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Comparative Analysis Among the Battery-Powered and Diesel Tractors

Análisis comparativo entre los tractores eléctricos y diésel

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ABSTRACT: The major advances in agriculture began with the beginning of the mechanization. However, this process has also caused significant environmental impacts. The introduction of tractors and other agricultural machines in Cuba have been developed impetuously in the period from 1959, but at the moment the research of options is required for a gradual renovation of the agricultural machinery due to its technical deterioration and obsolescence. The Agricultural Engineering Research Institute has performed an intensive test work and researches of new models of machines like option to the government and the farmers for the acquisition of the most advantageous models. It is objective of the present work to show the results of a comparative study among the electric tractors and those powered by diesel motors, analyzing as methodological aspects the saving of fuel, reduction of expenses in repair and maintenance, operation easiness, and impacts on the environment. The results indicate that the electric tractors have numerous advantages, although for their massive introduction it is necessary to consider some important factors.
Keywords: agriculture, electrification, environmental protection, energy saving.

RESUMEN: Los grandes avances en la agricultura se iniciaron con el surgimiento de los medios mecanizados. Sin embargo, la mecanización también ha traído grandes afectaciones al medio ambiente. La introducción de tractores y otras máquinas agrícolas en Cuba se ha desarrollado impetuosamente en el período desde 1959, pero actualmente se requiere la investigación de opciones para una renovación gradual debido a su deterioro técnico y obsolescencia. El Instituto de Investigaciones de Ingeniería Agrícola ha venido desarrollando un intensivo trabajo de prueba e investigación de nuevos modelos de máquinas como opción al gobierno y a los productores agropecuarios para la adquisición de los modelos más ventajosos. Es objetivo del presente trabajo mostrar los resultados de un estudio comparativo entre los tractores eléctricos y los accionados por motor diesel, analizando como aspectos metodológicos el ahorro de combustible, reducción de gastos en reparación y mantenimiento, facilidad de operación, e impactos sobre el medio ambiente. Los resultados indican que los tractores eléctricos tienen numerosas ventajas, aunque para su introducción masiva es necesario considerar algunos factores importantes.
Palabras clave: agricultura, electrificación, protección medioambiental, ahorro de energía.

INTRODUCTION

The agricultural production achieved a fundamental advance when were developed the first self-propelled machines moved with energy produced by the combustion: firstly with mechanisms worked by water vapor at high pressure and later with motors of internal combustion. These last ones began using as energy source the gasoline, generally with low power, but the development of the diesel motors facilitated to a sensibly increasing of the power and to diminish the costs, and from then on the fuel oil has been the fuel more used in the tractors, self-propelled harvesters and other motorized machines (FAO, 2022).

In 1959, to the victory of the Revolution, 9 thousand tractors existed; in 1975 it had been increased to 54 thousand. In 1998 was reached the figure of 105 thousand tractors and self-propelled harvesters, buy now exist about 70 000, although more than 34 % are inactive, mainly for lack of components and spare parts for their repair (Minag-Cuba, 2022). The Table 1 shows the quantity tractors in existence in each county, and the Figure 1 the number for ranges of power.

TABLE 1. Inventory of tractors in Cuba

Classification	Range, hp	Quantity of tractors	%
Low	Up to 80	37 924	54
Medium	81 - 120	27 390	39
High	More than 120	4 917	7
Total		**70 231**	**100**

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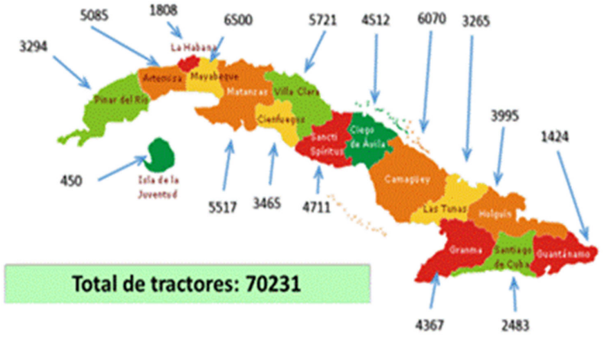

FIGURE 1. Total of tractors and existence by provinces.

In Cuba a state politics exists regarding the continuous development of the equipment of the agriculture. The Resolution No. 6, of June 27, 2015 of the President of the Council of Ministers, settled down like some of the specific functions of the Ministry of the Agriculture: "To promote the development of the systems of mechanization, irrigation and agricultural drainage, to validate the introduction of new technologies and their efficient exploitation and to establish the regulations for the technical maintenance".

In accordance with it, were emitted the Ordinance Law 2/2019 "Of the Mechanization, the Irrigation, the Agricultural Drainage and the Supply of Water to the Animals" GOC-Cuba (2020a), dealing with the whole politics on these activities, and the Ordinance 21/2020 that establishes the Regulation for its performing (GOC-Cuba, 2020b). In these Ordinances are settled down the orientations about the rehabilitation and replacement of tractors and other agricultural machines and these are implemented by means of the annual plans of the economy starting from the approved programs of agricultural development, being prioritized the proprietors of lands or productive forms having the biggest agricultural yields (Minag-Cuba, 2002).

Most of the existent tractors in Cuba have more than 20 years of exploitation, for what the gradual renovation of these is required. If we consider the renovation of alone 5 % per year, this implies the annual import of more than 3 500 tractors, what justifies fully to look for options as for the characteristics of the models, cost of exploitation, and easiness of maintenance and repair.

In very recent years has had a vertiginous advance the employment of the electricity for the movement of vehicles: automobiles, trucks, motorcycles, bicycles, and even already airplanes, ships and railroads. These advances have also arrived to the agricultural machinery, and numerous factories have developed tractors and other equipment using motors that are moved by means of the electricity accumulated in more and more compact and effective portable batteries.

For it Agricultural Engineering Research Institute undertook the task of the testing of diverse models of electric and diesel tractors motor and at the same time to carry out a comparative study between both types of machines. It is objective of the present work to show the main results of the study, especially in what refers to the comparison between the electric tractors and the similar models with diesel motors, emphasizing in the advantages and disadvantages of their use.

MATERIALS AND METHODS

In the study were used mainly the methodologies used by the Agricultural Engineering Research Institute to evaluate the fundamental indicators of the agricultural tractors in the state tests, especially in what refers to the technical characteristics of them, their performance and its parameters of exploitation. Methodologies of evaluation of the environmental impact of the agricultural machinery proposed by several authors were used (Águila, 2000; Díaz y Pérez, 2007).

For the collection and analysis of the information the methodological procedure understood searches in Internet sites about companies now producing electric tractors and the technical data of the models that they offer, as well as of the available information in the reports of the tests made in the IAgric of tractors with combustion motors and electric ones.

Discussion meetings were carried out with specialists in tests of tractors, as well as with ruling personnel and workers dedicated to the operation of the tractors. The results were processed by means of statistical analysis, with the use of tools and computing programs.

It was also gathered information on the topic (published works, papers presented in scientific events, reports of researches, laws, resolutions, institutional politics, etc.) about the mechanization of the agriculture and the importance of the tractorization, the energy saving and the availability of resources for the acquisition, repair and maintenance of these machines and the reduction of the (Newsletters, 2021; Ríos, 2021; Ríos, 2024).

RESULTS AND DISCUSSION

Importance of saving fuel in agricultural works

The rational use of the tractors and other machinery in the agricultural processes constitute the biggest potential of saving fuel and of the decrease of the contamination (Herrera *et al.*, 2011). Among the conventional energy sources more used in the mechanized processes of the agriculture are the liquid fuels (gasoline, diesel and other petroleum products), gasses (methane) and solids (mineral coal, firewood coal, wood), as well as the electricity (Petersson *et al.*, 2021). All these energy sources come from the combustion of organic substances or minerals and produce gases with very undesirable consequences (Domingo *et al.*, 2003; Milanés, 2020; Infoagro, 2023).

In the activities of agricultural mechanization in Cuba is a task of first order the reduction of the energy consumption (fuel and electricity) due to the high cost of the petroleum and their products in the international market and the shortage of foreign currencies and obstacles to obtain the fuel.

It should also be considered that the decrease in the consumption of fuel is a favorable action from the environmental point of view since the combustion motors produce the emission of the polluting gases that cause sour rains and the hothouse effect due to the damage to the layer of ozone, among other affectations (Herrera *et al.*, 2011). The electrification is convenient in the cases that are substituted for electric motors the diesel motors or gasoline motors, like it is the case of the tractors, combines and irrigation machines (Ríos, 2021).

More representative marks of electric tractors

Some companies producers of agricultural machines have begun in the last years in the production of electric tractors (Fiori *et al.*, 2022). For example, the John Deere, with factories in USA and other countries, has been advancing in the development of electric and hybrid tractors. They presented in 1916 the model Sesam, being one of the first battery-powered tractors, but not started the production in great scale (John Deere, 2021). However, the firm Monarch, of USA, already offers in commercial scale an electric tractor that also has possibilities to work in an autonomous way.

The German company Fendt produces the model e-100 Vario, that is a compact electric tractor, especially for its use in gardening, hothouses, and small agricultural farms. Another North American firm, the Soletrac, is marketing low power models (Smith *et al.*, 2021; Kara *et al.*, 2023). The Chinese YTO produces two models, one of 50 kW and another of 100 kW, the first of them it is being evaluated in Cuba by the IAgric.

Energy saving

The main advantage of the electric tractors, in comparison with those equipped with combustion motors, resides in the saving of fuel, an aspect that can be evaluated comparing the monetary costs of the type energy used in both types. In the Table 2 the fundamental data appear for different ranges of power according to the most widespread classification (Altrac, 2022; Larrazabal, 2022; Soca, 2022).

If we take as example a tractor of medium power, that is to say, of 90 - 100 hp, the saving in the cost of the energy is of about 626 CUP/h, a very important element to consider. The data of the cost of the electricity and the fuel are only illustrative, because the cost of the electricity and the diesel fuel can vary, and there are even subsidized entities or having a special treatment (see Table 2). Also, it is necessary to highlight the fact that generally the availability of fuel in offer doesn't always satisfy the necessities of the farmers and some of them should acquire a part of the fuel that they need buying it in the establishments that operate in foreign currencies. An additional aspect to consider is the energy efficiency: while a diesel motor has an energy efficiency of 30 - 40 %, in the electric motors it is near to 90 %.

Protection of the environment

Another advantage of the electric tractors resides in the facts that are friendlier with the environment, since they don't produce emissions of polluting gases. The combustion motors generate escape gases mainly composed of CO_2 that is the most harmful for the ozone layer. The emission of gases is in dependence of the power of the motor, but also influenced by the work load that it undergoes, the efficiency of operation of the motor and its technical state. The diesel motors emit 2.68 kg of CO_2 approximately for liter burnt. A tractor of 100 hp (74 kW) emits about 25.9 - 39.2 kg/h of CO_2, and small quantities of other gases like N_2O and NH_4, but that they are much more harmful for the ozone layer that the CO_2. These other gases produce an equivalent effect to 1.0 kg/h of CO_2, for what the equivalent total emission is of 26.8 - 40.2 kg/h of CO_2, as it is shown in the Table 3 (Infoagro, 2023; Kara *et al.*, 2023).

Noise levels

The electric tractors work with a very low level of noise, which is beneficial for the tractor driver and for people that can be in the proximities. A tractor with combustion motor, still those equipped with a good system of subduing the noise, can generate sonic levels that affect the driver in the continuous work, reason why strict regulations exist in this respect (NC ISO 116: 2001).

TABLE 2. Analysis of cost of the energy in the tractors electric YTO and of combustion

Power, hp	Electric tractor			Diesel tractor		
	Example	Type of battery, kWh	Cost of the recharge by hour of use, CUP/h	Example	Consumption, L/h	Cost, CUP/h
50-65	e-504	70	11,41	MK-654	15,7	471,00
90-100	e-1004	100	16,30	LX-904	21,6	648,00

TABLE 3. Analysis of emission of CO_2 in different classes of tractors

Power, hp	Class	Consumption, L/h	Emission of CO_2, kg/h
50	Small	5 - 8	13,4 - 21,4
100	Mean	10 - 15	26,8 - 40,2
200	Big	15 - 25	40,2 - 67,0

It is of highlighting that the almost entirety of the tractors in Cuba has open cabs, for what the driver is subjected to support up to about 70 - 85 dB that can be increased to 120 dB when undergoes accelerations or heavy work. The norms of hygiene and security of the work specify that continuous noise levels of more than 85 dB can damage the health, what can be showed in sickness, disorientation and other affectations. The electric tractors have a very low noise level that doesn't surpass the 3 - 5 dB.

Maintenance and repair

The tractors with combustion motor have numerous components that require a maintenance and continued repair, especially the motor, lubrication system, cooling, starting, fuel pumping, etc., but the electric tractors don't have these components, reason why the works and maintenance costs are very low.

Time of autonomy

The main disadvantage of the electric tractors lies in the limited time of autonomy, this is in dependence of the duration of the charge of the battery, as well as other factors. In the Table 5 are given the average hours of autonomy with complete load in a tractor equipped with standard batteries of 40 - 100 kWh that for medium intensity works can be from 3 to 6 h in most of the works that are carried out in the agriculture. For example, the mark YTO offers tractors with two types of lithium batteries: the model e-504, of 50 hp, with battery of 70 kWh and the e-1004, of 100 hp with battery of 120 kWh. However, there are optionally batteries of high capacity whose duration of the charge can reach from 6 to 12 h. The batteries for the vehicles are being perfected to a vertiginous rhythm with new components, reason why continually is being increased the time of operation before a new recharge.

The heavy works diminish the time of autonomy, as well as other factors that require high energy consumption: the work in lands with slopes, the use of high speeds, the excess of heat or of humidity, etc., (Cheng *et al.*, 2023).The Table 4 shows examples of autonomy for a tractor of medium power in different types of works.

It is necessary also to consider the time of recharge. While in a diesel tractor time for refueling is of some minutes, in the electric tractors the time of recharge of the battery can be of 8 - 12 h when a conventional loader is used, but it could decrease at 2 - 3 h if one of quick load is used. Models of tractors have been offered in which the package of batteries can be exchanged, that is to say that while the tractor works the other package it is loading.

Cost of acquisition

Another disadvantage is that the electric tractors have a cost of acquisition in a 30 - 40 % bigger that those with diesel motor, although also with the advances in the development and production of this type of machines, and especially, of the batteries, the initial cost decreases continually. However, the biggest initial cost is compensated quickly by the savings in fuel and in maintenance. It is considered that the investment in a combustion tractor recovers in a 5 year-old term, while one similar with electric motor it is of about 3 years.

Summary of the comparison among the electric and diesel tractors

In the Table 5 are shown in a comparative way, a summary of some differences among the technical characteristics for medium power tractors of typical models with electric and combustion motors. As it has been expressed in the previous epigraphs, the main advantages of the electric tractors are the smallest operation costs, zero emissions of noxious gases, smaller levels of noise, while the disadvantages reside in low autonomy, bigger initial cost and a weight until 20 % bigger (due to the weight of the battery) that can influence in the increment of the compactation of the soil (Folger, 2022).

TABLE 4. Duration of the recharge of the electric tractors according to the work

Type of work	Examples	Autonomy, hours
Slight	Transport, reaping, weeds chopping, spraying	4 - 8
Medium	2nd ploughing, furrowing, cultivation, sowing	3 - 6
Heavy	1st ploughing, heavy harrowing	2 - 4

TABLE 5. Comparison of some important characteristics in diesel and electric medium power tractors

Characteristic	Unit	Electric tractor	Diesel tractor
Mass	%	10 - 20 % more	
Cost of the tractor	%	30 - 50 % more	
Autonomy	h	3 - 6	Continuous use
Emission of CO_2	kg/h	Not	26,8 - 40,2
Emission of noise	dB	3 - 5	70 - 85
Cost of operation	peso/h	16,30	648,00

Aspects to consider for the exploitation of electric tractors in Cuba

The main aspect to keep in mind is to have a point of recharge of the battery of the tractor, with the necessary power and voltage. To reduce the electricity consumption it is recommended the installation of recharge points equipped with photovoltaic panels, that also represents an elevation of the costs of introduction of the system, but that can be recovered in a brief term. When the electric net is used, it is recommended the recharge of the batteries during the night, for not affecting the consumption picks.

Another aspect to consider is the type of works to those that the tractor is dedicated, because the time of duration of the load of the battery cannot be in correspondence with the necessities of the works in the farm. Soil ploughing is a heavy work that requires a bigger energy consumption that the transport, and therefore, smaller time of operation before the battery is out.

The limitations in the time of autonomy would imply, for example, to have more than a tractor or of a reserve battery. Also, the electric tractors are 30 - 50 % more expensive, what generally depends on the high cost of the battery.

CONCLUSIONS

In the study were determined in a comparative way the main technical characteristics and data of the operation of different representative models of electric and diesel tractors. The results show that the electric tractors of medium power that are the most used, produce saving of about 631 pesos/h in operation costs, they avoid the emission of 26,8 - 40,2 kg of CO_2/h, have noise levels that represent the 4 - 6 % with regard to the diesel tractors, among other advantages.

The negative factors are manifested in that the electric tractors have autonomy of 3 - 6 h, what implies long stops for recharge. Also, their use in heavy works or in difficult lands reduces the time of autonomy. The cost of acquisition can be of a 30 - 50 % bigger that those of diesel motor.

RECOMMENDATIONS

It is recommended to consider the advantages of the electric tractors in the acquisition of new machinery, with a gradual introduction for being creating the conditions and the knowledge in the use of these.

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