ORIGINAL ARTICLE

Determination of Energy and Operation Costs of the Mechanized Rice Harvest

Determinación del costo energético y de explotación de la cosecha mecanizada del arroz

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ABSTRACT. The objective of the present study was to determine the energy and operation costs of the mechanized rice harvest and to compare the energy and operating costs of the most used harvesters (Claas Dominator-130 and Claas Crop Tiger C-210) under the conditions of Agroindustrial Grain Company (EAIG) "Los Palacios". During the execution of the work, the methodology established for the calculation of energy cost of the mechanized operation was applied, as well as the operating indicators were determined. The obtained results allowed knowing the structure of the total energy hourly and of operation for the harvesters studied. When comparing the energy costs per area worked, in Claas Dominator 130 harvester, these values are 298.92 MJ/ha, while in the Claas Crop Tiger C-210 harvester, they are higher, reaching values of 306.79 MJ/ha, which is equivalent to 6.25 L/ha and 6.71 L/ha of diesel fuel, respectively. This is because Claas Dominator-130 is a machine with higher hourly productivity (4.30 vs. 3.24 ha/h) and a wider working width than Claas Crop Tiger C-210. With the application of these results, considerable fuel savings per campaign and greenhouse gas emissions reductions are achieved in Agroindustrial Grain Company "Los Palacios".

Keywords: Harvester, Energy, Fuel, Harvested Mass, Productivity.

RESUMEN. El objetivo del presente trabajo fue determinar el costo energético y de explotación de la cosecha mecanizada de arroz y comparar el costo energético y de explotación de las máquinas cosechadoras más utilizadas (Claas Dominator-130 y Claas Crop Tiger C-210), en las condiciones de la Empresa Agroindustrial de Granos "Los Palacios". Durante la realización del trabajo se aplicaron la metodología establecida para el cálculo del costo energético de la operación mecanizada, así como también se determinaron los indicadores de explotación. Los resultados obtenidos posibilitaron conocer la estructura del costo energético total horario y de explotación para las cosechadoras estudiadas. Al hacer la comparación de los costos energéticos por área trabajada, en la cosechadora Claas Dominator 130, estos valores son 298,92 MJ/ha, mientras en la cosechadora Claas Crop Tiger C-210, son mayores, alcanzando valores de 306,79 MJ/ha, que equivalen a 6,25 L/ha y 6,71 L/ha, de combustible diesel respectivamente. Esto se debe a que la Claas Dominator-130 es una máquina con mayor productividad horaria (4,30 vs. 3,24 ha/h) y de mayor ancho de trabajo que la Claas Crop Tiger C-210. Con la aplicación de estos resultados se logra en la Empresa Agroindustrial de Granos "Los Palacios" un ahorro considerable de combustible por campaña y se reducen las emisiones de gases de efecto invernadero.

Palabras clave: cosechadora, energía, combustible, masa cosechada, productividad.

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INTRODUCTION

Energy evaluation is a process of analysis that consists on the identification and measurement of the quantities of energy required, associated to the products and equipment that intervene in the production of a certain goods (ASAE, 1993), describe a series of analyzes, such as: energy required and input (Input-Output) and other statistical procedures, the first consisting of determining the energy required per unit of a good, or service produced and the others from statistical data.

Among the most updated research we can highlight the De las Cuevas *et al.* (2009, 2011), all of the theoretical-practical type, whose main objective are aimed at evaluating the energy cost of machinery. Tractors and agricultural machines have a high cost of acquisition and operation in monetary ($/h, $/ha) and energy terms (MJ/h, MJ/ha). On the other hand, several authors have studied energy efficiency of different farming systems and sustainability in agriculture. Others have investigated on agricultural maintenance when harvesting in intensively cultivated soils, energy cost for fuel, which represents a high percentage of the total energy cost of production in farming systems to be used in agribusiness (Rawson y Gómez, 2001; Paneque y Prado, 2005; Meul *et al.*, 2007b; Fumagalli *et al.*, 2011; Mohammadhossein *et al.*, 2012)

In Cuba, rice harvest is an operation carried out with the help of agricultural machinery, which represents heavy investments and fuel expenses. For that reason, the rational use of energy is vital to ensure the increase of food production efficiently and to improve productivity.

Taking into account the need to increase the efficiency of energy use in the mechanized rice harvest, the objective of this work was to determine the behavior of the energy cost and operation of the mechanized rice harvest.

During the realization of the work, the methodology established for calculating energy cost of the mechanized operation presented by Hetz y Barrios, (1997) was applied. Economic indicators of CLAAS DOMINATOR-130 and CLAAS CROP TIGERC-210 harvesting machines were also determined.

The final objective of a harvester is obtaining a product of high quality through a great capacity of work, versatility, comfort and easy maintenance. Although the characterization of Hydromorphic Gley Nodular Ferruginous soils (Hernández *et al.*, 1999), in Agroindustrial Grain Company "Los Palacios" makes difficult the activities of mechanization for the case of mechanized harvest, during the present work of investigation, the technological advance and the capacity of work of this machinery will be measured.

On the other hand, Jimenez (2003), points out that technological management is considered as a criterion to maximize opportunities and as a sustainable element over time, since it, not only provides new integration mechanisms within the organization, but is also required in the innovation processes of any company that manufactures products and/or services and sales the final product.

When reviewing the technological capacity in the field of agricultural research and extension FAO (2001), points out that this is insufficient in most countries in Latin America. That source also states that it is the result of not available technologies and others that are not sufficiently adapted to the local conditions and conclusive research results or that do not propose technological solutions adapted to the diversity of the existing socioeconomic and agroecological conditions of each country.

These are reasons of great importance for the study of energy cost of a mechanized agricultural operation in Agroindustrial Grain Company "Los Palacios", for which the present work was carried out. Its objective was the technological evaluation of CLAAS DOMINATOR-130 and CLAAS CROP TIGERC-210 harvesters, during the mechanized harvesting of rice. The research was developed during the rice harvest campaign 2016 ... 2017.

METHODS

All the field studies were carried out in Agroindustrial Grain Company "Los Palacios". It is located in the southern plain of the province of Pinar del Río, specifically at 22 º 44 'north latitude and at 83 º 15 'of west longitude, at 60 m above sea level with slope of 1%, in a Hydromorphic Gley Nodular Ferruginous soil (Hernández *et al*., 1999). The research was developed during the rice harvest campaign 2016 ... 2017.

Methodology Used to Determine the Energy Cost

The methodology was used to establish the energy cost of execution of the operations previously executed by Paneque *et al*. (2002); Paneque y Prado (2005); Paneque y Sánchez (2006); Paneque y Soto (2007), supported by the background presented by Stout (1990); Fluck (1992); Hetz y Barrios (1997). This methodology determines the total energy costs of the mechanized agricultural operation (MJ/h), adding the energy sequestered in the construction materials including manufacturing and transportation, fuel, lubricants/filters, repairs / maintenance, and the labor needed to operate the equipment, proposed by ASAE (1993), cited by Paneque y Sánchez (2006).

Methodology Used to Determine Operating Costs

For the determination of operating costs, in the execution of mechanized agricultural operations, a calculation methodology was developed from the Cuban standard NC 34-38, (2003). This methodology determines the operating costs in weight / h, adding the costs for salaries, amortization, repairs-maintenance and in fuel, as well as the costs per unit of area worked (weight / ha).

RESULTS AND DISCUSSION

Characterization of the Experimental Area

Agroindustrial Grain Company "Los Palacios" is located in the southern plain of the province of Pinar del Rio, specifically at 22 º 44 'north latitude and 83 º 15' west longitude, 60 m above sea level with slope of 1%, in a Gley Nodular ferruginous Hydromorphic soil (Hernández *et al*., 1999).

The productive activities to which it is dedicated are fundamentally rice as a main crop as well as diverse cultures and cattle ranch.

Agroindustrial Grain Company "Los Palacios" plays an important role in the production of rice since it contributes a third of the national production. In the province of Pinar del Rio, 15,000-18,000 hectares are planted annually and produce no less than 60,000 tons of wet rice and 26,000 tons of consumption rice, in its two seasons. In the cold season, 60% of the annual rice production is harvested and in spring the other 40% is produced, which contributes to the substitution of imports.

The Integral Base Business Unit of Technical Services (UEB ISB) is located in the center of the rice plantation in the Agricultural Base Business Unit (UEB) Vuelta Abajo, belonging to Consolación del Sur Municipality, Pinar del Río Province, Herradura Town. It has a staff of 155 workers; the social object of it is the provision of soil preparation services, harvest and workshop services to the state, cooperative and peasant sectors, within the areas of the plantation.

Energy Cost and Operating Expenses

Energy Cost

Analyzing the values obtained by means of the methodology used, the following analysis emerges globally: the hourly energy cost (CEt) (MJ/h) increases in an ascending way when the working width of the machine increases. However, with respect to the energy cost per area (MJ/ha) and per mass processed (MJ/t) they behave in an inverse manner, because the cost per area decreases due to the higher productivity of the machine. It shows that the cost per area is independent of the size of the machine, since for the same agricultural yield and for a certain increase and decrease in the original working width of the machine, the variation between costs per unit area remained approximately constant.

The different energies sequestered in materials, manufacture and transport of the harvesters, energy required in fuel, in lubricants, in repairing and maintenance and energy required in labor, all in MJ/h, can be seen in the graphs of the figures. The results of energy costs of rice harvesting machines can be seen in the graphs of Figures 1 and 2.

In Figure 1 it is shown that, the value of the energy required in fuel is the highest of all for the Claas Crop Tiger C-210 harvester, reaching 645.30 MJ/h. However, in Figure 2, it can be appreciated that the highest energy costs are in this same indicator, those required by the Claas Dominator 130 harvester, reaching values of 779.14 MJ/h. This is mainly due to the higher productivity, size, complexity and high cost of this machine.

In the structure of the energy cost, the total hourly cost for the harvesters, the energy corresponding to the fuel (ESc), represents a high consumer of the partial energies. It is followed by the energy corresponding to maintenance/repair (ESmr), reaching this value in Claas Crop Tiger C-210 harvester valued at 176.96 MJ/h and for Claas Dominator 130 harvester, this value amounted to 261.94 MJ/h, being negligible those required in lubricants/filters (ESl) and in labor (ESmo), respectively.

In the analysis of variance of the energy cost behavior, according to F test, significant differences were detected between the treatments of the two harvesters (P <0.000). The coefficient of variation was 0.005%, indicating an excellent experimental precision. The comparisons between the means are shown in the graph of Figure 3.

According to the analysis of variance with a confidence level of 95%, it can be seen that the hourly energy costs and the area worked by both machines differ from one another.

Claas Crop Tiger C-210 harvester has an hourly energy cost lower than the hourly cost of Claas Dominator 130 harvester, however the energy cost per area worked is greater. The results of energy cost of the two machines under study are shown in Figure 3.

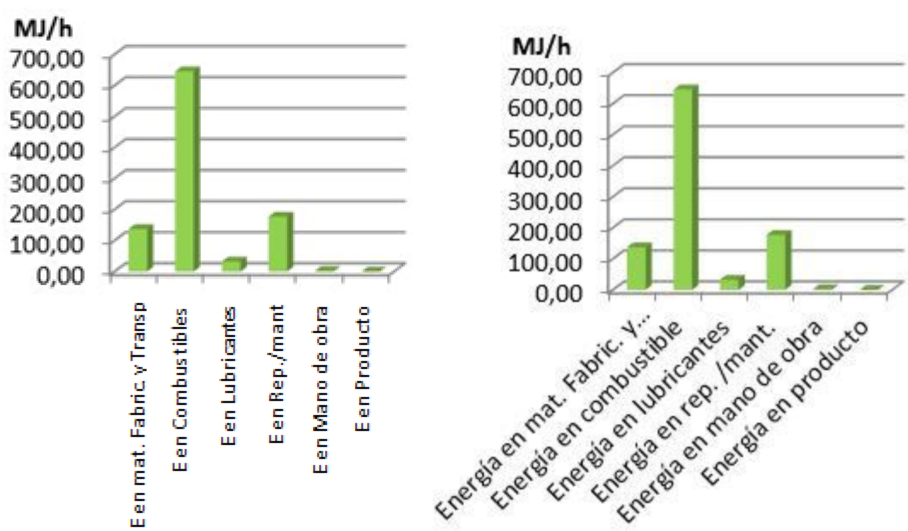

FIGURE 1. Energy sequestered of Claas Crop Tiger C-210 harvester.

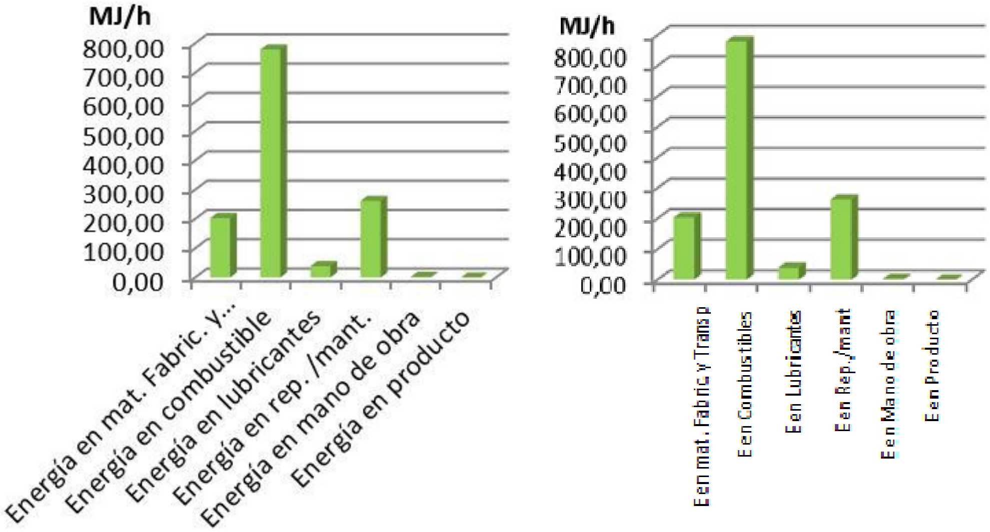

FIGURE 2. Energy sequestered of Claas Dominator 130 harvester.

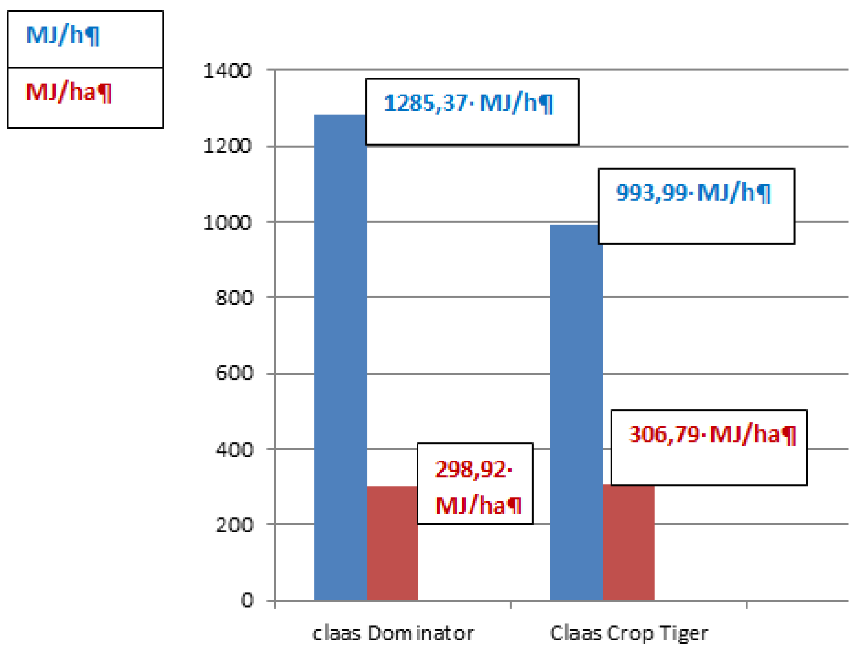

FIGURE 3. Comparison of Energy Cost of Claas Crop Tiger C-210 and Claas Dominator 130 combines.

When making a comparison of the hourly energy costs of both machines it can be seen that the largest correspond to Claas Dominator 130 harvester, reaching values of 1 285.37 MJ/h, while in Claas Crop Tiger C-210 harvester, the values are 993.99 MJ/h. When comparing energy costs per area worked, in the Claas Dominator 130 harvester, these values are 298.92 MJ/ha, while in Claas Crop Tiger C-210 combine, they are higher, reaching values of 306.79 MJ/ha, equivalent to 6.25 L/ha and 6.71 L/ha, of Diesel fuel respectively. This is because Claas Dominator-130 is a machine with greater hourly productivity (4.30 vs. 3.24 ha/h) and a wider working width than Claas Crop Tiger C-210. Analyzing the obtained values, the following analysis emerges globally: hourly energy cost (CEt) (MJ/h) increases in an ascending way when increasing the working width of the machine. However, with respect to the energy cost per area (MJ/ha) and per mass processed (MJ/t) they behave in an inverse manner, because the cost per area decreases due to the higher productivity of the machine, and this shows that the cost per area does not depend on the size of the machine.

The energy corresponding to the fuel used amounted to 199.16 MJ / ha, for the Claas Crop Tiger C-210 harvester and 181.19 MJ/ha for Claas Dominator 130 combine, equivalent to 4.16 L/ha and 3, 79 L/ha of oil respectively. The results obtained are close to those obtained by Stout (1990) y Paneque *et al.* (2002).

Claas Dominator 130 harvester presented the highest total hourly energy cost with a value of 1 285.37 MJ/h and the lowest per area worked 298.92 MJ/ha. However, at the same time it reached the best total energy cost per harvested mass (56.40 MJ/t), achieving an approximate productivity of 4.3 ha/h (22.79 t/h), reaffirming it is the most productive of the machines under study. The highest total energy cost per area worked was the Crop Tiger C-210 with a value of 306.79 MJ/ha, presenting the highest values of cost per mass processed with 57.79 MJ/t.

Operating Costs

In the graphs of Figures 4 and 5 the operating costs of both harvesters, such as: salary, amortization, repairs and maintenance, fuel consumption and products used can be seen.

In Figure 4, it is shown that the costs of operation, for repair and maintenance, are the largest of all, in Claas Crop Tiger C-210 harvester, reaching values of 118.74 peso/h. The direct operation costs amounted to 138.50 peso/h in this harvester and by area worked were 42.75 peso/ha.

The direct costs of operation in Claas Dominator 130 harvester amounted to 9 203.58 peso/h and per area worked were 2 140.37 peso/ha.

In Figure 5, it can be seen that the higher operating costs are also due to the repair and maintenance of Claas Dominator 130 harvester.

The results of the investigation show that the direct costs of operation in Claas Dominator harvester (9 203.58 peso/h and 2 140.37 peso/ha), are greater than those obtained in Claas Crop Tiger C-210 combine (138.50 peso/h and 42.75 peso/ha). This is because Claas Dominator-130 is a larger machine in mass.

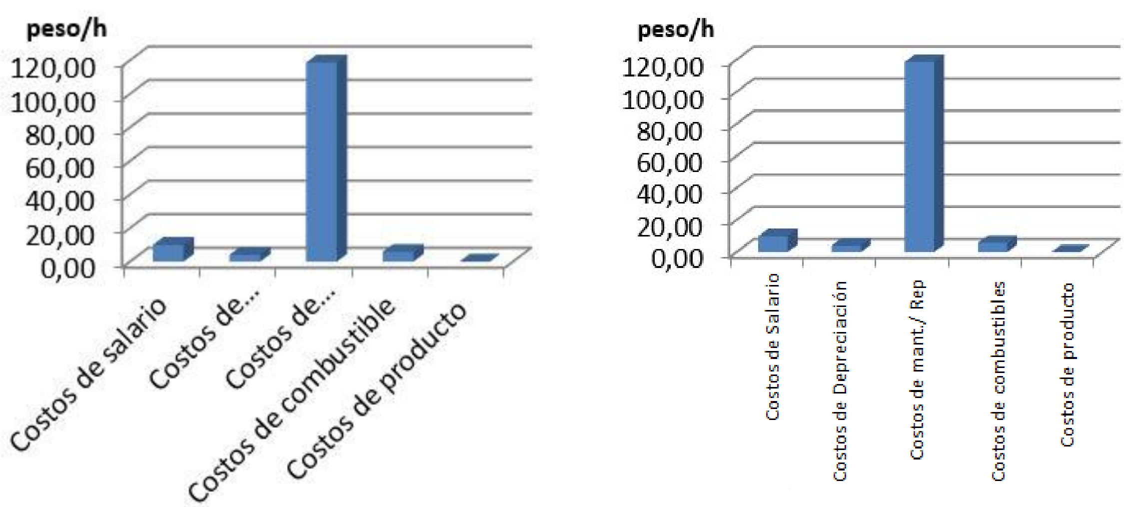

FIGURE 4. Operating costs of Claas Crop Tiger C-210 harvester.

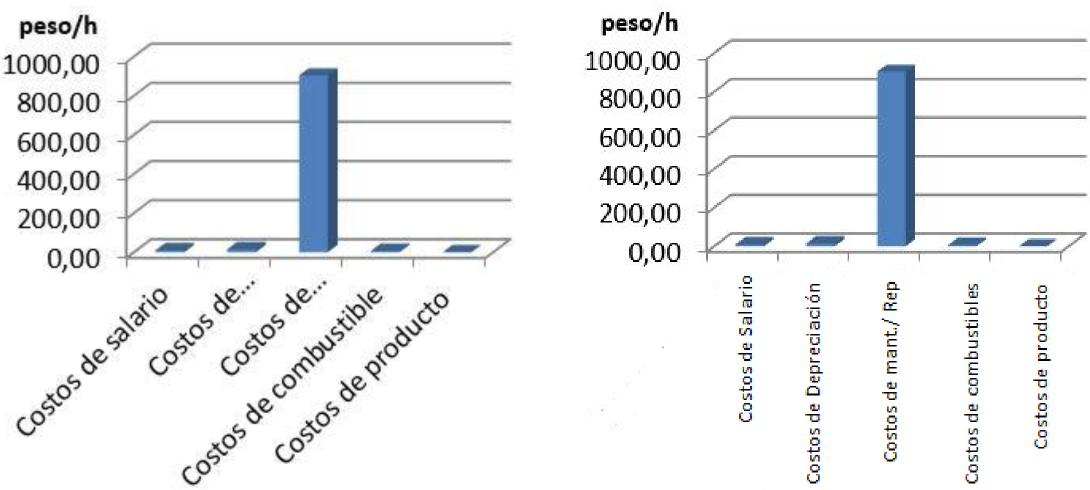

FIGURE 5. Costs of operation of Claas Dominator 130 harvester.

CONCLUSIONS

- When comparing the hourly energy costs of both machines, it can be seen that the largest ones correspond to Claas Dominator 130 harvester, reaching values of 1 285.37 MJ/h, while in Claas Crop Tiger C-210 combine, the values are 993.99 MJ/h.
- When comparing the energy costs per area worked, in Claas Dominator 130 harvester, these values are 298.92 MJ/ha, while in Claas Crop Tiger C-210 combine, they are higher, reaching values of 306.79 MJ/ha, equivalent to 6.25 L/ha and 6.71 L/ha diesel fuel, respectively. This is because Claas Dominator-130 is a machine with greater hourly productivity (4.30 vs. 3.24 ha/h) and a wider working width than Claas Crop Tiger C-210.
- The energy corresponding to the fuel used amounted to 199.16 MJ / ha, for Claas Crop Tiger C-210 harvester and 181.19 MJ/ha for Claas Dominator 130 harvester, equivalent to 4.16 L/ha and 3.79 L/ha of oil, respectively.
- Claas Dominator 130 harvester presented the highest total hourly energy cost with a value of 1 285.37 MJ/h and the lowest per area worked 298.92 MJ/ha. Nevertheless, at the same time, it reached the best total energy cost per harvested mass (56.40 MJ/t), achieving an approximate productivity of 4.3 ha/h (22.79 t/h), reaffirming it is the most productive of the machines under study.
- The highest total energy cost per area worked was for Crop Tiger C-210 with a value of 306.79 MJ/ha, presenting the highest values of cost per mass processed with 57.79 MJ/t.
- The results of the investigation show that the direct costs of operation in Claas Dominator harvester (9 203.58 peso/h and 2 140.37 peso/ha), are greater than those obtained in Claas Crop Tiger C-210 harvester (138.50 peso/h and 42.75 peso/ha). This is because Claas Dominator-130 is a greater machine in mass, productivity, width of work and price than Claas Crop Tiger C-210.

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