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Economic-Operational Evaluation Methodology for Pasture Rehabilitation Based on Coring with Soil Samplers Tubes

Metodología de evaluación económico-operativa para la rehabilitación de pastizales degradados basada en horadación con tubos sacabocados

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ABSTRACT: Given the problem of soil compaction in Cuban grasslands caused by overgrazing, which reduces productivity and degrades the ecosystem, the methodology of drilling technology with punch tubes is proposed. This method, less invasive and expensive than traditional techniques such as subsoiling or plowing, consists of drilling into the soil to extract small plugs of soil, thus improving aeration, water infiltration and root development in the surface layer affected by livestock trampling. The methodology seeks to evaluate the economic and operational viability of this technology in local conditions, demonstrating that it represents an efficient alternative, with low energy consumption and minimal environmental impact for the sustainable rehabilitation of grasslands.
Keywords: soil compaction, grassland overgrazing, soil aeration, water infiltration.

RESUMEN: Ante el problema de la compactación del suelo en pastizales cubanos causada por el sobrepastoreo, que reduce su productividad y degrada el ecosistema, se propone la metodología de una tecnología de horadación con tubos sacabocados. Este método, menos invasivo y costoso que las técnicas tradicionales como el subsolado o el arado, consiste en perforar el suelo para extraer pequeños tapones de tierra, mejorando así la aireación, la infiltración de agua y el desarrollo de las raíces en la capa superficial afectada por el pisoteo del ganado. La metodología busca evaluar la viabilidad económica y operativa de esta tecnología en condiciones locales, demostrando que representa una alternativa eficiente, de bajo consumo energético y mínimo impacto ambiental para la rehabilitación sostenible de los pastizales.
Palabras clave: compactación del suelo, sobrepastoreo de pastizales, aireación del suelo, infiltración de agua.

INTRODUCTION

Grasslands constitute the main food for herbivores destined for human consumption, which have allowed certain regions to be characterized by their abundant and varied livestock production. Likewise, until not many years ago, agriculture has not been given the appropriate technological importance and currently its interest has been directed to crop methodologies and, especially, to the design of agricultural machinery and accessories that seek to improve efficiency in multiple agricultural activities such as planting, fertilizing, aeration, renewal, transportation of products, harvesting among others (Matteucci & Colma, 1997).

Grassland conservation is essential to protect wildlife and maintain ecological balance, as they act as natural sponges, absorbing rainwater and preventing flooding.

Botta *et al.* (2022) points out that the constant trampling of the pasture by cattle produces soil compaction, this implies that permeability is gradually lost, preventing water, air and nutrients from entering it, progressively reducing the production of the pasture. To recover grasslands that, due to overgrazing, see their yield reduced as a result of surface compaction, highly invasive and expensive technologies are used in Cuba.

Among the most common are subsoilers and decompactors, which improve soil aeration and drainage by breaking up compacted layers. Chisel plows prepare the soil for planting, while direct seeders allow sowing without the need for prior tillage, reducing erosion. In addition, the compaction rollers ensure good contact between the seeds and the soil, and the sprayers apply phytosanitary products uniformly.

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Aeration of agricultural soils

Soil aeration refers to the supply of oxygen for the proper development of microorganisms and the roots of the plants in the soil. Among the important factors for good plant development is soil aeration, since its pores contain a mixture of water and gases, constituting the soil atmosphere (Curran-Cournane et al., 2011).

Importance of soil aeration in grasslands

Periodic soil aeration is essential to keeping farmland healthy. The health of crops or livestock pastures depends on allowing plants and herbs to form deep, strong root networks. Compacted soil is the result of the passage of tractors and large animals that compress it, which inhibits the growth of roots and the formation of beneficial microorganisms by collapsing the necessary air pockets, the formation of thatch has the same effects. Consequently, the process of reinserting air holes by making holes in the soil has a healthy effect on the growth of agricultural flora by promoting root growth and improving irrigation. The optimal times to aerate the soil depend on the crop and its usual growing season (Bakker & Hidding, 1970).

Economic importance of grasslands

According to Altesor *et al.* (2011) grasslands, as extensive ecosystems covered mainly by grass and herbaceous plants, where trees and shrubs are scarce. They play a crucial role in environmental sustainability and the global economy. Grasslands are vital to the livelihoods of millions of people. According to the Food and Agriculture Organization of the United Nations (FAO), more than 800,000,000 people depend on grasslands for their livelihoods. These ecosystems provide a wide range of services and products, such as food, forage and energy (Prieto & Ernst, 2010).

In addition to their importance for human nutrition, grasslands play a crucial role in the conservation of biodiversity. They are home to numerous species of animals and plants, many of which are endemic and found nowhere else in the world. Grassland conservation is essential to protect wildlife and maintain ecological balance (Altieri, 2002).

Finally, grasslands play an important role in regulating the water cycle and carbon storage. These ecosystems act like natural sponges, absorbing rainwater and helping to prevent flooding. They also store large amounts of carbon, helping to mitigate climate change (Altieri, 2002).

The compaction phenomenon and its impact on pasture degradation

Soil is a fundamental component of the region's farms and productive lands, making it a key element in the development of their agroecological, agricultural, and livestock systems. The study of soil compression due to trampling by animals during grazing is of great importance regarding their current and future productivity (Botta *et al.*, 2022).

Based on the review conducted, the objective of this study is to propose a soil boring technology using coring tubes. This technology involves perforating the soil to extract small plugs of earth, thereby improving aeration, water infiltration, and root development in the surface layer affected by livestock trampling. The methodology seeks to evaluate the economic and operational viability of this technology under local conditions, demonstrating that it represents an efficient, low-energy, and minimal-environmental-impact alternative for the sustainable rehabilitation of grasslands.

TOPIC DEVELOPMENT

Methods

The methodologies will be used at Granja El Guayabal, part of the Agrarian University of Havana, where fieldwork and experimental research are being conducted. The study will require a 2-hectare area of grassland and a 14 kN traction class tractor. For the work, overlapping and combined row movements will be used, and a turn without overlap, as shown in figure 1.

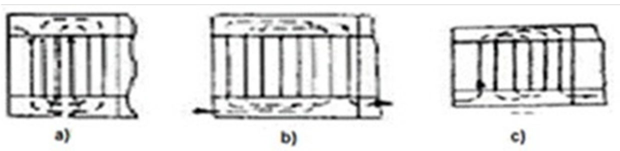

Figure 1. Types of turns and forms of movements and types of movements for the tasks to be performed, a) splitting movement in stripes, b) combined movement in stripes and c) form of turning without laso.

To determine the experimental conditions, the procedures established in PG-CA-042 (2013), will be followed to characterize the test plot and in which it is established:

Type of soil and its name and terrain relief. The existing maps will be taken where the tests will be carried out, in accordance with the II Genetic Classification of Soils in Cuba (Hernández-Jiménez et al., 2019).

Determination of volumetric density, γd. Samples shall be taken at several points along both diagonals of the test plot at three depth levels (0 to 0.1 m; 0.1 to 0.2 m; 0.2 to 0.3 m). An auger and 100 cm3 capacity cylinders shall be used, in accordance with NC ISO 11508: (2000). The sample masses shall be determined after drying in a MEMMERT oven at 105°C for 24 h, using a METTELEL TOLEDO precision balance, model B 2002-S (±0.1 g). The values of the dry soil masses between the fixed volume of the cylinders determine the values of γd, averaging for each depth level. It will be calculated by expression 1:

$$\gamma_d = \frac{G_n}{V_c} \qquad (1)$$

where: γd- is the volumetric density of the soil, g cm^{-3}; Gn- is the mass of the soil sample after drying, g; Vc- is the volume of the cylinder for sampling, cm^3.

The soil samples in each of the selected points of the experimental area will be placed in previously numbered nylon bags and taken to the soil mechanics laboratory for weighing before and after drying.

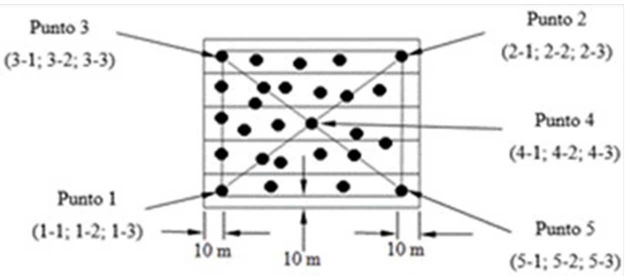

Figure 2. Diagram of points and soil sampling

Determination of soil moisture. It will be determined by the gravimetric method, according to NC 110: (2010) and at the same points and depths designated for the apparent density of the soil, a part of the soil will be placed in hermetic containers (greater than 250 cm^3 capacity), determining its mass at the time of being taken and after being dried, as explained above and averaged by depth levels.

Measurement of the footprint of the perforations

For the research tests, it was considered to measure the dimensions of the perforation mark, the pulling force necessary to work with the proposed machine, as well as the technical expertise of the machine.

The dimensions of the footprint of the holes made by the implement will be determined by measuring their diameter and depth.

The diameter and depth will be determined using a caliper with an accuracy of 0.1 mm. The diameter will be measured in two diametrical directions, while to determine the depth, a sector of metal bar will be fitted into the holes on which the ground level is marked after its introduction, taking the measurement with the caliper on said bar. The distance between the holes and their distribution on the ground surface will be determined with a ruler graduated with accuracy up to 1 mm.

Methods and means to be used for the experimental measurement of draft force under field conditions.

Figure 3 shows the measurement of the pulling force required to drag the aerator cylinder; a KRD-2 type extensometric dynamometer (2) is inserted between the tractor (3) and the implement being measured.

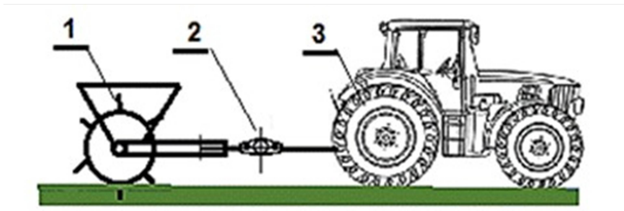

Figure 3. Conformation of the aggregate for measuring the pulling force under field conditions

The analog signals captured with the KED-2 dynamometer are sent through a strain gauge connection box model YE 29003A, to the SINOCERA dynamic voltage amplifier model YE 3817C, which amplifies them and sends them to the SINOCERA dynamic data acquisition card model YE 6231, which carries out the analog-digital conversion of the signals and the transferred to the Intel (R) Pentium (R) i3 3.00 GHz processor for registration figure. 4.

Technical expertise of the machine

The technical expertise of the machine will include:

- Expertise on the construction of the machine. It consists of the determination of the fundamental work parameters, the technical description, characteristics and photographs, the construction weight, working width, height, as well as center of gravity and stability according to NC 19-02-13 (1986).
- Expertise on technical security and mechanisms. During the test, the following must be determined: the safety of the parts and assemblies exposed to the action of the environment, periodicity and nature of wear, breakage and its causes, deformation of the parts.

Methodology for the technological and exploitation evaluation used for the decompaction-aeration of grasslands

The evaluation of exploitation indices will be based on Timing Model 1, adapted from Standard NC- 3437 (2003) and PG-CA-042 (2013).

To determine the technological exploitation indices, the times of timing model 1 were classified according to what was established in PG-CA-042 (2013).

For the determination of productivity indices

Based on the primary timing data reflected in the summary, the following indices will be determined during the test period:

Figure 4. Some components of the strain gauge measurement system: a) strain gauge bridge box model ye 29003a; b) sinocera dynamic voltage amplifier model ye 3817c; c) sinocera dynamic data acquisition card model YE 6231

First you need to calculate the productivity or capacity of the machine, it is the amount of work done by it in a certain unit of time. The amount of work can be measured in hectares worked and in tons of product processed per hour, here it will be determined in ha/h.

Productivity per hour of clean time, (W1):

$$W_1=\frac{Q}{T_1},\frac{ha}{h} \quad (2)$$

Where:
Q- Volume of work carried out with the machine in ha, kg and others

Productivity per hour of operating time. (W_{02})

$$W_{02}=\frac{Q}{T_{02}},\frac{ha}{h} \quad (3)$$

Where:
T_{02}- Operating time, h;

$$T_{02}= T_1+ T_2, h \quad (4)$$

Productivity per hour of productive time. (W_{04})

$$W_{04}=\frac{Q}{T_{04}},\frac{ha}{h} \quad (5)$$

Where:
T_{04}- Productive time, h;

$$T_{04}= T_1+ T_2+T_3+ T_4, h \quad (6)$$

Productivity per hour of shift time without failure. (W_t)

$$W_t=\frac{Q}{T_t},\frac{ha}{h} \quad (7)$$

Where:
T_t- Shift time without failure, h;

$$T_t= T_1+ T_2+T_3+ T_5+T_6, h \quad (8)$$

Productivity per hour of operating time. (W_{07})

$$W_{07}=\frac{Q}{T_{07}},\frac{ha}{h} \quad (9)$$

Where:
T_{07}- Operating time, h

$$T_{07} \equiv T_1+T_2+T_3+T_4+T_5+T_6,\ h \quad (10)$$

General rehearsal time. (T_g)

$$T_g \equiv T_1+T_2+T_3+T_4+T_5+T_6+T_8;\ h \quad (11)$$

Operating coefficients.

Working pass coefficient (K_{21})

$$K_{21} \equiv \frac{T_1}{(T_1+T_{21})} \quad (12)$$

Technological service coefficient (K_{23})

$$K_{23} \equiv \frac{T_1}{(T_1+T_{23})} \quad (13)$$

Technical maintenance coefficient (K_3)

$$K_3 \equiv \frac{T_1}{(T_1+T_3)} \quad (14)$$

Technological safety coefficient (K_{41})

$$K_{41} \equiv \frac{T_1}{(T_1+T_{41})} \quad (15)$$

Technical safety coefficient (K_{42})

$$K_{42} \equiv \frac{T_1}{(T_1+T_{42})} \quad (16)$$

Coefficient of utilization of productive time (K_{04})

$$K_{04} \equiv \frac{T_1}{(T_1+T_{04})} \quad (17)$$

Coefficient of utilization of operating time (K_{07})

$$K_{07} \equiv \frac{T_1}{(T_1+T_{07})} \quad (18)$$

Methodology for evaluating quality in grassland decompaction-aeration

The quality of the decompaction-aeration process is evaluated through a comprehensive protocol based on international regulations that includes three phases: pre-evaluation (analysis of physical properties of the soil), real-time monitoring (recording of operational parameters) and post-evaluation (verification of effects) (Smith, 2020).

Key indicators such as effective depth (penetrometric rod ±1 mm), diameter of perforations (digital caliper ±0.05 mm) and resistance to penetration (electronic penetrometer 0-1000 layer) are measured, with strict controls on humidity (12-18%) and speed (3.5-5 km/h). To determine the working depth, at least 25 measurements are carried out distributed along the diagonals of the field 14 m from its ends (figure 5). These measurements allow a reliability of 95% and an error of 0.5 according to González-Cueto et al. (2017).

Uniformity is quantified by the Spatial Distribution Index (SDI ≥85%) using geostatistical analysis, while changes in apparent density (minimum 8% reduction) and aggregate stability were statistically validated (ANOVA, $p<0.05$), ensuring reliable and reproducible results for process optimization.

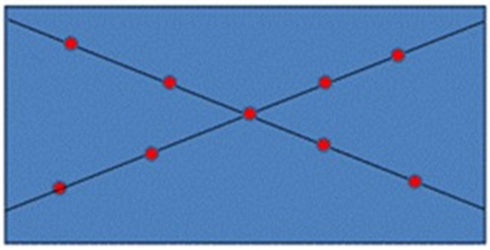

Figure 5. Scheme of depth measurement in the field

Determination of aggregate stability

The dynamic stability is determined by statistically comparing the average values of the depth and its error (deviation) for each row of the working organs and for each working pass in the tests carried out. The measurement is repeated 15 times to achieve generalizable results. If there is no significant difference between these values for each row and for each pass, it can be stated that there is adequate transversal dynamics. Longitudinal dynamic stability is checked if these values of the average deviation at depth do not exceed 15%. To determine the aforementioned parameters, Statgrafics statistical software version 5.1 will be used.

CONCLUSIONS

- Drilling with punched tubes facilitates aeration of the root profile, reduces the apparent density of the soil and favors the regeneration of palatable grasses, increasing biomass and plant cover on degraded surfaces.
- Soil aeration and reduced compaction increase water infiltration, reduce erosion and promote soil biodiversity.
- The drilling technique with punched tubes is aligned with sustainable management practices when combined with plowing work plus grading in appropriate phases, strategic use of fertilizers and control of undesirable forage plants.
- Success depends on variables such as water availability, forage prices, input costs and climate variability. A phased approach is recommended (pilots by quarters), monitoring of soil indicators (moisture, porosity, organic matter) and adjustment of drilling density and frequency. Incorporate incentives for rehabilitation, species diversification, and a risk mitigation plan (e.g., density variation, input reserves).

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