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# Energy contributions and greenhouse gas emissions in pepper (*Capsicum annuum* L.) cultivation with plastic mulch

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## ABSTRACT

The objective of this work was to determine the use and efficiency of energy and to quantify the greenhouse gas (GHG) emissions, per hectare, for the cultivation of pepper, *Capsicum anuum* L., hybrid MIRELLA F1, using plastic mulch in the open-field. The assays were performed in a farm of Puerto La Boca (1° 20' 51" S and 80° 43' 51" W), the precinct of the Puerto Cayo parish of Jipijapa Municipality, Manabí province, Ecuador. The data was collected through field research, between March and September 2021, under observation and timing techniques. There was evidence of energy consumption and production (in the form of pepper berries) of 18,442.29 and 27,702.74 MJ $ha^{-1}$, respectively, and a total GHG emission of 3,058.90 kg $CO_2$-eq $ha^{-1}$. The energy efficiency was determined at 1.50, the energy productivity 1.88 kg $MJ^{-1}$, the specific energy 0.53 MJ $kg^{-1}$, and the net energy 8,858.46 MJ $ha^{-1}$. The quotas of direct and indirect energies were calculated at 9,513.15 and 8,929.15 MJ $ha^{-1}$, respectively, and the proportion of renewable and non-renewable energies at 12,994.03 and 5,448.27 MJ $ha^{-1}$, respectively. The GHG index per kg of MIRELLA F1 pepper yield was 0.088.

**Keywords:** energy efficiency; GHG emission index; agricultural mulch; open-field production system.

## INTRODUCTION

The efficient use of energy provides competitive advantages among nations (Türkoğlu & Kardoğan, 2018) and could guarantee sustainable production in environmental and economic terms in rural and business agriculture (Yildizhan, 2018; Taleghani *et al.,* 2020).

Agricultural actions are responsible for approximately 20% of greenhouse gas (GHG) emissions globally (Ozbek *et al.,* 2021). In Latin America, GHG emissions are continuously increasing, which reinforces urgent climate action by governments, at the national and regional levels, and by non-state actors (Comisión Europea, 2019).

In 2021, Ecuador's energy consumption was around 93.5 million BOE (barrels of oil equivalent). The agricultural, fishing, and mining component required 1,121 thousand BOE. GHG emissions, made up of 99.33% $CO_2$, 0.22% $N_2O$ and 0.45% $CH_4$, generated by this sector were 447 thousand t $CO_2$ eq (IIGE, 2022). However, within the framework of the Paris Agreement, Ecuador, had projected to reduce emissions by 9% in the energy, industry, waste, and agricultural sectors (Toulkeridis *et al.,* 2020).

The pepper (*Capsicum annuum*, L. 1753) is native to Tropical America and is the second vegetable consumed worldwide (Hulse-Kemp *et al.,* 2019). Ecuador allocates 2,232 ha for its cultivation, with approximate yields of 8,101 t (FAO, 2019). Pepper cultivars are made in the open-field and greenhouse production systems, mainly located in

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the provinces Guayas, Santa Elena, Manabí in the Coastal region, and Chimborazo, Loja, and Imbabura in the Sierra - high altitude region (Chuquitarco *et al.,* 2021).

In the province of Manabí, the Jipijapa Municipality has 90,129 ha for agricultural activities (INEC 2021). In the Puerto Cayo parish, 47 Agricultural Production Units (UPA) cultivate peppers in the open-field and in an artisanal way, like 40 families in the Puerto La Boca area that sustain incomes with short-cycle agriculture (GADPRPC, 2022).

The area of intensive farming systems (mulches, tunnels, and plastic greenhouses) has been expanding in recent years (Khoshnevisan et al., 2014). Polyethylene mulch is widely used in intensive agricultural production systems. It provides advantages for crops both from the agronomic and phytosanitary points of view (Marín-Guirao et al., 2022). In this sense, in the farm under study, the technique of agricultural mulch, of the polyethylene type, was incorporated in 2020 in an open-field productive system, and the use of genetic materials adapted to the area, such as the MIRELA F1 hybrid pepper, relieving this way the direct sowing.

International studies, like those of Ozbek *et al.* (2021) and Baran *et al.* (2020), determined the energy efficiency and GHG emissions of onion and almond crops, respectively; Houshyar *et al.* (2015) studied the energy consumption in tomato production and Eren *et al.* (2019a) worked on GHG emissions in various crops in Turkey, in the open-field production system. In Ecuador, no related publications were found in these fields. In consequence, the objective of this work was to determine the use and efficiency of energy and quantify emissions of greenhouse gases (GHG), per hectare, in the cultivation of the MIRELLA F1 hybrid pepper, with the use of plastic mulch in an open-field production system, on a farm in the Puerto La Boca compound of the Puerto Cayo parish of the Jipijapa Municipality, Manabí province, Ecuador.

## MATERIALS AND METHODS

### *Edaphoclimatic characterization of Puerto Cayo - Puerto la Boca*

The Puerto Cayo rural parish, a recreational area that incorporates exuberant vegetation, registers an approximate territorial dimension of 23,600 ha. It presents maximum annual rainfall of 730 mm, an average temperature of 25°C, and a relative humidity of 81%. The currents, cold from Humboldt and warm from El Niño, condition the environment by specifying two express seasons, summer or dry, from June to December, and the rainy season, from January to May, respectively (GADPRPC, 2022).

Puerto La Boca is one of the 15 enclosures that make up Puerto Cayo (GADPRPC, 2022), despite being located close to the sea, it has fresh water for vital subsistence and diverse agricultural production such as fruits, vegetables, legumes, cereals, vegetables, and tubers (SENPLADES, 2015).

### *Experimental site*

The time frame of the study was between March and September 2021 in Puerto La Boca. The farm was selected for being a pioneer in including the agricultural mulch technique in the open-field production system. The property was located between geographic coordinates 1° 20’ 51” S and 80° 43’ 51” W and had an average altitude of 31.16 meters above sea level (Mobile Topographer, 2022).

The farm, with three hectares in extension, was located to the west of Puerto Cayo where there is a predominance of inceptisols that cover 52% of its territory (GADPRPC, 2022), In addition to the pepper, other crops grown, according to the season, are caigua (known locally as achojchas - *Cyclanthera pedate* – Cucurbiatceae), tomato, red onion, cucumber, coriander, cabbage, pumpkin, watermelon, melon, beans, and broad beans.

### *Labors for the production of the pepper crop*

The tillage of the land was carried out with the Baldán CRSG 24-disc (24 in) eccentric pull harrow with a structural weight of 1,950 kg, working width of 2,700 mm (Federal, 2005), a useful life of 5,000 h (Frank, 1998), driven by the coupling system, and coupled to the hydraulic system of tractor Valtra Valmet HiTech 1850 of 92 kW with a construction mass of 5,090 kg (AgriDatos, 2021) and economic life of 12,000 h (Frank, 1998). The average working depth of the mechanized set was 0.228 m.

For the construction of ridges (0.30 x 1 m), the “lampa” (shovel) manual tool was used; later the drip irrigation tapes (a line) were laid and covered with plastic mulch.

For the transplantation of the MIRELLA F1 hybrid pepper, the hand tool was used as a skewer and 24,000 units of seedling $ha^{-1}$ of between 20-22 days after germination with an average weight of 0.0292 kg $seedling^{-1}$, determined with the CAMRY ACS-30-JC21 digital scale. The MIRELLA

F1 genetic material and plastic mulch were supplied by a commercial agricultural input company.

Pest and disease control was carried out with a 20 L backpack-type pump. The agricultural insecticides Randiant, Match, and Movento Smart were used, alternating their application. On the other hand, weeding was also executed manually.

For irrigation and fertilization, an electric pump (2 hp) was used, which extracted water from a deep well built 80 m from the farm. Water to the pepper crop was supplied by connecting a polyvinyl chloride (PVC) pipe to the pump and drip irrigation tapes, depending on weather conditions. In addition, by this means of irrigation, the work of dosed fertilization (fertigation) was carried out with the products Yara Tera Kristalon Yellow (NPK 13 - 40 -13%) and Yara Mila Complex (NPK 12 -11- 18%).

Harvesting was done manually and sequentially due to the productive cycle of this hybrid. The weight of the pepper berries reached 0.165 kg on average. Finally, the total yield of the product amounted to 34,628.43 kg ha$^{-1}$.

For the commercialization of the product, the buyers went to the farm to stock up and take it to other locations for sale and final distribution.

### *Methods*

Through field research, under direct observation and timing techniques, supported by formats designed for recording agricultural work daily, the number of inputs needed was known (machines, human labor, diesel, biocides, fertilizers, electricity, water for irrigation, and seeds - seedlings), product yield (output), and intensity in the execution of agricultural activities of the MIRELLA F1 hybrid pepper crop.

The documentary research allowed obtaining energy conversion factors and GHG emissions for inputs and outputs in the production of this solanaceous; in addition, the methodologies necessary to achieve the proposed objectives.

### *Efficiency and use of energy*

To obtain the total energy input of the inputs and output, by yield in the form of pepper berries, the quantities of inputs used (machines, human labor, diesel, biocides, fertilizers, electricity, water for irrigation, seeds - seedlings) and output (pepper production, kg), were multiplied by conversion factors to correspondence (Canakci & Akinci, 2006; Pishgar-Komleh *et al.,* 2012). The energy equivalents are shown in Table 1.

**Table 1:** Energy conversion factors associated with inputs and outputs in pepper cultivation

| Inputs | Unit | Energy equivalent (MJ unit$^{-1}$) | Source |
|---|---|---|---|
| **A. Imputs** | | | |
| 1. Human labor | | | |
| (a) Man | h | 1.96 | (Mandal *et al.,* 2002) |
| (b) Woman | h | 1.57 | (Mandal *et al.,* 2002) |
| 2. Machinery | | | |
| (a) Tractor | kg | 138 | (Kitani, 1999) |
| (b) Harrow | kg | 149 | (Kitani, 1999) |
| 3. Fuel | | | |
| (a) Diesel | L | 47.80 | (Kitani, 1999) |
| 4. Biocides | | | |
| (a) Insecticides | kg | 295 | (Kitani, 1999) |
| 5. Fertilizers | | | |
| (a) Nitrogen (N) | kg | 78.10 | (Kitani, 1999) |
| (b) Phosphorus ($P_2O_5$) | kg | 17.40 | (Kitani, 1999) |
| (c) Potassium ($K_2O$) | kg | 13.70 | (Kitani, 1999) |
| 6. Electricity | kW h | 12 | (Kitani, 1999) |
| 7. Irrigation water | m$^3$ | 1.02 | (Kitani, 1999) |
| 8. Seeds (seedlings) | kg | 10 | (Hedau *et al*., 2014) |
| **B. Outputs** | | | |
| 1. Pepper | kg | 0.8 | (Hedau *et al*., 2014) |

The energy of the machines was determined with equation (1), according to Canakci & Akinci (2006).

$$Mpe = (G \text{ x } Mp) / (T \text{ x } W) \quad (1)$$

where $M_{pe}$, is the energy of machines (MJ $ha^{-1}$); $G$, the weight of tractor and machine (kg); $M_p$, the energetic equivalent of production of tractor and machine (MJ $kg^{-1}$); $T$, the economic life of tractor and machine (h); and $W$, the effective field capacity (ha $h^{-1}$).

The effective field capacity (0.75 ha $h^{-1}$) of the Valtra Valmet HiTech agricultural tractor and Baldán CRSG harrow, was obtained from the relationship between the worked area of 1 ha and the total time to carry it out, 1.33 h.

The equivalent energy of production of the tractor and agricultural implement "Mp" (equation 1), is made up of the amount of energy, in the materials, in the manufacturing process, the transport to the consumer, and the energy sequestered by repairs (Kitani, 1999).

The specific fuel expenditure of the agricultural complex, per unit of work (L $ha^{-1}$), was established through measurements at the beginning and end of the day occupied for this purpose (Quimis-Guerrido & Shkiliova, 2019).

Through the quantification of input and output energies, the energy indices were determined. These indices are a tool that allows systems to be compared and their components to be studied (Naderi *et al.,* 2019). They include energy use efficiency, energy productivity, specific energy, and net energy, which were calculated by equations 2, 3, 4, and 5, respectively (Mohammadi-Barsari *et al.,* 2016; Naderi *et al.,* 2019).

$$\text{Efficiency of energy use} = \text{Output energy (MJ ha}^{-1}) / \text{Input energy (MJ ha}^{-1}) \quad (2)$$

$$\text{Energy productivity} = \text{Product Yield (kg ha}^{-1}) / \text{Input energy (MJ ha}^{-1}) \quad (3)$$

$$\text{Specific energy} = \text{Input energy (MJ ha}^{-1}) / \text{Product yield (kg ha}^{-1}) \quad (4)$$

$$\text{Net energy} = \text{Output energy (MJ ha}^{-1}) - \text{Input energy (MJ ha}^{-1}) \quad (5)$$

Energy needs, in agricultural systems, can be divided into direct and indirect or renewable and non-renewable forms (Mohammadi & Omid, 2010).

Direct energies included human labor, diesel, electricity, and water for irrigation, while indirect energies included energy incorporated into the machinery, fertilizers, biocides, and seeds-seedlings. On the other hand, non-renewable energies, were electricity, machinery, fertilizers, biocides, and diesel fuel; while renewables were human labor, water for irrigation, and seeds - seedlings (Heidari & Omid, 2011). In this study, solar energy was not considered.

### *Emissions of GHG – Carbon footprint.*

The amounts of GHG emissions (kg $CO_2$-eq $ha^{-1}$) of inputs (machinery, human labor, fertilizers, biocides, diesel, seeds-seedlings, irrigation water, and electricity) used for pepper production, per hectare, were calculated with equation (7) (Hughes *et al.,* 2011).

$$GHG_{hai} = \sum_i R(i) \, x \, EF(i) \quad (7)$$

where $R(i)$ is the application rate of input i (unit $ha^{-1}$) and EF (i) is the GHG emission coefficient of input i (kg $CO_2$-eq. $unit^{-1}$).

The index to evaluate the amount of kg $CO_2$-eq emitted per kg of yield was also calculated with equation (8) (Khoshnevisan *et al.,* 2014; Houshyar *et al.,* 2015).

$$I_{GEI} = \frac{GHG_{ha}}{Y} \quad (8)$$

where $I_{GEI}$ is the GHG emission coefficient and $Y$ is the yield in kg $ha^{-1}$ of pepper crop.

Table 2 illustrates the GHG emission coefficients of inputs and production.

Data collection and recording, as well as basic arithmetic operations, were worked on Excel spreadsheets.

## RESULTS

Agricultural activities were developed such as: tilling the land which occupied 1- day laborer and 1.33 h (March/10). The construction of ridges along with the laying of irriga-

**Table 2:** GHG emission coefficients associated with inputs and outputs in pepper cultivation

| Inputs | Unit | GHG emission Coefficient (kg $CO_2$-eq unit$^{-1}$) | Source |
|---|---|---|---|
| 1. Human labor | h | 0.70 | (Nguyen *et al.,* 2007) |
| 2. Machinery | MJ | 0.07 | (Dyer & Desjardins, 2006) |
| 3. Diesel | L | 2.76 | (Dyer & Desjardins, 2003) |
| 4. Biocides | | | |
| (a) Insecticides | kg | 3.90 | (Lal, 2004) |
| 5. Fertilizers | | | |
| (a) Nitrogen (N) | kg | 1.30 | (Lal, 2004) |
| (b) Phosphorus ($P_2O_5$) | kg | 0.20 | (Lal, 2004) |
| (c) Potassium ($K_2O$) | kg | 0.20 | (Lal, 2004) |
| 6. Electricity (Ecuador) | kWh | 0.19 | (CTFE, 2020) |
| 7. Irrigation water | $m^3$ | 0.17 | (Lal, 2004) |
| 8. Seeds (seedlings) | kg | 1.99 | (Clark *et al.,* 2016) |

tion tapes and plastic covers required 32-day laborers and 256 hours (March/28). Irrigation and fertigation used 44-day laborers and 88 h (2/April-August/31) with a frequency of 3.3 and 13.6 days, respectively. For transplantation, 6-day laborers and 48 h were employed (April/5). Weeding employed 15 laborers and 120 h (April 30-June 27) every 28 days. Pest control required 42 laborers and 336 h (12/April-August/30) every 7.1 days. In the harvest, there were 50-day laborers and 400 h (4/July-September/5) with a sequence of every 14 days.

The necessary number of workers and total hours employed, during the pepper production cycle, were 190-day laborers and 1,249.33 h, respectively. The working hours were distributed in 1,033.33 and 256 h for men and women, respectively, in double shifts of 4 h, totaling 8 h daily, except for irrigation and fertigation work, which required only 2-h shifts to be carried out.

### *Determination of efficiency and use of energy in pepper cultivation*

The inputs with the greatest contribution to energy consumption were seeds-seedlings, followed by water for irrigation and human work (Table 3). On the contrary, the inputs, use of machinery, fertilizers, biocides, diesel, and electricity presented a lower amount, in the structural composition of the total energy consumption, which was lower than the amount of total output energy generated by the yield of the pepper (in the form of berries) MIRELA F1 hybrid.

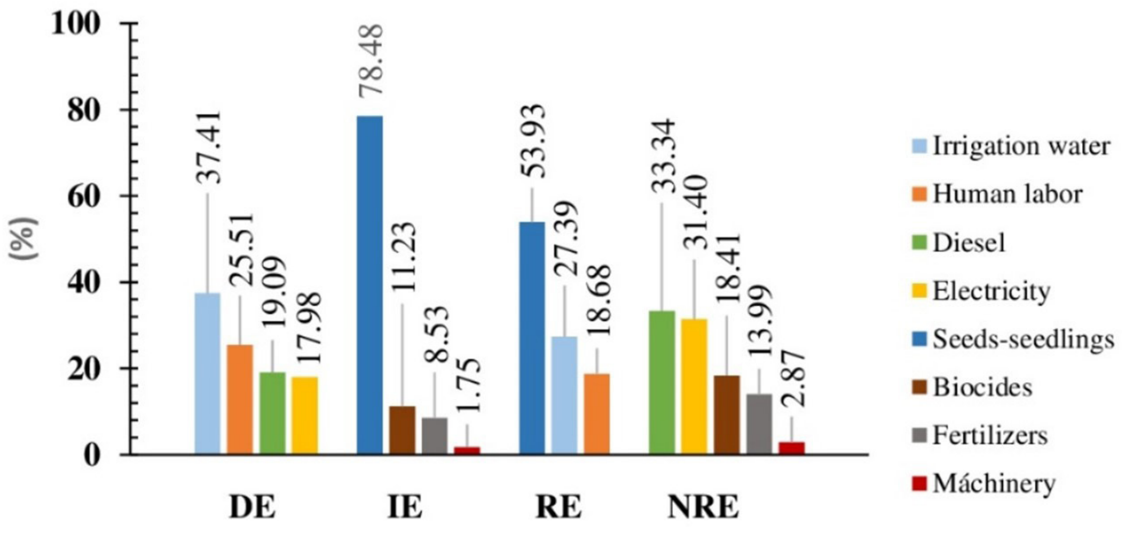
### *Determination of energy indices and classification of inputs*

The ratio of energy inputs to product yield reached 1.50. Energy productivity was 1.88 kg MJ$^{-1}$. The specific energy was reported at 0.53 MJ kg$^{-1}$. The energy gain per production unit was 9,260.45 MJ ha$^{-1}$. Figure 1 shows the percentage distribution of energy inputs within the energy classification structure associated with pepper cultivation.

The share of direct energies (human labor, diesel fuel, electricity, and water for irrigation) presented 9,513.15 MJ ha$^{-1}$ (51.58%), and the water inputs for irrigation and human work constituted 37.41 and 25.51%, respectively. Similarly, the share of indirect energy (machinery, biocides, fertilizers, and seeds-seedlings) recorded 8,929.15 MJ ha$^{-1}$ (48.42%). The share of renewable energies (human labor, water for irrigation, and seeds-seedlings) amounted to 12,994.03 MJ ha$^{-1}$ (70.46%), with the input seeds-seedlings being the largest contributor to the shares of indirect and renewable energies with 78.48 and 53.93%, respectively. The share of non-renewable energy (machinery, diesel, biocides, fertilizers, and electricity), which registered 5,448.27 (29.54%), was dependent on diesel and electricity supplies, which contributed 33.34 and 31.40%, respectively.

**Table 3:** Inputs and outputs of energy in pepper cultivation

| Inputs | Unit | Energy equivalent (MJ unit$^{-1}$) | Input used (unit ha$^{-1}$) | Energy value (MJ ha$^{-1}$) | (%) |
|---|---|---|---|---|---|
| **A. Inputs** | | | | | |
| 1. Human labor | | | | | |
| (b) Men | h | 1.96 | 1,033.33 | 2,427.25 | 13.16 |
| (b) Harrow | h | 1.57 | 256 | | |
| 2. Machinery | | | | | |
| (a) Tractor | kg | 138 | 0.57 | 156.14 | 0.85 |
| (b) Harrow | kg | 149 | 0.52 | | |
| 3. Diesel | L | 47.80 | 38 | 1,816.40 | 9.85 |
| 4. Biocides | | | | | |
| (a) Insecticides | kg | 295 | 3.40 | 1,003 | 5.44 |
| 5. Fertilizers | | | | | |
| (a) Nitrogen (N) | kg | 78.10 | 7.76 | 606,06 | 3.29 |
| (b) Phosphorus ($P_2O_5$) | kg | 17.40 | 5.12 | 89,09 | 0.48 |
| (c) Potassium ($K_2O$) | kg | 13.70 | 4.88 | 66,86 | 0.36 |
| 6. Electricity | kW h | 12 | 142.56 | 1,710.72 | 9.28 |
| 7. Irrigation water | m$^3$ | 1.02 | 3,489.00 | 3,558.78 | 19.30 |
| 8. Seeds (seedlings) | kg | 10 | 700.80 | 7,008 | 38.00 |
| Total energy input | | | | 18,442.29 | 100 |
| **B. Outputs** | | | | | |
| 1. Pepper | kg | 0.80 | 34,628.43 | 27,702.74 | 100 |




DE-Direct Energies; IE-Indirect energies; RE-Renewable energies; NRE-Non-renewable energies.

**Figure 1**: Percentage structure of energy inputs.

### *Determination of GHG emissions - carbon footprint in pepper production*

GHG emissions in pepper cultivation amounted to 3,058.90 kg $CO_2$-eq ha$^{-1}$. A higher proportion of $CO_2$ was emitted by the use of the input seeds-seedlings 1,394.59 kg ha$^{-1}$ (45.59%). They were followed by emissions derived from human work and irrigation water of 902.53 and 593.13 kg ha$^{-1}$, with a proportion of 29.51 and 19.39%, respectively. Table 4 illustrates records of partial and total emissions derived from the crop.

Other energy inputs, use of machinery, fertilizers, biocides, and electricity emitted $CO_2$ in a proportion of less than 1%. Finally, the relationship between GHG emissions and the yield of the MIRELLA F1 hybrid pepper was 0.088.

## DISCUSSION

Analysis of the energy system is essential to take advantage of limited resources and improve production processes in agriculture (Naderi *et al.,* 2019). The total input energy equivalent amounted to 18,442.29 MJ ha$^{-1}$ in the pepper crop evaluated in this work. Among the main contributing energy inputs in the cultivation of the MIRELA F1 hybrid pepper were seedlings 38%, followed by irrigation water 19.30%, and human labor 13.16%. In this sense, the number of seeds-seedlings is a function of the sowing population, which also influences the water requirement together with edaphoclimatic factors of the production site and the type of crop developed. Although human labor is among the contributing inputs, the incorporation of the agricultural mulch technique (plastic mulch) decreased the use of biocides, the workforce for their application, and for weeding.

Within the same topic, crop rotation is an important factor for soil conservation. Evidently, the MIRELLA F1 hybrid genetic material showed satisfactory edaphoclimatic adaptability. The adequate agronomic practices allowed it to extend the production cycle, characteristic of this hybrid, making it possible to collect sequential crops, every 14 days, between July and September. On the other hand, fertilization (fertigation) was controlled and effective. Likewise, the use of diesel fuel was limited by the scarce mechanization of agricultural operations on the farm and specifically in this crop.

The energy efficiency of 1.50 meant that, by consuming one MJ of input energy, 1.50 were produced. In this sense, Ozbek *et al.* (2021), in onion cultivation with a predominance of fertilizers, 60.43% reported an energy ratio of 2.21. Baran *et al.* (2020) in the organic production of almonds, whose contributing inputs to energy consumption were diesel and use of machinery 37.21 and 27.56%, respectively, obtained an energy ratio of 2.02. For their part, Houshyar *et al.* (2015), in tomato cultivation reported an energy ratio of 1.16, the most contributing inputs were fertilizers (30%), farm manure (28%), and irrigation water (20%).

**Table 4:** Carbon footprint in open-field pepper production

| **Inputs** | **Unit** | **Coefficient GHG (kg $CO_2$-eq unit$^{-1}$)** | **Inputs (unit ha$^{-1}$)** | **Emissions GHG (kg $CO_2$-eq ha$^{-1}$)** | **%** |
|---|---|---|---|---|---|
| 1. Machinery | MJ | 0.07 | 156.14 | 11.09 | 0.36 |
| 2. Human labor | h | 0.70 | 1,289.33 | 902.53 | 29.51 |
| 3. Diesel | L | 2.76 | 38 | 104.88 | 3.43 |
| 4. Biocides | | | | | |
| (a) Insecticides | kg | 3.90 | 3.40 | 13.26 | 0.43 |
| 5. Fertilizers | | | | | |
| (a) Nitrogen (N) | kg | 1.30 | 7.76 | 10.09 | 0.33 |
| (b) Phosphorus ($P_2O_5$) | kg | 0.20 | 5.12 | 1.02 | 0.03 |
| (c) Potassium ($K_20$) | kg | 0.20 | 4.88 | 0.98 | 0.03 |
| 6. Electricity (Ecuador) | kWh | 0.19 | 142.56 | 27.33 | 0.89 |
| 7. Irrigation water | m$^3$ | 0.17 | 3,489.00 | 593.13 | 19.39 |
| 8. Seeds (seedlings) | kg | 1.99 | 700.80 | 1,394.59 | 45.59 |
| **Total emission GHG** | | | | 3,058.90 | 100 |

The energy productivity of 1.88 kg $MJ^{-1}$ indicates that, per input MJ, 1.88 kg of product are produced. This value exceeds that presented by Ozbek *et al.* (2021) and Allali *et al.* (2016) in onion cultivation of 1.38 and 0.54 kg $MJ^{-1}$, respectively, by Houshyar *et al.* (2015) of 1.45 kg $MJ^{-1}$ in tomato production and Ibrahim (2011) of 0.13; 0.25 and 0.12 kg $MJ^{-1}$ in sweet pepper, onion and tomato crops, respectively, indicating a higher yield of the MIRELLA F1 hybrid pepper with lower input energy consumption.

The specific energy registered in the pepper crop was 0.53 MJ $kg^{-1}$ and the net energy was 9,260.45 MJ $ha^{-1}$. In this aspect, Ozbek *et al.* (2021) and Houshyar *et al.* (2015) working with onion and tomato productions, respectively, reported specific energies of 0.72 and 0.68 MJ $kg^{-1}$, which indicates that, compared to the MIRELLA F1 hybrid pepper, these authors required more energy per kg of yield, and net energy of 27,240.48 and 7,947.58 MJ $ha^{-1}$, respectively.

However, Mohammadi & Omid (2010) and Heidari *et al.* (2012) in vegetable production under protected conditions, presented negative values for net energy. Khoshnevisan *et al.* (2014) argue that the net energy can be modified, either by reducing the input energies or by increasing the yield using the same or lower input energies.

For the cultivation of the MIRELLA F1 hybrid pepper, the quotas of direct energy composed of human labor, diesel fuel, electricity, and irrigation water exceeded that of indirect energy (machinery, biocides, fertilizers, and seed-seedlings) by 3.16%. In addition, the proportions of renewable energies, derived from energy inputs, exceeded non-renewable energies by 40.92%. This is consistent with the importance of increasing the amount of renewable energy in energy consumption exposed by (Tan, 2018).

In contrast, Ozbek *et al.* (2021) reported that, in onion cultivation, there was a predominance of non-renewable energies in 61.26% compared to renewables, recommending reducing chemical fertilizers and using animal manure.

The total GHG emission generated by the MIRELLA F1 hybrid pepper crop was 3,058.90 kg $CO_2$-eq $ha^{-1.}$ The most important input was seedlings with 45.59%. The GHG index registered 0.088 kg $CO_2$-eq per kg of product yield.

Ozbek *et al.* (2021), in onion cultivation, calculated total emissions of 2,920.73 kg $CO_2$-eq $ha^{-1}$, the contributing inputs were human labor 42.13% and fertilizers 37.71%, and a GHG index of 0.094 kg $CO_2$-eq per kg of product yield. Baran *et al.* (2020) reported total GHG emissions in the organic almond production for 2,518.46 kg $CO_2$-eq $ha^{-1}$, human labor with 54.20% was presented as the predominant input, and GHG index of 1.80 kg $CO_2$- eq per kg of product yield. Eren *et al.* (2019a) reported emissions of 4,742.69 and 1,933.61 kg $CO_2$-eq $ha^{-1}$, in sugar beet and pea crops, seeds, and human labor were presented as inputs of greater proportion with 73.07 and 33.36 %, and GHG indices of 0.070 and 0.090 kg $CO_2$-eq per kg of product yield, respectively. Also, Eren, *et al.* (2019b), in tobacco cultivation, reported total GHG emissions of 6,604.68 kg $CO_2$-eq ha-1, the predominant input was human labor in a proportion of 67.62% and GHG index of 6.29 kg $CO_2$-eq per kg yield of tobacco leaves.

## CONCLUSIONS

The cultivation of pepper, hybrid MIRELLA F1, using plastic mulch under an open-field production system and under the conditions of a farm located in Puerto La Boca area, registered energy consumption and production (in the form of pepper berries) of 18,442.29 and 27,702.74 MJ $ha^{-1}$, respectively. Energy efficiency, energy productivity, specific energy, and net energy were calculated as 1.50; 1.88 kg $MJ^{-1}$; 0.53 MJ $kg^{-1}$, and 9,260.45 MJ $ha^{-1}$, respectively, and were considered satisfactory. The share of direct energy exceeds that of indirect energy by 3.16% and the proportion of renewable to non-renewable energy by 40.92%, which refers to an environmentally responsible agricultural operation. Total GHG emissions registered 3,058.90 kg $CO_2$-eq $ha^{-1}$ and the GHG index was 0.088 kg $CO_2$-eq per kg of product yield. Agriculture provides food sovereignty and economic income to the people; therefore, its sustainability is a right.

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