RESEARCH ARTICLE

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: awaiting peer review]

Carina Maribel Taipe Velasco¹, Ronnie Xavier Lizano Acevedo ², Bence Mátyás ²,³

¹Ingeniería Ambiental, Universidad Politécnica Salesiana, Quito, 170702, Ecuador
²Grupo de Investigación en Ciencias Ambientales, Universidad Politécnica Salesiana, Quito, 170702, Ecuador
³Grupo de Investigación Mentoría y Gestión del Cambio, Universidad Politécnica Salesiana, Cuenca, 010102, Ecuador

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
Corresponding author: Ronnie Xavier Lizano Acevedo (rlizano@ups.edu.ec)

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

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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\cite{ghg}, live-stock, 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\cite{agbio}. 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\%\cite{wsis}. 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 food 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 \(^\circ\) 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)\cite{hoekstra}. 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 (m\(^3\)/ton)**

Conventional case:

**Water Footprint = Green Water Footprint + Blue Water Footprint + Grey Water Footprint(m\(^3\)/ton) (Hoekstra etal., 2011)**

For the Carbon Footprint calculation, the equation given by greenhouse gases (GHG) Protocol, World Resources Institute and wbcsd (2011)\cite{wcs} was used:

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

For the (GHG) calculation in the conventional plots, due to the use of fuels, the equation given by the IPCC\cite{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.

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

Source: IPCC (2006a)

where:

Emission: total emissions expressed in KgCO\(_{2eq}\)

Fuel: fuel consumption TJ

EF: Emission factor (KgCO\(_{2eq}\) 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\cite{wrc}. Regarding greenhouse gases, due to direct emissions of N\(_2\)O, the contributions of nitrogen in managed soils were taken into account and for the study the equation given by the IPCC\cite{ipcc} was adapted so that for the case studies it was applied as follows.

\[
N_2O = N_{Contributions} = (F_e N + F_e R) \times EF_j
\]

For the conventional systems, the equation was reduced to:
And for the agro-ecological systems:

$$N_{2}O - N_{\text{contribution}} = (F_{o}N + F_{c}R) \times EF_{1}$$

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:

$$N_{2}O_{(\text{ADT})} - N = (F_{SN} \times Frac_{GASF}) \times EF_{4}$$

Agro-ecological systems:

$$N_{2}O_{(\text{ADT})} - N = (F_{ON} \times Frac_{GASM}) \times EF_{4}$$

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 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>
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<tbody>
<tr>
<td>kg CO₂/ha</td>
<td></td>
<td></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 CO₂/ha</td>
<td>731.59</td>
<td>1352.23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Plot 1</th>
<th>Plot 2</th>
<th>Plot 3</th>
<th>Plot 4</th>
<th>Plot 5</th>
<th>Plot 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel (diesel or petrol)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>616.57</td>
<td>274.45</td>
<td>765.93</td>
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<tr>
<td>GHG fertilisers (production)</td>
<td>184.61</td>
<td>767.60</td>
<td>41.25</td>
<td>278.62</td>
<td>278.62</td>
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<td>GHG fertilisers (use)</td>
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<td>584.63</td>
<td>148.42</td>
<td>47.52</td>
<td>129.21</td>
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<td>Phytosanitary control</td>
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<td>0</td>
<td>0</td>
<td>2.92</td>
<td>13.27</td>
<td>38.13</td>
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<tr>
<td>Total kg CO₂/ha</td>
<td>731.59</td>
<td>1352.23</td>
<td>189.67</td>
<td>945.63</td>
<td>695.55</td>
<td>851.69</td>
</tr>
</tbody>
</table>
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.

In relation to the Water Footprint, we used the values provided 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 tomatoes (grown in the Coquimbo Region in the Choapa basin in Chile). The results obtained show that an agro-ecological system is the most efficient in terms of consumption of resources. Its produce can encourage the consumption of these by expanding markets for this production system.

### Discussion

In the La Esperanza and Tabacundo parishes an 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 Villaviccencio 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.

As a whole, an agro-ecological system emits on average of 757.83kg CO₂eq/ha whilst a conventional system emits on average 830.96kg CO₂eq/ha. In the latter system, the greatest generation of emissions corresponded to the use of fuel, with an average of 552.32kg CO₂eq/ha whilst for the agro-ecological system the greatest generation of emissions corresponded to the use of biofertilisers with 426.68kg CO₂eq/ha.

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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### References

3. Emisiones de gases de efecto invernadero de la agricultura, silvicultura y otros usos de la tierra America Latina y el Caribe. FAO. 2014. Reference Source

**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.

Dataset 2: Calculated water footprint for each plot. Green, blue and grey water footprint in l (water)/kg(tomato).

Dataset 3: Calculated carbon footprint for each plots. Total GHG emission (kg CO₂eq): Fuel (CO₂, N₂O), fertiliser production (N, K₂O, P₂O) fertiliser use, photosanitary.

Reference Source

Reference Source

Reference Source


Data Source

Data Source

Data Source
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