footprint for each plot**

http://dx.doi.org/10.5256/f1000research.14334.d203751

Green, blue and grey water footprint in l (water)/kg(tomato).

**Dataset 3. Calculated carbon footprint for each plots**

http://dx.doi.org/10.5256/f1000research.14334.d203752

Total GHG emission (kg CO₂ eq): Fuel (CO₂, N₂O), fertiliser production (N, K₂O, P₂O) fertiliser use, photosanitary.

**Discussion**

In the La Esperanza and Tabacundo parishes an agro-ecological system requires less water compared to a conventional system, which the latter consumes 18.45 litres more water to produce a kilogram of tomatoes. In terms of emissions, the agro-ecological system obviously generates less, since it does not include the use of fuels because all the activities are carried out manually.

In relation to the Water Footprint, we used the values provided by Villavicencio et al. as a referential Water Footprint for fresh tomatoes (grown in the Coquimbo Region in the Choapa basin in Chile). They found a total water footprint of 84.2l/kg for the central region whilst we found a total water footprint of 59.57l/kg of tomatoes in the conventional system and 41.11l/kg in the agro-ecological system. Our values reflect the characteristics of the study area.

**Data availability**

Dataset 1: Experimental setup. Area of the lands, total crop production (Kg), fertilizer application rate on total crop production, concentration of NPK in each solid fertilizer, mount of NPK (Kg), Liquid fertilizer application rate on the total crop production, Concentration of NPK in each liquid fertilizer, Amount of NPK in liquid fertilizer (Kg), GPS coordinates.

The present research was supported by Universidad Politécnica Salesiana and Secretaría de Educación Superior, Ciencia, Tecnología e Innovación (SENESCYT) [PIC-16-BENS-005].

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4. FAO. (s.f): Agua y cultivos uso agrícola del agua. Reference Source

Reference Source


Reference Source


Reference Source


Data Source


Data Source


Data Source
Open Peer Review

Current Referee Status: ?

Version 1

Referee Report 27 July 2018
doi:10.5256/f1000research.15597.r36277

Maria Fernanda Cárdenas
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In the abstract, the presented results refer only to the water footprint calculated for the conventional system. Without the missing information, it is not possible to follow your conclusions, presented in the abstract but not in the document.

The introduction of the manuscript does not provide the reader a context to understand the importance of this study. This is, for example, the relevance of agroecology, the current politics about it, or the significance of tomatoes in particular or agriculture in general for the region where the study was carried out. I believe the earlier would enhance the study.

The study sites and their location would be clearer presented in a table or in a figure. In a table would be interesting add, besides the coordinates, some information about the field characteristics, since I suspect it has a relationship with the results obtained. Particularly, it would be interesting if helps to explain the huge differences you found among plots.

Also, and related to the earlier, it would be necessary to justify why you decided to work with 3 plots in each assessed system. This is a big concern to me due to the differences presented in fig. 1... there is no explanation in the document and is it must be statistically supported.

Fig 2. and Fig. 3 are not relevant since they are not showing new information.

Finally, it is important to review the references. I.e, #9 says IPCCc, but it actually refers to Eggleston et al. Also, the letter c does not have sense if there is no a or b.

In general, English needs to be reviewed.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly
If applicable, is the statistical analysis and its interpretation appropriate?  
Partly

Are all the source data underlying the results available to ensure full reproducibility?  
Yes

Are the conclusions drawn adequately supported by the results?  
Partly

**Competing Interests:** No competing interests were disclosed.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.