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ENERGY CONSUMED AND GREENHOUSE GASES EMITTED IN TWO CORN PRODUCTION SYSTEMS

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Abstract: The energy and GHG emission analysis of the corn cultivation system was carried out in mechanized direct sowing on the plane and manually on the slope. Energy values proposed in the literature were assigned to the manufacture and use of machinery and equipment, fuel consumption, use of fertilizers and pesticides, as well as to corn grain and manual activities, to obtain Energy Efficiency based on the output minus energy input, while Productive Energy Efficiency was obtained by relating the energy consumed between the performance obtained. Parallel to the above, the CO2eq emission for each production process was considered and strategies were proposed to reduce pollutant emissions and the form of carbon capture. The mechanized system consumed 2,493,743 and the manual system consumed 2,355,274 kcal/ha, with yields of 3,333 and 1,550 kg/ha, respectively. Both had an energy surplus, with the highest gain corresponding to the mechanized system with 9105.097 kcal/ha, due to its higher performance. The GHG emitted were 525.32 and 487.21 kg of CO2eq for mechanized and manual cultivation, respectively. Increasing input costs, reducing tillage, the use of nitrification inhibitors, the use of manure, agroforestry systems and cover crops, among others, are suggested as strategies to reduce GHG emissions. In the practical aspect, the carbon emitted for both systems is captured by growing 8.7 and 8.1 trees for 10 years for mechanized and manual planting, respectively.
Keywords: CO_2, N_2O, fertilizers, diesel, kcal

INTRODUCTION

In 2022, the world population will reach 8 billion (United Nations, 2023), with China and India being the most populous countries with 1.4 billion each. In Mexico, according to the National Institute of Statistics and Geography (INEGI, 2022), the population in 2020 was greater than 126 million, even though this figure is very contrasting with that of the aforementioned countries, due to the global economy, all of them participate. nations, there are important repercussions on the food supply. To cover the nutritional needs of this population, there must be enough land and energy available to cover the nutritional goals, so energy efficient systems must be designed and implemented, not only for the production process, which can be through mechanization. (Pimentel, 2009) but rather integrate the stages of processing, conservation, distribution and consumption (Sachs, 1984).

Although the need to have sufficient food arises, it is necessary to consider the environmental impacts that this implies. Without failing to consider the environmental impact due to the destruction of native vegetation in the opening of new crop lands, if that were the strategy, it is worth highlighting the amount of energy necessary and the impact caused by the inputs and activities carried out. to obtain food. The risk of having a food deficit increases when crops are considered to obtain fuel, since there may be a displacement of food and energy balances may be counterproductive as energy sources, in cases where they produce less energy than that required for their production. production (Dyer et al., 2014). In the case of using corn to produce ethanol, Pimentel and Patzek (2008) indicate that 29% more energy is required than that produced when processing this grain, while to produce biodiesel from sunflower, 118% more energy is required than that obtained. The energy deficit does not only apply to agriculture, Pimentel and Pimentel (2008) exemplify that producing 1.0 kcal of diet soft drink requires 500 kcal, in addition to the 1,600 kcal to produce the aluminum container, for a 2,100:1 ratio. In modern agricultural production systems, the use of machinery facilitates work and reduces execution time. Pimentel (2009) indicates that the operation time of a mechanized corn crop is 11 hours and is equivalent to 110 times less time. that manual production, however, mechanization, integrated into the manufacture and repair of machinery, as well as the fuel to operate it, uses 333,000 kcal/ha and corresponds to one third of the total energy used (Pimentel and Patzek, 2008). Within the energy used by crops, energy that is difficult to quantify and that is renewable is generally not considered, such as that derived from photosynthesis, a process that can fix about 1.6 tons of CO2 per ton of biomass produced (Skowrońska and Filipek, 2014), however, the energy to prepare the seed bed, seeds, fertilizers and pesticides, as well as that implicit in the products obtained, have an energetic value and can be measured (Bridges and Smith, 1979). This energy can be direct and indirect, integrating fuels, fertilizers and pesticides in the first form, while indirect energy consumption is associated with the energy for manufacturing and that found in the frame of the machinery and equipment (Stout, 1980; Ledgard et al., 2011). This quantification is difficult to generalize for a crop in a region due to the social and economic conditions of the producers, as well as the conditions of land, equipment and materials available to them (Sachs, 1984). Under this approach, Lal (2004) indicates that in the production process there is great variation in Greenhouse Gas (GHG) emissions due to the use of machinery and implements and exemplifies this with tillage operations that range from 2 to 20 kg of CO2 equivalent (eq). GHGs are those that can absorb and radiate in the infrared (IR) range and therefore, effectively absorb and emit thermal energy, keeping the Earth's atmosphere warm (Bhattacharyya et al., 2020). The International Panel on Climate Change (IPCC) indicates that there are 60 products that are GHGs, highlighting carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O), which have a global warming potential for an 100-year horizon of 1, 25 and 298, respectively (IPCC, 2018), with sulfur hexachloride corresponding to one of the highest impact values with 22,800 kg CO2eq. According to the IPCC cited by Rackley (2017), the concentration of CO2 in the atmosphere increased from 280 to 370 ppm by the year 2000 and approximately 400 ppm in the year 2015 and due to human activities, GHGs are responsible for the increase in temperature of the 1.1 oC of global warming occurred from 1850 to 1900 (IPPC, 2021).

Global warming is not new, since 1856 there have been reports that identified the problem and it has not been given due importance, in such a way that those with the power of decision are called criminals who "failed to prevent and stop activities." and that they are murdering the planet and the life we know" (Kramer, 2020). In the case of N2O, the amount emitted by the application of nitrogen fertilizers is exponential and non-linear (Shcherbak et al. (2014). Water vapor (H2O) is also a natural GHG, however, its concentration is not affected by human activities (Bhattacharyya et al., 2020). Just as there is variation in the different crop production systems, there is also variation in the emission of GHGs in the manufacture of fertilizers, Ledgard et al. (2011) exemplifies this. in the manufacture of urea, since in China it is manufactured mostly with coal, while in the United States it is with natural gas and this implies a third of the GHG emitted by using this product. According to the International Fertilizer Association (IFA), worldwide, agricultural activities contribute 10-12% of GHGs and fertilizers account for 2-3%, mainly carbon dioxide and nitrous oxide, integrating production, distribution and use into this figure (IFA, 2009). In 2010, in Mexico, agriculture contributed 12.3%

of the GHG with 92,184.4 Gg of CO2eq, derived mainly from the burning of fossil fuels, while nitrous oxide emissions were 223.0 Gg, contributed by the soils. agricultural 67.2%, coming mainly from the management of excreta and the use of nitrogen fertilizers (Mexico, 2012), mainly associated with the denitrification process, which is the biological reduction of nitrogen oxides to nitrous oxide and/or dinitrogen (Tate, 2021). In the case of carbon dioxide, Skowrońska and Filipek (2014) indicate that its contribution is 1.6 t of CO2 per 1.0 t of ammonia (NH3), while for nitrous oxide it is 2-2.5 kg per 1.0 t of acid. nitric (HNO3), in addition, we must consider the dispersion of nitrogen in the environment, which is 30-40% of that used. It must be noted that naturally there are also contributions of carbon to the environment through the decomposition of organic matter, volcanic eruptions, fires and the respiration of plants and animals, among others (Ussiri and Lal, 2017). Ledgard et al. (2011) applied the Life Cycle Study methodology of fertilizers for New Zealand, integrating energy consumption from the extraction of the raw material in their country and abroad to the Application at the plot level, obtaining the highest emission value for calcium ammonium nitrate and the lowest corresponded to potassium chloride with 1.93 and 0.58 kg CO2eq/kg of fertilizer, respectively. Shcherbak et al. (2014), when summarizing research results on N2O emissions, estimate that 1% of the applied amount of nitrogen fertilizer is emitted as this greenhouse gas, while when the source is manure, 0.8% is considered.

These values are considered average, since there may be crop, climate, soil and management factors that increase them, such as contents greater than 1.5% of organic matter, pH less than 7.5, low temperatures, applying the fertilizer in a single event (Bouwman et al., 2002; Tate, 2021). It must be considered that N2O emissions are not only due to the application of excreta and nitrogen fertilizers; crop legumes, such as alfalfa, can contribute more than four times this value (Eichner, 1990), in addition to not all the oxide. Nitrous emitted is due to denitrifying organisms, rather, it is also contributed by a variety of heterotrophs, as well as autotrophic nitrifiers as a metabolic product (Tate, 2021). The effect of nitrous oxide as a greenhouse gas impacts the decrease in the ozone layer (Tate, 2021) and compared to CO2, its effect is 298 times greater (IPCC, 2018). In the case of production in Europe, the energy used for the manufacture of urea, ammonium nitrate, triple calcium superphosphate and potassium chloride are 48.5 MJ/kg of nitrogen, 39.4 MJ/kg of nitrogen, 16.4 MJ/kg of nitrogen, kg of phosphorus and 6.3 MJ/kg of potassium, respectively (Alluvione et al., 2011). In the case of fuels, 1.12 kcal of oil per kcal of fuel are required to produce diesel and gasoline (Pimentel et al., 2008). There are three approaches to capturing carbon from the atmosphere; as a pure torrent within a process where CO2 is being generated, at the discharge of an industrial process, as well as directly from the air or within a chemically stable and already captured product, it can be injected into permeable rock formations or into deep waters of the oceans (Racley, 2017), but it can also be transferred from the atmosphere to the biosphere (West and Marland, 2002). Generally, evaluations of production systems are done in a comparative manner and the one with the greatest economic advantage is selected, without considering the energy they used for the inputs and activities, nor the pollutants they emit, also because there are price distortions. between regions and localities in Mexico, due to government subsidies in fuel, fertilizers, seeds and grains (Contreras et al., 2004). In the economic analyzes of production systems, costs and prices in national currency are assigned to inputs, activities and products, while in energy analyzes the energy units must be standardized. To quantify this, the kilocalorie (kcal) or its conversion to Mega Joule (MJ), kilo Watt hour (kW h) or British Thermal Units (BTU) can be used by multiplying it by the factors 0.004187, 0.001163 and 3.968, respectively (Miller Jr., 1980). In addition to the fuel consumption to operate the machinery, the energy cost for its manufacture and the implicit cost of the frame are considered, considering the iron and carbon content in it (Hawker and Keenlyside, 1977). In the case of implements with tires, it is assumed that these represent 17.9% of the weight and that the real useful life of the machinery and implements is 82% of that stipulated by the manufacturers. The useful life of the machinery is considered to be 12 years working 121.4 hectares per year, while for the implements it is 15 years. The energy for maintenance and total repair accumulated over the real useful life is equivalent to 89.1% of the cost for the tractor and 92.58% for the implements and of this energy a third corresponds to maintenance and labor costs (Doering III, 1987). In the case of simple iron implements, Pimentel and Burguess (1987) consider a value of 20,712 kcal/kg. In the case of machinery and implements, the energy for manufacturing the tractor is 3,494 and for the implements 2,061 kcal/kg, respectively. While the energy in the frame considers 11,814, 15,000, 20,013 and 20,500, for the tractor, implements, seeder and tires, respectively (Doering III, 1987).

In the case of fuels, per liter of diesel is considered 9,235 and 2,179 kcal/kg in its content and production, respectively, for a total of 11,414 kcal/kg (Cervinka,1987). For fertilizers, Lockeretz (1987) indicates the energy cost per kilogram of nitrogen in the form of urea and for phosphorus, as triple calcium superphosphate with 13,600 and 2,200 kcal/kg, respectively. In the case of pesticides, fossil energy is required for their production. In the manufacturing process of the active ingredient (A.I.), energy is used in the form of heat and electricity, as well as energy from fuels to integrate the hydrocarbon chains used in manufacturing. To this value is added the one derived to give the form of presentation of the product, by packaging and transportation to the distributor, considering in this item 0.53 kcal/kg km (Pimentel, 1987). Based on the above, for the herbicides Atrazine, 2,4-D and Paraquat, their energy indices are 45,240, 24,200 and 109,520 kcal/kg of A.I. Due to the form of presentation as a wettable powder and miscible oil, 2,500 and 33,300 are considered, while the packaging corresponds to 2,600 and 8,500 and for transportation, 670 and 1,100 kcal/kg of A.I., respectively. For seeds, Pimentel and Burguess (1987), per kilogram of corn grain indicate an energy value of 3,480 kcal, while when seed is used, this value is 24,830 kcal, a difference derived from the improvement process (Heichel, 1987). To estimate the energy consumed by labor, the factor proposed by Pimentel (1987) for work with a hoe is used and the consumption is 6.8 kcal/min, while for operating the machinery half of this factor is considered, although some authors they do not consider the energy cost of manual activities because humans breathe CO_2 even though they are working (West and Marland, 2002).

MATERIALS AND METHODS

It was considered to analyze energy consumption and GHG emitted in two production systems described in part in Contreras et al. (2004) and Contreras et al. (2019), both cataloged as direct sowing, the first mechanized in valley soils, according to the Conservation Technology Information Center (CTIC, 2002) and the other system is manual sowing on a slope. The total energy costs and the emission of pollutants due to the use of inputs and the activities carried out were considered, recording them based on energy indices proposed in the literature. For the mechanized system, an 80 horsepower tractor with a weight of 3,450 kg was used and the sowing is carried out with a three-unit zero tillage seeder, with a weight of 1,050 kg, 15 liters of diesel are consumed, the activity lasts 2.5 hours and 19 kilograms of Creole (native) corn are used as seed. As external inputs, 250 kg of urea and 150 kg of diammonium phosphate were used, while as herbicides, one kilogram of Atrazine with a concentration of 90% plus one liter of 2,4-D at 50% of concentration and was applied with a manual sprayer weighing 4.7 kilograms. Due to the use of labor, eight-hour work days are considered, two to apply the fertilizer, two to apply the herbicide and ten for the harvest. For the cultivation of corn on the slope, prior to sowing, the weed vegetation was cleared using a 45 cm long metal machete, weighing 0.490 kg, considering a useful life of 15 years. Planting is done with an iron planting stick (barretón) that has a flat tip of eight centimeters and weighs 1,220 kg with a useful life of 15 years. The sowing distances range from 0.90 to 1.30 meters depending on the obstacles encountered and three to five seeds are deposited per blow, 14 kg are used and it is done in eight days. Weed control is carried out using a manual sprinkler weighing 4.7 kg with the herbicide Paraquat at 25% concentration using 2.7 liters per hectare. Manual activities consider four days for clearing the vegetation, two for applying the fertilizer, two for applying the herbicide and the harvest is carried out manually for 16 days. For both systems, obtaining the yield in dry weight to the environment was done through an estimate considering that there is great variation regarding the transportation from the plot to the producers' house, as well as the time and method of shelling. Furthermore, the energy in the waste was not considered, which represents a profit for the producer. To estimate the amount of pollutant emissions in the evaluated technologies, the Environmental Protection Agency (EPA) of the United States indicates that 2.69 kg of CO2 are emitted into the environment through the combustion of one liter of diesel (EPA, 2023), while that for N2O due to the application of nitrogen fertilizers, it is considered that 1% of that amount is emitted (Shcherbak et al., 2014) and the factor of 298 was applied to that amount for its conversion to CO2eq (Statistics Netherlands, 2019). In the case of diammonium phosphate, the energy cost was estimated considering nitrogen as if it were urea and phosphorus as triple calcium superphosphate, while the GHG emissions due to its use were considered as factors 2,555 and 1,000 g of CO2eq/kg of N. and P2O5, respectively (Kongshaug, cited Wood and Cowie, 2004). Herbicides also have an impact on GHG emissions and Lal (2004) indicates values of 3.8, 1.7 and 9.2 kg of carbon equivalent (Ceq) per kg of A.I. for Atrazine, 2,4-D and Paraquat, respectively and based on the molecular weight, the factor 3.66 was considered for the conversion of Ceq to CO2eq. The indices to evaluate the relationship and efficiency of the energy consumed, the energy obtained and the performance were obtained through the Energy Efficiency (EE) of the process by relating the energy outputs minus the inputs to verify if there were gains or losses, while Productive Energy Efficiency (PEE) was obtained by relating the energy inputs to the yield obtained, in order to obtain the energy cost per unit of grain produced.

RESULTS AND DISCUSSION

Table 1 presents the energy analysis for the corn production system in mechanized planting. It can be seen that the main energy consumption corresponds to fertilization

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with 83% of the 2493,743 kcal/ha consumed and is followed by sowing with 11%. Because direct sowing is a reduced tillage compared to conventional sowing, it is considered that the energy obtained by sowing (285,347 kcal/ha) was relevant, since it commonly represents about a third of the total (Pimentel and Patzek, 2008) and can be reduced by more than 50% by using smaller machinery (Pimentel et al., 2008).

Table 2 presents the energy analysis for the case of manual corn hillside planting, where it can be seen that 80% of the 2355.274 kcal involved in the entire process was due to the use of fertilizers. For both cases it was the same situation, the above implies, on the one hand, the need to provide nutrients to the plants, however, the use of commercial nitrogen must be totally or partially replaced by cover crops and manure and it can even be make the conversion towards organic agriculture and thus increase efficiency per unit of production (Pimentel, 2006). Another strategy may be to eliminate subsidies and increase the costs of external inputs, especially fuel and fertilizers, which would tend to make the production process more efficient by reducing quantities (Sachs, 1984).

Based on the results and despite the fact that the two evaluated systems involve corn production processes restricted in activities, mainly soil tillage, a direct relationship was obtained, that the greater the amount of energy consumed, the greater the yield and therefore, energy gain by the grain, obtaining an energy surplus (EE) for both systems. Thus, by consuming more energy, the mechanized tillage system obtained an energy gain of more than nine million kilocalories, while in manual hillside cultivation the energy gain was more than three million, all of the above derived from the greater corn yield in both systems (Table 3). In the case of productive energy efficiency (PEE), the cost of producing one kilogram of corn considers 748 kcal in the case of mechanized agriculture, while for hillside agriculture the energy cost was 1,519 kcal (Table 3). Although an increasing amount of food will be required over time due to population increases, it must be considered that this increase will require additional nitrogen fertilizers (Pimentel and Pimentel, 2008). In addition to taking into account that the raw material of some fertilizers is a non-renewable resource, such as phosphate rock, contrary to what happens with nitrogen fertilizers.

Production system	EE kcal/ha	EEP kcal/kg corn
Mechanized labor	+ 9105,097	748.1
Manual tillage	+ 3038,726	1,519.5

Table 3: Energy indices of production systems

Tables 1 and 2 present the greenhouse gases emitted, even though they are not comparable systems, since one was carried out using mechanical energy (525.32 kg/ha CO2eq), while the other was using manual energy (487.21 kg /ha CO2eq), it can be seen that it was higher in the mechanized system, mainly due to the use of diesel, since in both the amount of fertilizers was the same. The systems approach is well considered, as the oxidation of soil organic matter by tillage is a source of CO2 emissions to the atmosphere (Rackley, 2017) and minimum tillage is considered a viable alternative. West and Marland (2002), when comparing conventional tillage systems with zero tillage, obtained values of 614.88 and 501.42 kg CO2eq, respectively. In addition to this option, Lorenz and Lal (2018) consider that erodible land must be eliminated from production and always have the land under cultivation, include cover crops and promote the use of direct sowing, under the consideration that carbon capture and its storage is finite and can be saturated between 10 and 100 years. Hillier et al. (2012) consider

Activities	Team/Newspaper (kcal)	Input (kcal)	Total (kcal)	CO_2eq (kg)
Sowing				
Tractor	38,244		38,244	
Seeder	9,263		9,263	
Diesel		171,210	171,210	40.35
Seed		66,120	66,120	
Application	510		510	
Fertilization				
Urea		1564,000	1564,000	342.7
Diammonium phosphate		519,000	519,000	138
Application	6,528		6,528	
Control of ailments				
Sprinkler	41		41	
Atrazine		45,909	45,909	3.42
2,4-D		33,750	33,750	0.85
Application	6,528		6,528	
Harvest				
Pinch	32,640		32,640	
Total			2,493,743	525.32
Performance (kg/ha)	3,333		11598,840	

Table 1: Energy analysis for the mechanized direct seeding system.

Activities	Team/Newspaper (kcal)	Input (kcal)	Total (kcal)	CO_2eq (kg)
Sowing				
Cleaning	13,056		13,056	
Implementation	2,706		2,706	
Seed		48,720	48,720	
Implementation	13,476		13,476	
Application	26,112		26,112	
Fertilization				
Urea		1564,000	1564,000	343
Diammonium Phosphate		519,000	519,000	138
Application	6,528		6,528	
Control of ailments				
Paraquat	102,883		102,883	6.21
Sprinkler	41		41	
Application	6,528		6,528	
Harvest				
Pinch	52,224		52,224	
Total			2355,274	487.21
Yield (kg/ha)	1,550		5394,000	

Table 2: Energy analysis for the manual direct sowing system.

that the environmental impact can be reduced by reducing the amounts of fertilizers, using those with lower impact and nitrification inhibitors, as well as reducing tillage activities and increasing carbon in the soil. Bronson et al. (1992) by using nitrification inhibitors they reduced the nitrous oxide emitted by approximately one third. To a greater or lesser extent, production systems will emit GHG, therefore, in addition to employing strategies to minimize their emission, others must be implemented to fully or partially capture what is emitted. This carbon capture does not distinguish its origin, since there can be elemental, organic and inorganic carbon (Ussiri and Lal, 2017) and Nair and Nair (2003) consider that agroforestry systems are an alternative for its capture and must be implemented in those conditions that allow it, in such a way that there is a significant ecological and economic interaction between woody species and non-woody components (basic crops) and that part of the emitted carbon accumulates in them. Depending on the spatial arrangements of species and time, Nair et al. (2010) estimate that annually agroforestry systems can store on the surface from 0.29 to 15.21 t/ha of carbon and from 30 to 300 t/ha from the surface to one meter deep and according to the EPA (2023a) the 525.32 and 487.21 kg of CO2eq emitted are equivalent to growing 8.7 and 8.1 trees for 10 years, respectively. One way to evaluate the impact of fertilizers on the environment is to study their life cycle, from production to application, in addition to the ways to repair the damage they cause (Skowrońska and Filipek, 2014). This way, production processes must be made even more efficient under the approach of Climate Smart Agriculture, proposed by the Food and Agriculture Organization of the United Nations (FAO, 2013) that pursues a technical, political and investment approach. to achieve food security under the conditions of climate change (Bhattacharyya et al., 2020) by integrating aspects of climate, crops, nutrition and carbon, among others.

CONCLUSIONS

In the two systems evaluated, the energy cost of the mechanized system was higher than the manual system and in both, more than 80% of the total corresponded to fertilization. Despite this, the mechanized system obtained greater Energy Efficiency since the energy output or gain was greater, because the corn yield was close to double that obtained through manual sowing. The energy cost of a kilogram of corn (EEP) was close to half for mechanized planting (748.1 kcal), however, the GHG emitted were greater for this system. As a strategy to capture that carbon, the cultivation of 8.7 trees over a 10-year period is required to capture the 525.32 kg of CO_2eq emitted in the mechanized corn production process.

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