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A comparative analysis among tractors and animal traction in agriculture: efficiency and costs

Análisis comparativo de la tracción animal y tractores en labores agrícolas: eficiencia y costos

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ABSTRACT: Animal traction is a vital technology worldwide for agricultural work and the transport of goods and people, especially in developing countries, but in Cuba, knowledge of its relevance and potential remains insufficient. To analyze the most important aspects of using working animals and disseminate their advantages, a study was conducted. This study involved a comprehensive literature review to analyze the global population of working animals, the energy capabilities of each species, and a comparison between individual animals, teams of oxen, and tractors. The results showed that approximately 246 million bovines and 116 million equines are used for work worldwide, while Cuba has 365,000 oxen and 300,000 horses. A comparative cost analysis determined that animals have lower operating costs on farms smaller than 10-15 hectares compared to tractors. The possibilities and challenges of using animals in agriculture are discussed.
Keywords: Artificial Intelligence (AI), Non-Destructive Sensors and Measuring Instruments, Traceability, Post-Harvest Handling.

RESUMEN: La tracción animal es una tecnología de vital importancia en el mundo para las labores agrícolas y el transporte de productos y personas, especialmente en los países en desarrollo, pero en Cuba son aún insuficientes los conocimientos sobre su relevancia y posibilidades. Con el objetivo de analizar los aspectos más importantes en el uso de animales de trabajo y divulgar sus ventajas se realizó un estudio en el cual mediante una revisión bibliográfica exhaustiva se analizó la existencia de animales de trabajo en el mundo, las posibilidades energéticas de cada especie, la comparación entre animales solos, yuntas y tractores, Como resultados se determinó que en el mundo se usan en el trabajo unos 246 millones de bóvidos y 116 millones de équidos, mientras que en Cuba hay 365 000 bueyes y 300 000 caballos. Se hizo un análisis comparativo de costos y se determinó que los animales tienen menor costo de operación en fincas de menos de 10-15 ha respecto al tractor. Se exponen las posibilidades y dificultades en el uso de animales en la agricultura.
Palabras clave: agricultura a pequeña escala, animales de trabajo, protección medioambiental, ahorro de energía, comparación económica.

INTRODUCTION

Globally, animal traction is a vital technology for agricultural work and the transport of goods and people, especially in developing countries. However, in Cuba and other developing countries, knowledge about its relevance and potential remains insufficient. In Cuba's current conditions, there are significant limitations in the availability of fuel, lubricants, and spare parts for agricultural machinery.

In this regard, it is necessary to promote the use of working animals, recognize their importance, and disseminate information about their capabilities. Despite their importance, there is a lack of detailed comparative analysis on the economic and operational efficiency of animal traction versus mechanization in specific contexts such as Cuba.

Therefore, the Institute of Agricultural Engineering Research undertook a study of the most important aspects of using working animals, taking into account the existence of working animals worldwide, the energy capabilities of each species, and comparing individual animals, teams, and tractors.

MATERIALS AND METHODS

For the collection and analysis of information, the methodological procedure included a comprehensive literature review using internet searches. Information on the topic was also gathered from published articles, papers presented at scientific events, research reports, laws, resolutions, institutional policies, etc., concerning the use of animals in agriculture.

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The use of working animals in Cuba and worldwide was analyzed. A comparative analysis of costs and traction capabilities between tractors and draft animals was conducted, the economic aspects of animal traction were determined, and a comparison was made between a single animal and a team of oxen.

RESULTS AND DISCUSSION

Use of working animals in Cuba and worldwide

Global and country-specific figures exist on the working animal population, but it is important to note that the data have limitations. The most reliable information comes from the Food and Agriculture Organization of the United Nations (FAO), although its estimates may vary due to the lack of up-to-date censuses in many countries. This organization estimates that approximately 246 million bovines (oxen, buffalo, etc.) are used for work worldwide. In addition, there are around 116 million equines (60 million horses, 50 million donkeys, and 6 million mules). Of these, approximately 112 million are found in developing countries. Figures for camels are more variable, with estimates ranging from 19 to 40 million. It is estimated that Cuba has around 365,000 oxen (182,500 teams), 300,000 horses, and about 30,000 mules.

In some countries, horses are primarily used for transporting people and goods, but, especially in Europe, there is also some tradition of using them for agricultural work. The United States has approximately 10.3 million horses, Mexico 6.4 million, Brazil 5.8 million, and Mongolia 4.3 million. China has approximately 3.7 million. In India, approximately 1.5 million oxen and buffalo are used for plowing, and in Latin America, the use of draft oxen in agriculture is common (FAO, 2023).

A significant finding is that some studies have demonstrated the potential for using dairy cows for agricultural work. Zerbini *et al.* (1999) showed that milk production from working cows was only 10% lower than that of non-working cows. The productivity index of cows receiving nutritional supplements was higher (0.38) than that of non-supplemented cows (0.24). The incremental benefit-cost ratio of having supplemented cows working was approximately 3.5, with an internal rate of return of 78%.

Comparative analysis between tractors and draft animals

Comparing a team of oxen or a horse with a tractor involves evaluating investment costs, maintenance, fuel, lifespan, and suitability for the terrain. The economic advantages of a team of oxen, assuming their use in small- or medium-scale agriculture, can be summarized as a low acquisition cost, since a pair of trained oxen costs much less than any new or used tractor in good condition. The use of fossil fuels or electricity is replaced, since for oxen the only "fuel" is grass, forage, or crop residue, often produced on the farm itself. Tractors require continuous maintenance: engine, tires, oils, filters, etc., while draft animals only require veterinary care, and equines only occasional shoeing. At the end of their lives, oxen have value as meat and leather. A tractor requires expensive infrastructure: a workshop, imported spare parts, and electricity. Animals produce less soil compaction, saving on future subsoiling or amendment costs (Pimentel *et al.*, 2007).

However, the tractor has greater hourly productivity, as it can plow 5 to 10 times more land per day than a team of oxen, resulting in lower operating costs per hectare for arable land of 10-15 hectares or more. With its machinery and implements, the tractor performs tasks that oxen cannot or would take much longer to do. A tractor driver replaces two or three workers, and the tractor can work 12-16 hours straight if necessary, while a team of oxen should not be used for more than 4 hours, and that's during cooler hours.

The actual capacity of a team of oxen depends on several variables, and mainly on the fact that the pulling force while moving is usually between 10% and 14% of the animals' live weight. An adult ox weighs between 500 kg and 700 kg, so, taking an average of 600 kg, a team (two oxen) of 1,200 kg can generate a stable force of about 140 kgf (1.4 kN) under steady working conditions, and can reach peaks of up to 222 kgf (2.18 kN) when starting or on difficult terrain. To set a heavy load in motion (such as a cart or a deeply sunk plow), the starting force can reach up to 95% of its weight (more than 1,000 kgf), although only for a few seconds.

The type of work must also be considered: A traditional plow can require forces between 85 kgf and 218 kgf, depending on the soil hardness and the maneuvers of the ox driver. This force allows for very heavy tasks that would be impossible for a human or an animal. With several teams of oxen, carts with a load capacity of up to 6 tons can be moved, and this was common practice in sugarcane harvesting (although on flat terrain). Animal traction has advantages over tractors on soft or muddy terrain, and they are capable of working on slopes of up to 45% (FAO, 2023).

Tests have been carried out to measure the pulling capacity of horses. Two horses generated an average pulling force of 17.3 N, moving at 1 m/s and developing an average power of 0.86 kW per horse. Some studies showed that camels can pull maximum loads of 5620 N with a cart and 2490 N with a sled (between 119-143% of their body weight) at constant speeds (Bobobee, 2007).

Comparison between a team and a single animal

A comparison was made between an ox and a horse, and between a single animal and a team. Comparing an ox with a horse from an economic perspective involves evaluating acquisition cost, maintenance, versatility, and lifespan. An ox exerts a force similar to that of a robust draft horse (approximately 70 kgf). Although the horse is faster (50% faster), the ox can pull heavier loads for longer periods without rest. Oxen do not need horseshoes and require less veterinary care than horses, as they are more resistant to disease. The horse needs less land than an ox for grazing.

Oxen are almost exclusively used in teams, but studies show that for the same tasks there are generally possibilities and economic advantages to working with a single animal. With a team, a substantial portion of the pulling power is wasted, and a single animal is much more maneuverable for the driver, especially when turning in small plots and in mountainous or obstacle-filled areas. A single ox is suitable for plowing, cultivating, pulling a cart, and similar tasks requiring low pulling power, while a team is more suitable for tilling the soil, harrowing, and pulling carts weighing more than 2 tons.

Challenges of Animal Traction

In developing countries, animal traction covers 23% of agricultural energy needs, while human power accounts for 71% and motorized power for only 6% (FAO, 2023). In these countries, the use of animals remains a crucial energy source for agriculture, but in some regions, especially in Africa, there is generally limited knowledge about working with oxen and horses. A similar situation exists in Latin America. In Brazil, animal power covers 30% of energy needs, human power 60%, and motorized power 10% (Ríos, 2020).

In Cuba, the use of animal traction has always been fundamental, even during periods of high availability of tractors and fuel. However, limitations exist, especially regarding the availability of animals, the preference for tractors, and protection against theft. A study from the University of Ciego de Ávila describes animal traction systems, highlighting their importance and limitations, such as animal theft and high dependence on imported inputs (implements, harnesses, medicines). Oxen are used for a wide variety of tasks on farms, while horses are particularly important for rural and urban transportation (Pérez, 2000).

In mountainous areas, working animals are sometimes essential; oxen for agricultural work and mules for transporting goods. Pimentel *et al.* (2007) and Pereira (2024), evaluated the energy efficiency and economic feasibility of using animals to pull farming implements in mountainous conditions, demonstrating that it is a renewable and viable alternative. The study demonstrates the need to improve the formation of the teams (animal-team-plow) to ensure their energy efficiency.

Another study compared the performance of three animal-drawn implements (a plow and two types of cultivators) in bean cultivation at a cooperative in Granma province, measuring their productivity and efficiency. The greatest working depth (17.50 cm) was achieved with the plow; the greatest working width (92 cm) with the five-tine cultivator; and the highest speed (2.80 km/h) with the three-tine cultivator (Olivet *et al.*, 2020).

Vargas *et al.* (2017) conducted an economic and energy comparison between a tractor and a team of oxen in bean cultivation, quantifying the difference in productivity and operating costs on a red Ferralitic soil. The team of oxen had a productivity 4.23 times lower than the tractor, but the small-horsepower tractors proved to be up to 48% cheaper and 58% more energy-efficient than the team.

Suárez *et al.* (2005) conducted a comparative study on the advantages of using animal traction instead of tractors, depending on factors such as farm size and economic conditions. The results indicate that animal traction is a particularly viable option on small farms (less than 18.8 ha) and for cultivation tasks. The study emphasizes that, although mechanized traction is essential and more economical under certain conditions, animal traction remains a relevant alternative.

A very important aspect is the availability of food for working animals. In many countries, the average workday in agricultural tasks is 3 hours per session, but animal welfare is frequently violated, such as the lack of water and insufficient supplemental feed, since the average fallow area per farmer is only 0.46 acres per animal, which is insufficient. Animal traction is underutilized in Africa, where manual labor is the primary tool. For many years, efforts have been underway to promote the use of draft animals, which requires overcoming deeply ingrained customs. An example of this is a study by Williams (1997), which demonstrated that using animal traction in Niger increased sorghum and maize yields by 12-15%, with the return on investment ranging from -4% to 18% in the dry zone and from 14% to 58% in the humid zone. In the humid zone, human labor was reduced by 50 man-hours per hectare.

Animals can also be used for other non-traditional tasks such as planting and pest control. Bagnall *et al.* (2016) designed and tested an animal-powered seeder for conservation agriculture in Africa. The seeder exhibited an average pull of 796 N, low enough to be pulled for 8 hours by a team of oxen. The desired sowing depth of 2 cm for cowpea seeds was achieved with a 25% deviation, and the seed spacing of 10 cm was achieved with a 50% deviation. It was designed and tested in Cuba at the Institute of Agricultural Engineering Research.

Nunes *et al.* (2023) explored the innovative use of animal traction in forestry for timber extraction in areas difficult to access for heavy machinery, highlighting the potential of working animals to create economical and efficient local value chains.

Especially in Africa, it is important to emphasize the importance of replacing manual labor with animal traction. A study in Zambia demonstrated that preparing one hectare of land with a ripper requires only 4 hours, instead of three full days. Turay *et al.* (2022) showed that a pair of oxen plows 1.4 acres in 5.1 hours. Oxen work an average of 5.2 days a week and 5.3 months a year. Many international organizations and research institutes have been actively promoting the use of animal traction, particularly in the development of improved harnesses, implements, and farming technologies. An important role has been played by the West African Animal Traction Network (ATNESA), which regularly holds workshops, symposia, and exhibitions, promotes fieldwork and research, and publishes numerous works on the subject (Starkey y Faye, 1990).

Even in more developed countries such as France, the USA, and Germany, among others, there is a renewed interest in animal traction, framing it within the agroecological transition. This practice, almost extinct in the mid-20th century, is being reclaimed by alternative movements and organic farmers seeking to reduce their dependence on fossil fuels and improve soil health (Miara *et al.*, 2023).

Animal traction has significant advantages in environmental protection. In addition to fuel savings, it is very important for soil protection, and numerous studies have been conducted on this topic. For example, García-Tomillo et al. (2017) conducted a study comparing the impact of tractor tillage versus tillage with oxen and donkeys on soil compaction in northeastern Portugal. Preliminary results showed that, although all methods increase soil bulk density, the increase is significantly lower with animal traction. The study reports an increase in soil bulk density at a depth of 0-5 cm: 15% with a tractor, compared to 8% with animals. Saturated hydraulic conductivity (Ks) was reduced to 33% with a tractor, while with cows it remained at 83%.

Numerous development, research, and promotional efforts are underway worldwide to improve animal traction methods. For example, improvements are being made to harnesses (yokes, collars, harnesses). One study evaluated how harness design affects traction force and, ultimately, sorghum production. In Burkina Faso, Barro *et al.* (2017) compared an improved ox yoke with a traditional one, and an improved donkey collar with a classic one. The improved yoke provided 57% more tractive force (8.3 N versus 5.3 N). In Cuba, IAgric has developed and researched new machines and harnesses for animal traction: seeder, multi-cultivator, multi-plow, sprayer, extendable yoke, etc., all with satisfactory results and expanding the possibilities for using these technologies (Ríos, 2020).

CONCLUSIONS

The study determined the widespread use of animal traction worldwide, with an estimated population of 246 million cattle and 116 million equines, while in Cuba there are 365,000 oxen and 300,000 horses.

The advantages of using animals in agriculture were analyzed: lower operating costs on farms smaller than 10-15 hectares compared to tractors, the possibility of using a single ox instead of a team, and the availability of new machinery and improved harnesses for animal traction. Among the challenges are animal theft and the need for sufficient food and water.

RECOMMENDATIONS

Intensify efforts to highlight the importance of knowledge and support for the use of animal traction in Cuba, especially among management personnel and students of agronomy and agricultural mechanization. Future research on this topic could focus on optimizing animal nutrition to maximize productivity and welfare, as well as on developing more efficient implements and harnesses for animal traction.

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