Animal Drawn BioMechanical System (ADBIS) for Tillage in Colombia

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Abstract

The feasibility of using draft horses in the Andean (oriental) region of Colombia, was determined from an agricultural, socio-economic, energy and environmental perspective. A mechanical prototype named Animal Drawn Biomechanical System (ADBIS), composed of a hitch-cart/work-cart, two draft horses and a chisel plow were used for the study. To register and measure the draft force and working depth, an electronic measuring system (datalogger) was designed and built for this study, based on Arduino 1 card complemented by a Polar M400 sport watch with equine heart rate monitor band, to measure heart rate and animal speed during tillage. The tests were conducted in five experimental units, under different soil conditions and altitudes (a.s.l.), on-farm soil sampling was taken to determine the percentage of soil humidity and, a non-standard soil shear resistance rod (vane shear tool) to determine soil compaction to evaluate animal draft performance and tillage tool efficiency/efficacy. The ADBIS, could effectively performed in heavy soils and altitudes between 2560 and 3400 meters (a.s.l.), demonstrating its capacity to till in highly compacted and shear resistance soils in the Andean region at a depth of 15 cm. The ADBIS' lighter weight reduces soil compaction and allows for the employment of soil conservation practices. In conclusion, the use of systems like ADBIS are a reliable and economical source of animal energy to perform multiple agricultural tasks with a minimal environmental impact and for use by small and medium size farmers in the Andean region of Colombia.

Résumé

La faisabilité de l'utilisation de chevaux de trait dans la région andine (orientale) de la Colombie a été déterminée d'un point de vue agronomique, socio-économique, énergétique et environnemental. Le système de travail du sol biomécanique à traction animale (SIBIOTA), composé de deux chevaux de trait, d'un chariot d'attelage et d'une charrue à chisel (outil de travail du sol) a été utilisé pour l'étude. Pour les enregistrements et les mesures des forces de traction et de la profondeur de travail, un système de mesure électronique en temps réel (datalogger) a été conçu, composé d'une carte Arduino 1 et complété par une montre de sport POLAR M400 avec une sangle équine, pour mesurer la vitesse de travail et la fréquence cardiaque des animaux pendant le travail du sol. Les tests ont été réalisés dans 5 unités expérimentales (UE) dans des conditions de sol et d'altitude (masl) différentes, où des échantillons de sol ont été prélevés pour déterminer les pourcentages d'humidité et une tige non standardisée (9 mm X 1000 mm) a été utilisée pour évaluer la compaction du sol et la résistance potentielle au cisaillement afin de la mettre en relation avec la performance des animaux et l'efficacité et l'efficience de l'outil de travail du sol. Le SIBIOTA s'est montré efficace dans des sols lourds et à des altitudes comprises entre 2560 et 3400 mètres au-dessus du niveau de la mer, démontrant ainsi sa capacité à travailler des sols à forte résistance à la pénétration/coupe à une profondeur de 15 cm dans la région andine. Le poids léger du SIBIOTA réduit le compactage et facilite l'utilisation des pratiques de conservation du sol. En conclusion, l'utilisation de systèmes tels que le SIBIOTA, sont une source fiable et économique de puissance animale pour effectuer de multiples tâches agricoles avec un impact environnemental minimal et à la portée des petits et moyens producteurs de la région andine de Colombie.

Kurzfassung

Die Durchführbarkeit des Einsatzes von Zugpferden in der (östlichen) Andenregion Kolumbiens wurde aus agronomischer, sozioökonomischer, energetischer und ökologischer Sicht untersucht. Für die Studie wurde das biomechanische, von Tieren gezogene Bodenbearbeitungssystem (SIBIOTA) eingesetzt, das aus zwei Zugpferden, einem Anhängewagen und einem Meißelpflug (Bodenbearbeitungsgerät) besteht. Für die Aufzeichnungen und Messungen der Zugkräfte und der Arbeitstiefe wurde ein elektronisches Echtzeit-Messsystem (Datalogger) entwickelt, bestehend aus: einem Arduino 1 Board und ergänzt durch eine POLAR M400 Sportuhr mit Pferdegurt, um die Arbeitsgeschwindigkeit und die Herzfrequenz der Tiere während des Pflügens zu messen. Die Versuche wurden in 5 Versuchseinheiten (UE) unter verschiedenen Bodenbedingungen und Höhenlagen (m ü.d.M.) durchgeführt. Dabei wurden Bodenproben entnommen, um den Feuchtigkeitsgehalt zu bestimmen, und eine nicht genormte Stange (9 mm x 1000 mm) verwendet, um die Bodenverdichtung und die potenzielle Scherfestigkeit zu bewerten und sie mit der Leistung der Tiere sowie der Effizienz und Wirksamkeit des Bodenbearbeitungsgeräts in Beziehung zu setzen. Der SIBIOTA war in der Lage, in schweren Böden und in Höhen zwischen 2560 und 3400 Metern über dem Meeresspiegel effektiv zu arbeiten. Er bewies damit seine Fähigkeit, Böden mit hohem Eindring-/Schneidewiderstand in einer Tiefe von 15 cm in der Andenregion zu bearbeiten. Das geringe Gewicht des SIBIOTA verringert die Verdichtung und erleichtert die Anwendung konservierender Bodenbearbeitungsmethoden. Zusammenfassend lässt sich sagen, dass der Einsatz von Systemen wie dem SIBIOTA eine zuverlässige und wirtschaftliche Quelle für tierische Energie ist, um verschiedene landwirtschaftliche Aufgaben mit minimalen Auswirkungen auf die Umwelt und in Reichweite kleiner und mittlerer Erzeuger:innen in der kolumbianischen Andenregion zu erfüllen.

Resumen

Los resultados de este estudio determinan que la utilización de caballos de tiro en la región (oriental) andina de Colombia, desde una perspectiva agronómica, socioeconómica, energética y ambiental son totalmente viables y productivos. El Sistema Biomecánico de Labranza a Tracción Animal (SIBIOTA), compuesta por dos caballos de tiro, un carro de enganche y un arado de cincel (herramienta de labranza) fue utilizado en este estudio. Para los registros y mediciones de las fuerzas de tiro y profundidad de trabajo, se diseñó un sistema de medición electrónica en tiempo real (datalogger), compuesto por una tarjeta Arduino 1, complementado con un reloj deportivo POLAR M400 con cinta equina. Este convulo permite medir la velocidad de trabajo y ritmo cardiaco de los animales durante la labranza. Las pruebas se realizaron en 5 unidades experimentales (UE) bajo diferentes condiciones de suelo y altitudes (msnm). Además, se tomaron muestras de suelo para determinar porcentajes de humedad, utilizando una varilla no-normalizada (9 mm X 1000 mm) para evaluar la compactación del suelo y la potencial resistencia al corte, lo que permite relacionarlo con el rendimiento de los animales y la eficiencia de la herramienta de labranza. El SIBIOTA, pudo desempeñarse eficazmente en suelos pesados y en altitudes entre 2560 a 3400 msnm, demostrando su capacidad para labrar suelos, con alta resistencia a la penetración/corte a profundidades de 15 cm, en la región andina. El peso liviano del SIBIOTA reduce la compactación y facilita el empleo de prácticas de labranza de conservación. En conclusión, el uso de sistemas como el SIBIOTA, son una fuente confiable y económica de energía animal para desempeñar múltiples tareas agrícolas con mínimo impacto ambiental y al alcance del pequeño y mediano productor de la región andina de Colombia

Introduction

The use of draft horses is becoming more appropriate in the context of sustainable agriculture development and means a responsible interaction with the environment. Given the growing need for producing more and higher quality foods, it is necessary to consider alternative sources of energy whose capacity should be based on the efficient use of local renewable resources. Incorporating the use of animal traction with equines in local and national level agriculture can generate opportunities for sustainable development at a lesser cost, reduced fuel consumption and the fostering of employment opportunities for the non-qualified (traditional) rural labor force.

Small family farming in the Andean Cundiboyacense region of Colombia, is described as very traditional and utilizes minimal, modern technologies that allow them to complete their fieldworks in an opportune and efficient manner. It is characterized by smallholdings with a high dependency on the use of hand labor with limited education and training and a strong rooted ancestral knowledge. The most utilized productive systems are: potatoes and double-purpose livestock.

The small size of their landholdings in actual terms are considered an obstacle to development opportunities since they do not facilitate the employment of modern schemes of production systems and limit the adoption of modern technologies in agricultural mechanization[1].

Small and mid-size farmers and farmhands, show low productive efficiency due to a lack of mechanization technologies that allow for a multifunctional role in crop, forage and vegetable production and the employment of conservation techniques to counter the growing physical deterioration of Andean soils.

Nowadays, the application of animal traction for tillage, pasture and crops seeding is limited to the use of oxen and to a certain extent to the use of workhorses. In a much larger scope, regional agriculture is highly dependent in the use of non-qualified labor force, which uses traditional farm hand tools. A growing concern is the exodus of the younger generation towards urban centers in search of employment opportunities and better quality of life. The animal traction technology has the potential for creating employment opportunities in the local rural sector to minimize or reduce the abandonment of rural communities. Similarly, it also offers training opportunities in the area of agricultural mechanization with draft animals, updating anrefreshingsh technical knowledge and know-how in sustainable agriculture.

Materials and Methods

Location

The five experimental units were located in the municipalities of: Guasca, Mosquera and Zipaquirá – in altitudes between 2560 to 3400 meters (a.s.l.), in variable soil, topography and thermic floors, in parcels considered apt for beef and milk cattle, intensive and semi-intensive crop and vegetable production (vegetables, grain and fruits) and forestry.

Components

1) The Electronic Measuring System in Real-Time (EMSRT) was designed for measuring and storage of draft force, work speed, tool depth and animal heart rate information in field conditions[2]). The EMSRT was built with the following components: an Arduino 1 card with microcontroller (MCU) ATMEGA328P; datalogger module shield V1 with RTC; SD card for data storage in plain text, type .csv; display module (LCD) with 12C serial; Sharp GP2Y0A21 (IR) distance sensor, to measure the tool's working depth; a load cell, S-type with 1000 kg capacity and a 150 % safety overload to measure draft forces. The integration of all the elements was energized with a 12v car battery.

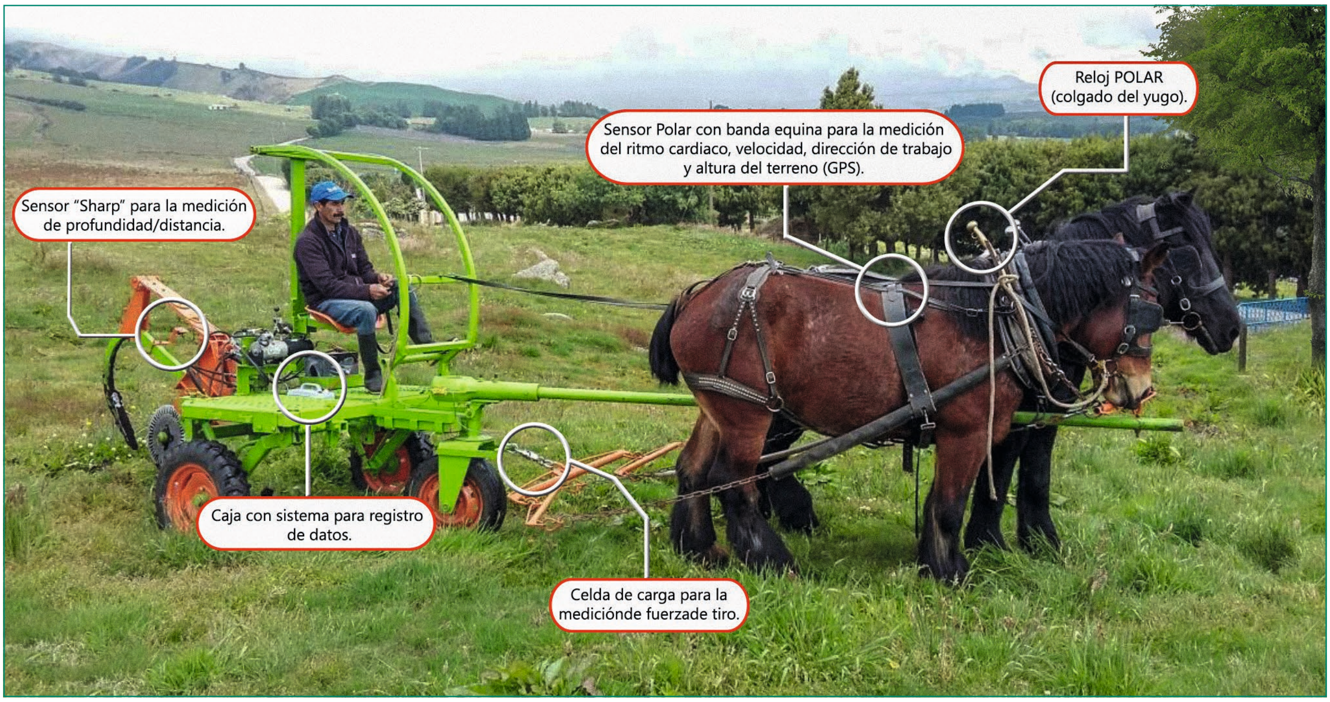

***Figure 1** – The EMSRT Electronic Measuring System installed in the ADBIS*

1 Cruz León 1997; IGAC 2005, 39.

2 Caballero et al. 2018; Venturelli et al. 2009.

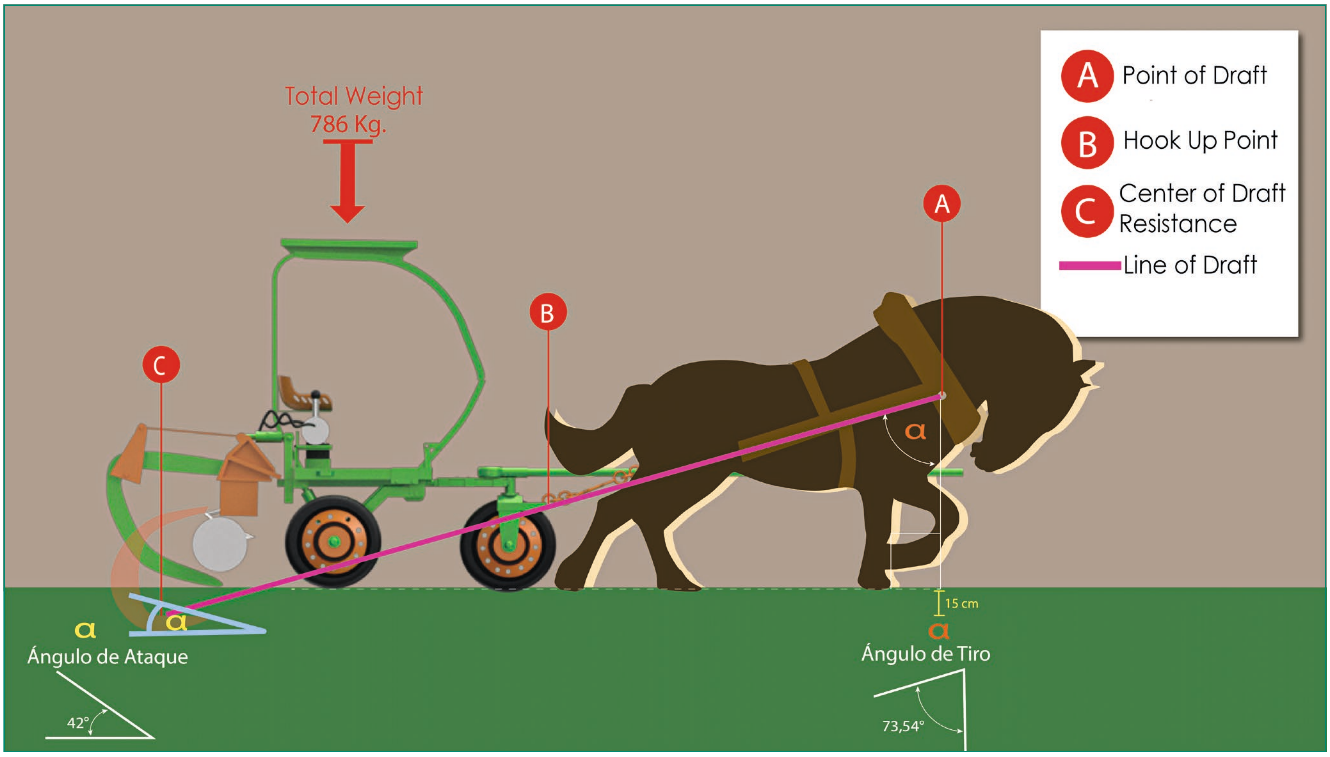

Figure 2 – Main forces that impact on the animals' draft force

2) A Polar 400 sports watch with an equine belt was used to measure, heart rate, work speed, time and traveled distance through an integrated GPS. The equine belt had two sensors (+/-) and a cardiac frequency sensor Polar H10 connected via Bluetooth to the watch. The information was discharged and stored in the Polar Flow application. The EMSRT installed in the ADBIS is shown in ***Figure 1***.

3) ADBIS – composed of: hitch cart, chisel plow (tillage tool), team harness and two draft horses.

- **Hitch cart:** A mechanical platform used for operating machinery and implements class I and II. Fossil fuel is not required to operate this machinery. It is characterized by its capacity to perform multiple functions, such as, tillage, seeding/planting, mechanical weeding, crops harvesting, transport, etc. It can operate with more than two horses, based on power requirements; adapts well to small fields; and causes minimal soil compaction. The hitch cart with the chisel plow, 12V battery; hydraulic system and operator, weighted 7639,38 N (779 kgf).
- **Chisel plow:** The "Tebben" chisel plow, with a 43.2 cm (17") coulter, flute type, was selected for the present study.
- **Work harness:** Amish style (imported), fabricated in a bioplastic material except for the collars, which are made of leather and barley straw filler. The locally produced harnesses are fabricated using strips of car tires of much lower cost but, unfortunately, these cause skin lacerations due to bad designs and the poor quality of materials.
- **Work horses:** Two young stallions of five and six-year-old and an eleven-year-old mare of the European Belgian breed (Brabant), with 1, 3 and 7 yr. work experience, respectively; The three equines showed their character and aptitude for tillage work, ratifying their genetic quality as draft animals; The combined weight of the two stallions was 1280 kg

Variables and Measuring Instruments

- **Shear resistance:** It was measured using a 0 - 250 kPa shear vane tool. Testing was performed at depths of: 0, 5, 10, 15 and 20 cm to determine the degree of soil's shear resistance in kilopascals (kPa)[3] .
- **Soil water content:** The "dry oven" technique was used to determine the percentage of humidity in the soil before starting the tillage[4]. The technique is based on drying the soil sample at 105 °C for 24-48 hours[5].

$$\%\ Soil\ Water = \frac{weight\ of\ wet\ soil\ (g) - weight\ of\ dry\ soil\ (g)}{weight\ of\ dry\ soil\ (g)} \times 100$$

- **Soil type and texture:** The tactile method was used to identify soil type and texture[6] .
- **Heart rate and work speed:** The Polar 400 sport watch with the equine belt was hung from the harness. The Polar Flow application stores and download the statistics of collected data. The equine belt was placed in the thorax section of the horse, based on manufacturer's instructions. The four categories of work intensity, based on the horses' cardiac frequency (bpm), are: low: <90; moderate: 90-110; intense: 110-150; highly intense: >1507 .
- **Draft force and working depth:** The EMSRT presented the draft force in Newton (N) and the working depth in centimeters (cm).

Just as ***Figure 2***, indicates, the chisel plow is straight aligned between the draft point (A) and the center of draft (C) in a straight line and generating a draft angle of 73.54° (B) as the chisel plow penetrates the ground 15 cm.

3 Rivera 2018.
4 USDA 1999.
5 URL: https://labmodules.soilweb.ca/gravimetric-soil-water-content/ [28-03-22].
6 USDA 1999.
7 NRC 2007.

- **Quality of Tillage:** The evaluation was based on recommendations provided in FAO 1994 and 1995 manuals and field observations. Special attention was on the vertical axis of the cutting wheel and the transversal axis of the chisel plow. It was further observed the removed soil quantity and its distribution on the surface, the number of turf pieces lifted with the chisel, and the quality of the cut and the size of the rupture made with the chisel plow.

These procedures are repeated in each experimental unit and it is implemented in four stages: 1) field evaluation, 2) EMSRT functioning and validation, 3) tillage work and data collection, and 4) post analysis and evaluation.

Methodology

The experimental design, named “parcels divided in time”, based on the methodology by Gomez[8], was used. The study took place in five experimental units of four productive systems. The field trials consisted in chiseling each experimental parcel, in Kikuyo (grass) and fallow, at 15 cm depth and 1-meter separation between rows.

Evaluations of Horsepower, Work Effectiveness, Field Efficiency and Technological Impact of ADBIS

- **Horsepower:** It was based on determining if the animals’ generated “power” was sufficient to perform tillage work with ADBIS and the chisel plow under typical soil and high-altitude conditions.
- **Effectiveness and efficiency of ADBIS under field conditions:** It was based on the capacity of ADBIS to operate with a chisel plow and to integrate other agricultural machinery. It was assumed that the animals would generate enough power to remain in the field for 4 hours working with the chisel plow, without having their physical and physiological conditions deteriorate significatively. The effectiveness and efficiency of fieldwork were measured according to: FAO[9]; Riquelme et al.[10]; Usman et al.[11]
- **Technological impact:** The impact evaluation of the animal traction technology was assessed from the “source” of renewable energy perspective, compared to the automotive technology, and considering the following factors: a) agronomic, b) social, c) economic, d) energetic, and e) environmental.

ADBIS and components

- **Hitch cart (multiple):** The displacement in the fields was done without a hitch with low friction between the tires and the ground, and a third frontal tire that facilitated the turns of the hitch cart directed by the pole. The operator handled the animals and operated the chisel plow with ease and skill with a clear view over the animals´ heads which gave him an unobstructed vision which helped him avoid holes and obstacles and maintain a straight line and avoid steep curves.
- **Chisel plow with coulter:** The displacement in the ground and its own weight helped the tool penetrate and endure the resistance and cutting forces to remain at the programmed depth. The 17” (43,2 cm) coulter was mounted in front of the chisel for a clean cut of the Kikuyo’s (grass) roots system at a standard depth of 8 cm. The use of the coulter helped reduce power requirements, avoid lifting big pieces of “carpet” (chunks of grass) and facilitated the chisel’s penetration and displacement in the soil up to the desired working depth.
- **Chisel point:** The following was the size: 27,94 cm in length, 5,08 cm wide, and 0,79 cm in thickness. The chisel point allowed the chisel to break the ground up to 15 cm in depth, traveling at an approximate angle of 42° (α) in relation to the soil’s horizontal profile (horizon).
- **Draft horses:** The animals were hooked to the hitch cart by means of their harness to a set of doubletrees. The distance between the animals and the hitch cart was adequate to allow for precision, security (positive control) and sufficient space in the turns to avoid the fences. The average rest time for the animals was registered (Polar) as around 3 to 4 minutes for each 15 to 20 minutes work segment. After 2 hours, the rest time was increased to approximately 10 minutes for runs greater than 100 metros. The two animals on average took 4 hours to complete one hectare working with the chisel plow, which was considered very reasonable.
- **Work harness:** They were used for hooking up the horses safely to the hitch cart. The 1,60 m height of the horses was not too high and allowed the operator to put the harness without difficulty.

Field Activities

The research activities started during the rainy season, in the months of December to April and September to October. Some of the experimental units experienced intensive rain augmenting excessively the water content in the soil, exceeding the field capacity level, causing some of the work to be postponed. But, in other places, the light rains and the lack of adequate moisture in the soil caused high degree of hardening (cementing) which was evident during the tillage with the work horses.

Statistical analysis

The SigmaPlot V11 program was used for creating Person´s correlation matrixes between variables for Heart Rate (bpm), Speed (km/h), Draft force (N) and Power (hp), for each experimental unit with grouped plots’ boxes for each variable.

RESULTS AND DISCUSSION

Experimental units: Experimental works took place in five different units. Following, we will discuss the results of E.U. #2, only: **E.U. #2. Garda Farm (Brabant’s Horse Breeding Farm)**

The ADBIS operated in two sub parcels (plots) with 8.014 m^2 total area and completed the assigned work in 2,45 hours (approx..). The fields (sub parcels) were located in a soft rolling hill with 7 to 12 % slope. The two sub parcels are dedicated to the production of forage with a mix of grasses like Kikuyo, red and white clover, ryegrass, native poa and oats. The plots were cleaned, and the grass was chopped up before the chisel plow was used, with a 1-meter separation between rows.

8 Gomez Lopez 1997.
9 FAO 1994.
10 Riquelme et al. 1991.
11 Usman et al. 2004.

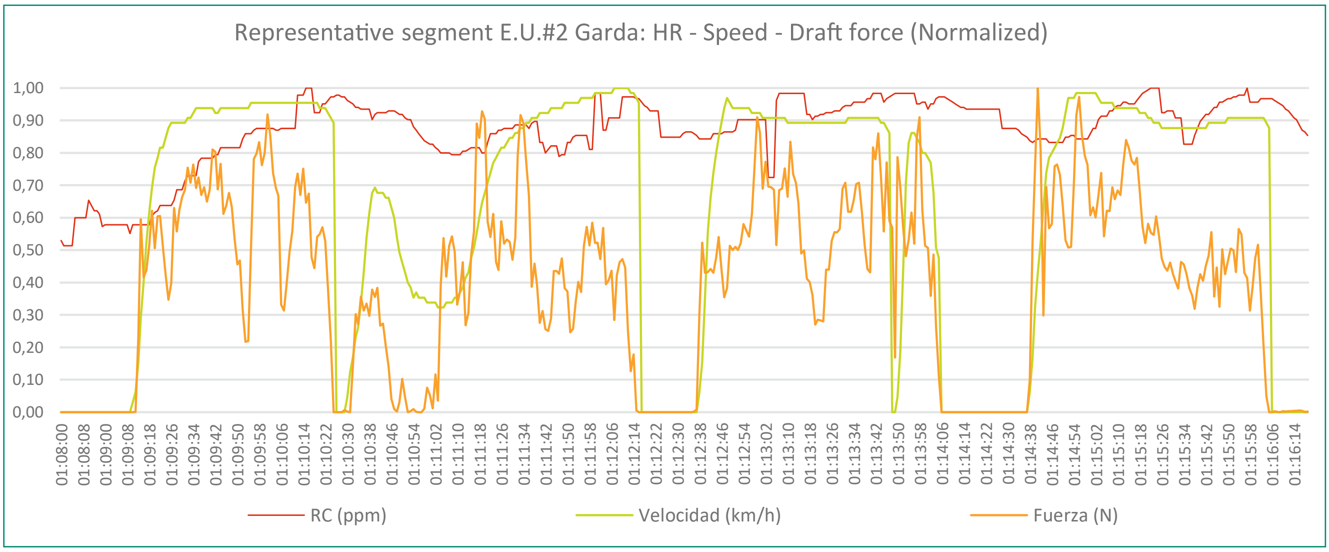

Figure 3 – Representative segment of a normal run, Garda farm

Animal performance: The animals worked comfortably during a cloudy and cool day with light rain. The horses showed a normal respiration rate during the duration of the exercise with regular periods of rest. The two horse's performance generated a force of 2260,1 N and power of 2519,4 W (3,5 HP).

Figure 3 shows a segment of a representative run with the following maximum values: HR: 185(bpm), Speed: 6,5 (km/h) and Draft force: 4359(N)

The variables of draft force and power represent a strong correlation (0,924), suggesting that "at a great generated force greater is the power of the animals. The velocity factor was relevant since indicated that "at a higher velocity greater is the generated force", therefore, greater is the power, see *Table 1*.

	HR (ppm)	Speed (km/h)	Force (N)	Power R. (HP)
HR (ppm)	1	0,208	-0,0679	0,0336
Speed (km/h)		1	0,503	0,743
Force (N)			1	0,924
Power R. (HP)				1

Table 1 – Pearson's Correlation for E.U. #2

In accordance with *Table 2*, the Experimental Unit #2 showed the soil´s lesser resistance and a medium humidity value that contributed to obtaining the highest velocity (5,4 km/h), resulting in a registered greater power value (3,5 HP) in comparison with the others E.Us

Soil Evaluation: The practice of aerating/chiseling the soil takes place twice a year (for the past three years) and it is combined with the spreading of (mature) horse manure mixed with lime, light commercial fertilizer and chicken manure.

Texture: Loamy Soil

It is considered a medium type of soil.

Water content: 50 %

The level of humidity was moderately high but demonstrated to be very appropriate for tillage, allowing the chisel plow´s forward displacement through the soil cutting with ease. It was observed that the soil was near the plastic state, it adhered easily to the tillage tool but it didn't burst (fragmentthe soil.

Shear resistance: 108 kPa.

This value is indicative of soil with a relatively low level of compaction, probably up to 15 cm deep.

Tool and accessory evaluation: The chisel plow, coulter and hydraulic system had no failures or accidents during the ground tillage and did not require of any sort of repairs or modifications to complete the job. The hydraulic system with a 1.5x10 inches cylinder/bottle had enough pressure to raise and lower the chisel. The charge of the 12v car battery lasted approximately four hours to complete the job.

Table 3 shows the results (average) of eleven variables of interest collected from all four participating farms in the study.

Analysis of Table 3

- Shear resistance: The greater resistance to soil´s shear resistance were the plots corresponding to E.U. #3 and #4B, which were characterized for having the lowest level of water content with respect to the other E.Us. Based on the obtained results, "at similar water content, greater is the power requirement for tilling a clay-loam versus a silt-loam soil. Due to conditions of low water content and a high degree of soil compaction (hardening), sudden changes in working depth and area of disturbed soil

Shear Resistance (kPa)	Humidity (%)	Working depth (m)	Heart Rate(ppm)	Speed (km/h)
108	50	0,15	127	5,4
Draft force (N/kgf)	Power (W)	Equivalency (HP)	Altitude (m.a.s.l.)	Temperature (°C)
2260,1/230,5	2519,4	3,4	2870	12-15

Table 2 – Power measurements (average) in E.U. #2

E.U.	Soil texture	Shear resistance (kPa)	Humidity (%)	Depth (m)	Heart rate	Speed (km/h)	Draft Force (N/kg)	Power (W)	Equiv. (HP)	Altitude (m.a.s.l.)	Temp. (°C)
1	Silt-loam	130,0	89	0,15	127	4,5	1781,3/181,6	1654,7	2,2	3400	8-11
2	Silt-loam	108,0	50	0,15	149	5,4	2260,1/230,5	2519,4	3,4	2870	12-15
3	Silt-loam	219,4	36	0,15	145	4,3	2722,6/277,6	2407,7	3,2	2850	10-12
4A	Clay-loam	176,0	47	0,15	139	4,8	1639,9/167,2	1620,8	2,2	2560	15-17
4B	Clay-loam	228,0	27	0,06 a 0,08	129	4,7	2086,9/212,8	2016,1	2,7	2560	14-16

Table 3 – Power Measurements (average) for a parabolic chisel plow with 2 draft horses of 640kg/ea

marked a significant difference in results of shear resistance and (draft) power. A similar situation is reported by Camacho and Rodriguez[12] in their research.

Based on the information presented in *Table 3*, can be inferred that when the soil presents major shear resistance the animals tends to slow their work speed.

- **Humidity content:** In 3 of 5 experimental units, the field trials took place under a high percentage of soil's humidity content. The greatest humidity level was registered in E.U. #1. The high level of humidity in the soil is considered too wet for efficient tillage since it is not near the point of plasticity. Similarly, it made the soil, in an aqueous state, stick to the chisel plow but, minimally affect the tool´s efficacy and increased in a way the animals´ draft force. The percentage which is closest to the optimum point of plasticity for effective tillage was registered in the E.U. #2 (50 %), facilitating the increase of work speed, generating greater power, therefore, resulting in mayor draft efficiency. The lowest percentage of humidity content shown by E.U. #4b compared to historical information of high compaction, also affected the higher demand for power. The soil's humidity content between the E.Us. ranged between 36 % and 89 % for light and heavy soils, respectively. The vane shear test registered shear resistance values of 108,0 to 219,4 kPa for medium-light soils and between 176,0 to 228,0 kPa in highly compacted soils.

The important "cultural" factor is highlighted, in the decision-making process about their agricultural practices. Both the farmer and the animals, perform tasks in the rain to take advantage of the rainwater to obtain a better harvest. We could say that the use of draft animals should be considered more acceptable in the cultural context of the Andean region than the tractor, in a sustainable agricultural context.

- **Soil type and texture:** The two types of soils identified in the samples taken in all participating E.Us. were silt-loam and clay-loam.
- **Working depth:** This was established at 15 cm deep with the purpose of exceeding the depth of the "Kikuyo" grass root system, which develops between 6 to 8 cm approximately, in this area. The exception to the established working depth was E.U. 4B, where the chisel plow was lifted off the ground surface due to the hardpan caused by heavy compaction of the soil. Small depth variations registered by the EMSRT were also caused by irregularities found in the ground; movements along the longitudinal axis of the hitchcart, and obstacles encountered by the chisel plow in the fields.

12 Camacho-Tamayo/Rodríguez 2007.

Analysis of Four Variables (Factors)

- **Draft Force (pull):** The two draft horses generated significant draft forces which oscillated between 1639,9 N and 2722,6 N, establishing a power range between 2,2 y 3,5 HP. The graph in *Figure 4* represents the *draft force* variable for the five experimental units. The most determining factor in the draft force variable was the soil water content, which represents a lesser dispersion with greater water content versus a mayor dispersion with less water content.

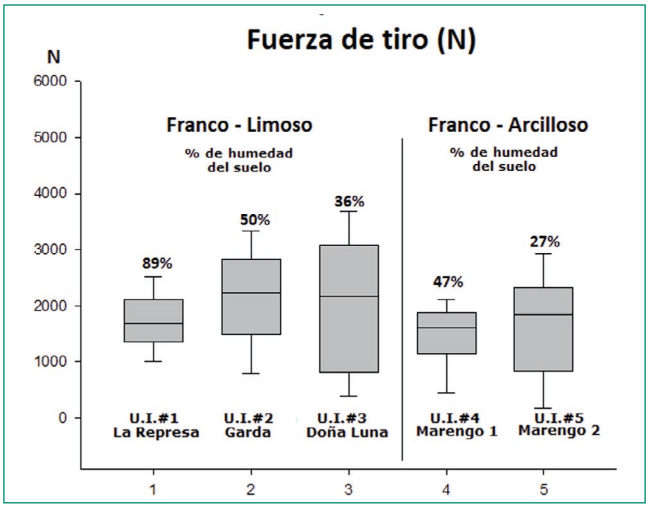

Figure 4 – Box plot for Draft Force (N) for all experimental units (E.U.'s)

- **Work Speed:** The majority of the velocities (km/h) were quite similar in range with the exception of E.U. #2, where the highest registered speed generated the biggest power. It is understood that average speed results were somewhat not normal given the possibility that in the soils with poor water content the chisel plow did not move softly and efficiently bursting the soil violently and irregularly with back-and-forth movements (accordion effect) between the horses and the hitch cart, due to a lack of elasticity of the hitching system when operates in the irregular ground. *Figure 5* represents the variable *speed* and it is observed a normal response to shear resistance and no significant differences were found between the treatments. The observed tendency was: "the greater the degree of compaction the lower the working speed" – see EU #3 and EU #4B.

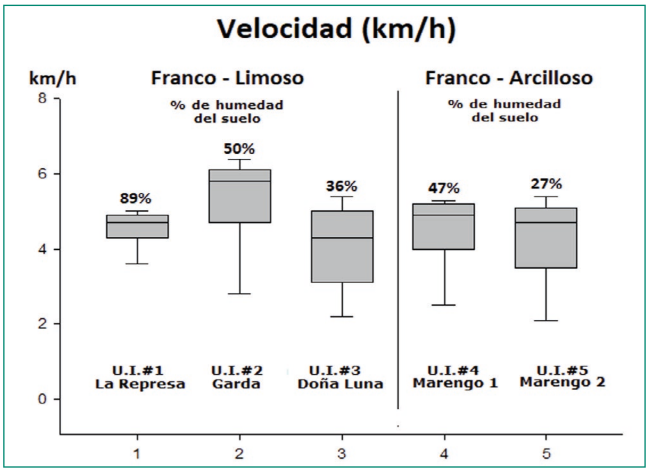

Figure 5 – Box plot for Speed (km/h) for all experimental units (E.U.s)

- **Heart Rate:** A significant HR difference between the E.Us. in relation to the varying altitudes (m.a.s.l.), could not be perceived. It cannot be concluded if a tendency in relation to the other variables exists, except that the physiological system in horses operated in a range of 127 to 149 bpm during the tillage with the chisel plow, of which it can be concluded that based on parameters established by the NCR[13], the work intensity in these trials can be classified from "moderate to intense". Based on the obtained results, it can be assumed that the heart rate was principally influenced by work speed and not by the Andean´s altitude as initially. Thereon, Nomura and Tominaga[14] from Tokyo University, reported that the relationship between heart rate and draft force was directly proportional and that the heart rate among trained (experienced) horses versus non-trained horses were lower[15].

The graphic in *Figure 6* shows the *heart rate* variable, where it is observed that the HR variable might have been affected by the type of work the animals performed but apparently, was not affected by the other variables. It should be noted that the altitude perhaps, did not affect the animals directly given the fact that both are considered "natives" (by birth) to the Cundiboyacense highlands and are well adapted to the local environmental conditions.

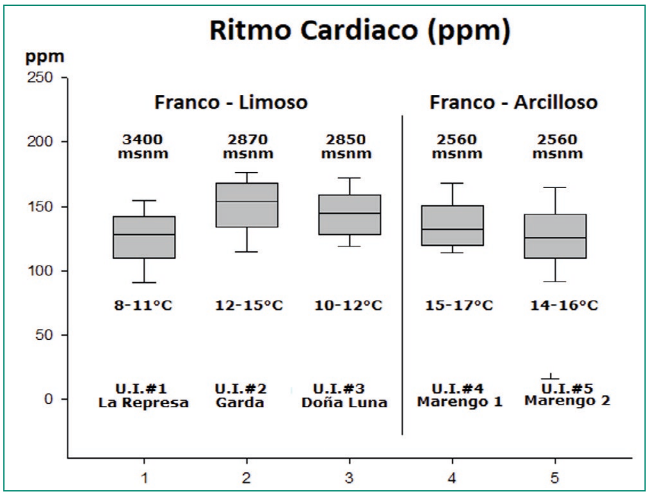

Figure 6 – Box plot for Heart Rate (ppm) for all experimental units (E.U.s)

13 NCR 2007.
14 Nomura/Tominaga 1960.
15 Hiraga/Sugano 2017.

The heart rate and the rest periods (recuperation) were closely monitored to avoid excessive fatigue and to protect the animals' well-being by avoiding dangerous or adverse physiological conditions. During work, it was observed that the heart rate remained at an adequate range and to maintain a good quality of (draft) force the rest periods were short but frequent. The physiological recuperation was quick making the horses' work capacity consistent and complementary. The draft horses demonstrated a great capacity for draft and work speed, under varied temperature conditions showing their adaptation to the changing climate of the highlands.

- **Power:** It is directly linked to the *draft power vs speed* relation. The greatest power (W) generated by the animals is registered in E.U. 2 where the high velocity (5,4 km/h) influenced a greater generation of draft power. This plot registered an intermedium level of water content and a lesser degree of compaction than the other E.Us. In the E.U. #1, for example, the two draft horses worked tilling a silty-loam type soil, the chisel plow operated at 15 cm depth, with 89% soil water content, work speed of 4,7 km/h at 3400 meters (a.s.l.), generating power of 1654,7 W (equivalent to 2,2 HP). However, in clay-loam-type soils, there were no conclusive results due to the limited available information (only two plots). The graphic in *Figure 7*, shows the variable *Power* (kW), where it is observed that it was affected by the water content and in a similar way by the draft force in both types of soils, silty-loam, and clay-loam. Being the power a result of the conversion, it cannot be clear the source of the difference in the results between the two types of soils studied.

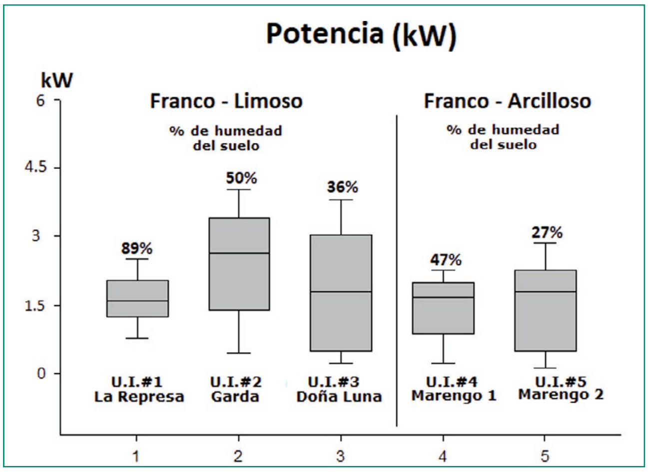

Figure 7 – Box plot for Power (kW) for all experimental units

Performance of the Hitch cart with the Chisel Plow

The use of the equipment in soils of identified hardiness, due to the high level of compaction, was effective and bear the forces and the impacts caused by the soils' shear resistance and other obstacles found in the field (fence post). The hitch cart and the horses left no marks of feet and tires on the ground. The (assumed) friction generated by the hitch cart with the chisel plow was identified as "displacement resistance" (or "rolling resistance", which is a term used to refer to automotive traction), where the rolling resistance is related to the machinery's/equipment's weight, type of soil and speed of work. The chisel plow's weight and the pressure exerted by the hydraulic servo were adequate/sufficient to assist the tool to penetrate the soil to a depth of 15 cm, in plots where soil compaction was evident. The soil's shear resistance was determined between 108,0 to 228,0 kPa (***Table 3***). The chisel's point angle of attack was 42° and was set/determined manually[16].

Performance and Output of Draft Horses

The results of the study confirm the great performance and output of draft horses and were consistent with those obtained by Collins & Caine (1926). Based on the registered draft power values during the trials (***See Table 3***), the animals generated a draft force of 230 kgf, 17 % of the total force capacity of both animals, with a power equivalency of 2,9 HP to pull the chisel plow through a depth of 15 cm. Unlike the works of Collins & Caine (1926), the participating draft horses in this study operated satisfactorily in the high plains at altitudes between 2.560 m.a.s.l. and 3.400 m.a.s.l., showing normal fatigue, similar capacity to draft horses working in the lowlands (closer to sea level). The average work period to complete the assigned task of one hectare with regular rest periods was four hours with runs up to 120 meters and with an average speed of 4.5 km/hr and 50% humidity, without significantly affecting their performance and demonstrating their capacity and nobility to pull the agricultural tool.

In general, the literature on the subject indicates that the draft horse has the capacity for "pulling" (dragging) loads that represent between 10 % and 15 % of their body weight for approximately 8 hours/workday[17]. In their study, Collins/Caine used 14-inch plows (35,5 cm) with three horses to plow parcels with sudangrass in soils of medium texture, generating draft forces of approximately 227 kgf (500 lbf), at a depth of 15,24 cm (6 in), and generating power equivalence of 2,15 to 2,26 HP.

In principle, a 640 kg draft horse would produce enough power to energetically sustain between 0,5 to 3 hectares and two horses could easily provide the work power required for approximately 5 to 10 hectares of a diversified commercial farm. It appears, there is an acquired synergy when two or more horses are hitched together potentiating their work.

The monitoring of the heart rate (HR) and time of recuperation in working horses, is essential for determining their performance, draft power and physiological condition. The information can also be used as a tool for identifying and selecting good-quality horses for breeding[18]. During fieldwork, the animals exhibited a normal HR which oscillate between 127 bpm and 149 bpm, similar to values of those results reported by Nomura/Tominaga[19] and mentioned by Hiraga/Sugano[20].

The "negative power" caused by the resistance of the horses' displacement (traveling) was estimated at less than 7 % which is similar to the average value of the "rolling resistance" produced by the tires of an agricultural tractor.

Use of a non-standard rod: The non-standard rod, 3/8" diameter x 39.37 inches long, was fabricated in stainless steel. It was introduced into the ground up to 7.87 inches in depth, in order to, explore the approximate level of soil compaction. The greatest degree of compaction was found between 10 to 12 cm. from the ground's surface. This method resulted very practical and aided in developing a feel for the level of compaction and soil water content in the depths where these soil conditions can be found, useful information for designing, selecting, measuring and adjusting tillage tools to facilitate penetration and permanence at a designated working depth, especially in highly compacted soils.

Correlations between Speed – Draft Force and Power: While comparing the results of the Pearson's correlations between the variables of speed, draft force and power, a major correlation between draft force and power versus speed and power. The previous information indicates that an increment in draft force has a direct result in an increase in power but, it does not occur in the same proportion with (work) speed, possibly due to the animals' physiological factors.

Impact of the agricultural mechanization technology with animal traction: The areas of strategic interest for local and national agriculture its related to objective #3 of the main thesis, "evaluate the capacity, efficiency, and impact in the agronomic, social, economic, environmental, and technological, of the use of draft horses and agricultural machinery on the Andean soils of the Cundiboyacense region of Colombia. It is inferred that the use of work horses could have a renewed impact, wide and positive, in many farming activities and rural development. Through education and training, the use of AT technology and likewise, would incentive the younger generations to remain in the rural areas. The Andean regions of Colombia, such as: Cundinamarca, Boyacá, Antioquia y Nariño, where the tillage in hillsides is done by hand and minimum mechanization. The use of upgraded animal traction tools would improve human capacity for increasing production and efficiency. Farmers owning machinery and implements for use with animal traction could supplement their incomes by offering tillage services with their machinery and work horses to neighbors and members of the local community.

- **Agronomic impact:** The main objective of sustainable agriculture is to improve agricultural production with a minimum environmental impact. Agricultural mechanization with draft horses is a valid option for supporting farming activities in the three main productive systems with economic importance to the region: milk, potatoes, and vegetables.

  The draft horse has the capacity to work effectively and efficiently in < 20° slopes (when using a hitch cart) with modern, well-designed or modified tools and fabricated with high-quality materials to supply the needs of local farming. In principle, initial results on the power (energy) generated by this size of draft horse, indicate that it should be enough to mechanize family and commercial farming in Colombia.

  The chisel plow used was selected for its symmetry, facilitating the harmonious work with the horses, improving their performance. The weight facilitated its penetration in the soil, opening narrow gaps to aerate, decompaction and improve water infiltration, controlling runoff and erosion. Additionally, it did not alter significantly the surface relief with the formation of "sod". Additional accessories can be added

16 Makudiuh 2016.
17 Collins/Caine 1926; Miller 2004.
18 Hiraga/Sugano 2017.
19 Nomura/Tominaga 1960.
20 Hiraga/Sugano 2017.

to the chisel plow, such as a ridger or a single row planter, making it a multifunctional tool.

The ADBIS uses a complementary 12 volts, electrical hydraulic pump to operate the hydraulic system, to control the working depth. The study was limited to the use of the Tebben chisel plow to perform subsoiling/aeration. No other tillage tools were used in this study.

- **Socioeconomic impact:** The transformation of agriculture in the Andean region, is very necessary to respond to the needs of rural communities, caused by latent endemic poverty, where specialized and better-paid jobs are needed. Transformed agriculture with renewed rural and socio-cultural values, techno-scientific know-how, and an improved rural economy with opportunities for all would facilitate consensus to foster changes based on new sustainable farming technics among the farmers and the hand labor force. Studies conducted outside Latin America; report of important benefits obtained by small farmers with the use of draft horses[21]. The costs of investments and operation of work horses versus tractor mechanization are very reasonable. Horse farming directly promotes a circular economy where limited locally produced resources are utilized, recycled, and reinvested in the local community for the prosperity of all.

  The Amish concept of traditional farming[22] is a valuable example of a successful family/commercial farming experience, worth studying and adapting. The Amish model of association and interdependence foster the participation of the entire community and takes the form of a circular rural economy. The participation of all family members in the activities of the farm including the handling of the horses in field operations, as a source of less expensive renewable power, are some of its important features. The main point to rescue is the Amish family's capacity to live modestly in relative prosperity. Fundamentally, the Amish concept is a system of self-sufficiency, sustainability and highly productive in comparison to conventional agriculture.

- **Environmental impact:** The use of work horses is very appropriate in the context of sustainable, biodynamical and conservation agriculture. The negative environmental impact is considered much less damaging than those caused by the use of tractor technology and associated machinery. Tillage practices with draft animals affect the environment to a lesser degree, due to the design, weight, and geometry of the tools. The lesser weight of the work horses and their smaller and lighter tools can contribute to reducing the soil compaction and help control the erosion in the hillsides.

  The agricultural mechanization with draft horses would allow for conservation practices aiming to reduce CO2 production and demotivate the burning of post-harvest stubble. The great uncertainty associated with climate change is how this could affect the agricultural calendar of planting and harvesting and plants' adaptability to the solar intensity and the availability and frequency of the rains. Animal traction would allow a great number of farmers access to a source of less expensive energy (power) to mechanize their farming operation in an opportune way amidst climate change.

- **Energy impact:** Small producers seldom use fossil fuel in their farming activities, because these are manually accomplished. The animal traction technology has the capacity to use locally produced forages and grains, and animal feed, which later converts into useful energy for tillage and manufacturing of machinery, implements, harnesses, horseshoes, animal feeds, drugs, fertilizers, etc. The animal traction technology proportionally consumes less energy than the energy used by the agricultural automotive industry[23].

  The need to reduce fuel consumption positions the use of working animals as the appropriate technological choice to achieve an important level of "energetic autonomy". The use of diesel fuel represents between 40 % to 50 % of the total hourly cost of the tractor operation[24], hence the necessity to employ other options or sources of less expensive energy, as is the case of the animal traction technology. The results of a comparative study by Huerga et. al.[25], indicated that the automotive power produced 8,2 MJ/ha, a generated power of 2,26 K, and consumed 102,6 MJ/ha, by contrast, two work horses produced 8,2 MJ/ha, generated power of 0,98 KW and consumed 90,77 MJ/ha creating a saving of 12 MJ/ha of energy, approximately.

  The E.U. 2 also uses a 25 HP motorized hitch cart with a hydraulic system to operate a mower, a mini round baler and a rotary tiller. The fuel consumption is "in demand" as the engine is started up when there is a need to operate the selected machinery. The transport to and from the fields is done with the horses.

- **Technological impact:** Given the simplicity of the animal traction technology, producers, and farm workers can operate agricultural tools with minimum difficulties. A limiting factor to the employment of work horses on steep hillsides is the larger size of their hooves and a higher gravity center (GC), in comparison to mules, oxen and donkeys and this could cause draft horses to lose their footing. The maintenance, repair and fabrication of less sophisticated machinery and implements can be done easily and less costly and can be accomplished in local shops. Harness fabrication and repair are possible, and they can be done with national and imported materials resources in saddle shops located in cities and rural communities.

  The successful transfer of concepts like ADBIS necessarily must be contingent on the training of the operators, so that farmers and laborers have the opportunity to learn and acquire new abilities, to handle animals and equipment, in a safe, effective and efficient manner and where the animal´s welfare becomes paramount. ADBIS can function as a didactic platform for the development of abilities and newer concepts in tillage techniques, safety, and animal traction technology in general.

Conclusion

The animal traction technology (ATT) with draft horses is an excellent alternative to the automotive technology because it uses other sources of fuels like greens (forages and grains), oils, etc., and provides an energy that exponentially increases available power per hectare, a lot more than rural hand labor can. It can make work compatible with the environment and it reproduces itself with

21 Rydberg et.al. 2002; James 2003; Kendall 2005; Nordell/Nordell 2012.
22 James 2003.
23 Rydberg/Jansen 2002.
24 Hetz/Reina 2013.
25 Huerga et al. 2011.

local resources. Also, the animal traction technology can foster and function in a circular economy where goods and services are sold and purchased within the local economy and for the benefit of all the community.

The hitch cart proved to be a highly efficient and multifunctional tool, comfortable, balanced and of good visibility. The hydraulic system was of great utility to handle the working depth of the chisel plow (also, to operate with other implements, such as furrower, seeders/planters, sprayers, etc.). The relation draft force/live weight of the animals was in the order of 17 % which is considered reasonable, where the weight was supported by the rubber tires. The chisel plow proved to be less damaging (on the hillsides) than the rotary tiller and the disc plow since it did expose the worked soil to displacement of the soil by erosion or washed by the rains.

The Electronic Measuring System in Real-Time (EMS-RT) functioned adequately in field conditions. The sensors used produced readings within trustworthy ranges. The use of Polar 400 watch to monitor the animals´ heart rate was useful to report on their critical physical and physiological parameters, recovery and rest periods during tillage. This accessory can also be employed to identify and select breeding stock with greater draft qualities for work in the hillsides of the Andean region and for monitoring adequately their well-being.

The three draft horses used in the study, demonstrated unequivocally to possess the (draft) power and the necessary nobility to work with the chisel plow efficiently and a reasonable time.

The Kikuyo grass facilitated the horses' work in those soils that exceeded their humidity field capacity (fc). Kikuyo's root system and its' stolon, weave with each other to form a "green carpet" which supports both the weight of the animals and the associated draft animals' agricultural machinery, facilitating traffic through the fields and pastures in high humidity conditions. A phenomenon that does not occur when operating with a tractor, is where the tires skid on the surface of the grass to the point of making deep ditches to the point of getting the tractor stuck in the mud. Additionally, the animals and the animal traction machinery operated efficiently in soils with a high percentage of humidity, facilitating drainage and the infiltration of rainwater. According to field observations, the work horses do not appear to be affected by the Andean altitude (2500m.a.s.l. to 3400 m.a.s.l.)

The economic impact of ADBIS to the local rural economy can be meaningful since it resolves the need for increased production efficiency, reduction in soil compaction and erosion, fostering rural employment, reduction of fuel consumption and includes sustainable agriculture practices and self-sufficiency in food production. ADBIS uses in a complementary manner, electrical engines to operate a hydraulic system, power take-off and control the tool's working depth.

The chisel plow efficiently cut through the soil leaving narrow furrows to allow for better aeration and decompaction of soil for improving infiltration of rainwater and diminishing water run-off and erosion. Additionally, it does not significatively alter the pasture's surface with the formation of "grass turf".

RECOMMENDATIONS

- Draw up government policy (law) to promote research, development, and extension of the animal-drawn technology with the rural communities and renewable technology in agricultural mechanization and source of clean and less costly energy.
- Foster coordinated efforts with alike institutions in the animal-drawn theme.
- Establish a Center of Excellence for Andean Agricultural Mechanization for R+D+E, to include the study of mixed mechanization with automotive technology.
- Establish a draft horse (and mule) breeding programs with imported breeding stock to promote the genetic improvement of local horses to promote ag. mechanization with the use of draft animals.
- Promote the use of draft horses as an excellent energy source with alike development programs.
- Include the animal traction technology as a vital component of the national agricultural development strategy and link it with programs of alternative sources of energy and conservation tillage[26].
- Promote animal traction as a complement to the available rural hand labor.
- Set up educational and training programs in ag mechanization with draft horses (or draft animals).
- Foster semi-industrial and cottage industries for the fabrication of machinery and implements for use with draft animals.

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