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Considerations regarding Motorcycle Adaptation as a Power Source for Agriculture

Consideraciones sobre la adaptación de motocicletas como una fuente de potencia para la agricultura

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ABSTRACT

In Colombia's agricultural areas, the number of 125 cm^3 motorcycles is increasing, while the availability of labor is decreasing. Nevertheless, the power requirements for agricultural work remain constant. Technological developments in the country have made some adaptations to motorcycles, including a new rear chassis and a different chain transmission, in order to have a power source suitable for small terrains and hillside areas that is accessible in terms of cost and technological level. The objective of this work was to analyze the stability and pull capacity of a modified motorcycle (*MM* AKT 2013 EVO 125 cm^3 - 7.5 kW Street – Sport type), by studying the power transmission of the original and the newly added chassis via a static overturning and pulling capacity analysis. With the driver and a total mass of 288 kg, this *MM* could pull up to 377.3 kg on flat ground with the drawbar 310 mm above the ground. The imminent roll-back occurred by pulling 299.5 kg at an inclination of 37.1°. The second chain in the new chassis caused a lateral force, which changed depending on the speed selector in the gearbox and the engine's rpm, and approached its maximum the further apart the two chains were. It was concluded that an *MM* can pull implements on flat terrain and slight slope, as long as they are designed while considering the geometry and capacity of the vehicle.

Keywords: mini-tractors, motorcycle adpatation, agricultural machinery

RESUMEN

En las zonas agrícolas de Colombia, el número de motocicletas de 125 cm^3 está aumentando, mientras que la disponibilidad de mano de obra está disminuyendo. No obstante, los requerimientos de potencia para el trabajo agrícola permanecen constantes. Los desarrollos tecnológicos en el país han hecho algunas adaptaciones a las motocicletas, incluyendo un nuevo chasis trasero y una transmisión de cadena diferente, con el fin de contar con una fuente de potencia adecuada para terrenos pequeños y zonas de ladera que sea accesible en términos de costo y nivel tecnológico. El objetivo de este estudio fue analizar la estabilidad y la capacidad de arrastre de una motocicleta modificada (*MM* AKT 2013 EVO 125 cm^3 – 7.5 kW tipo Street–Sport), mediante el estudio de la transmisión de potencia del chasis original y del chasis recientemente adicionado a través de un análisis estático de volcamiento y capacidad de tiro. Con el conductor y una masa total de 288 kg, esta *MM* pudo tirar hasta 377.3 kg en terreno plano con la barra de tiro a 310 mm sobre el suelo. El vuelco inminente ocurrió al halar 299.5 kg en una inclinación de 37.1°. La segunda cadena en el nuevo chasis causó una fuerza lateral, la cual cambiaba según el selector de velocidades en la caja de cambios y las rpm del motor, y se aproximaba a su máximo a medida que las dos cadenas se separaban. Se concluyó que una *MM* puede halar implementos en terreno plano y en pendiente ligera, siempre que estos se diseñen considerando la geometría y la capacidad del vehículo.

Palabras clave: minitractores, adaptación de motocicletas, maquinaria agrícola

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Introduction

In many countries, small farmers often use labor animals, human force, and tractors for agricultural production. Tillage requires the highest power available to overcome the high pulls of plows and harrows, which must be done in a short time.

The highest levels of power and control allow reducing the time and effort required for performing tasks. For instance, preparing 1 ha for seeding requires nearly 33 days by hand and hoe, five days with two oxen and a 0.25 m wide plow, 13 h with a 5 kW walking tractor and a 0.30 m wide disc plow, and just 1.5 h with a category-two tractor and a 1.9 m wide disc harrow [8], [19]. Moreover, just for stability, an average tractor could safely work in hills with a slope of up to 20%, while a couple of oxen can work in hills of up to 25%. [19].

In 2014, Colombia had around 17 490 tractors and 902 walking tractors [20]. Most of the country's mechanized power is located in its plain and highly productive zones.

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According to [39], between 2015 and 2020, the imports of tractors exhibited an average increase of 30 million dollars per year. Moreover, between 2019 and 2023 Colombia imported between 5500 and 6000 tractors thanks to government policies and the increase in the agricultural productivity of some cereals. This growth, hoever, might be hindered by issues like climate change, trade liberalization, and public order [35].

It is difficult to calculate even an approximate figure for the population of labor animals. In 1980, it was estimated that 120 000 couples of oxen were used for tillage alone [36], but no recent data are available for the country.

In summary, small and medium-sized farmers in Colombia have been carrying out their agricultural tasks using human force, as well as draught animals in some cases, which represents high time investment, low efficiency, and lack of competitivity. More studies and innovations are required to improve the use of the available power sources or propose new ones, such as motorcycles.

The objective of this study is to analyze the technical restraints and implications using modified motorcycles (*MM*) in this regard, especially in terms of stability and pull capacity. We conducted a theoretical analysis of the capabilities of a machine based on a motorcycle, including the addition of a new chassis, in order to predict the slope, pull, and load limits of the setup, as well as the general sizes of the agricultural implements that these *MM* could move.

Motorcycles in Colombia

In 2017, 25.6% of the families in Colombia had a motorcycle. Among the heads of household with motorcycles, 26% were women, and 43.4% were less than 40 years old. The main educational level in this group was basic primary and secondary education, while less than 4% were professionals. 18.7% of the heads of household with motorcycles worked in the countryside, sea, and rivers [18].

Regarding rural transportation, motorcycles represented 15.4% of the total. In rural areas, the number of families with motorcycles was between 12.5 and 52.4% [9], [18].

In 2018, the 0-110 and 111-135 cm^3 categories each amounted to 36.9% of the registered motorcycles. In addition, 11% were between 151 and 180 cm^3, and those above 180 cm^3 represented 1.7%.

The Street (tourism) and Sport classes registered in 2018 represented 72.6% of the total, followed by the Scooter class with 12.2% and Enduro motorcycles with 6.7%.

State of the art

A new chassis has been developed which can be added to the rear axle of a motorcycle with no structural changes, allowing it to be used either as a traditional vehicle or as an *MM* [31], [34]. This innovation for 7.5 kW motorcycles involves a two-stage reduction from the output of the gearbox, using sprockets, a chassis connected to the rear swingarm of any motorcycle within this average power, R1 agricultural tires, and a drawbar. The new power transmission was developed using the performance curves of the engine of an AKT EVO 124 NE – 2013 (125 cm^3, 7.6 kW @ 8500 rpm engine, five forward gears).

Since a motorcycle produces more rotational speed than torque, a second roller chain and two sprockets with a speed ratio of 2.8:1 were added to the rear power raise the torque. Furthermore, the prototype has a differential and hydraulic brake.

To the rear power train of a Yamaha XTZ 125 (124 cm^3, 7.1 kW @ 7800 rpm-engine, five forward gears), [21] attached a new chassis and a speed reduction using a roller chain and sprockets, for a speed ratio of 1.67:1.

In addition, [7] designed a final reduction with a 4.7:1 gearbox moved by the original motorcycle chain, for a total ratio of 1:10, and [17] designed a proportional power take off (PTO), employing helical gears and a gear ratio of 1:1, also powered by the original chain of the motorcycle.

As examples of commercial adaptations, in India, a motorcycle adaptation called *three-wheel minitractor* was developed, which includes a larger chassis, PTO, and three-point linkage, like that of Royal Enfield bullet tractor [25]. Moreover, there are minitractors with engines of one cylinder between 7.5 and 16.4 kW at 2200-3000 rpm, 750-1500 cm^3; rear tires between 406 and 458 mm (16 to 18 inches); and weighing between 550 and 1010 kg [40]. In addition, [37] developed a small two-wheeler tractor using a motorcycle with a new chain speed ratio of 1.75 and a rear lifting mechanism powered by the driver's legs.

Colombian developments have adapted normal motorcycles that use sprockets and chains for power transmission by adding a new universal chassis that can be adapted to most vehicles while preserving their primary function as a means of transport.

Main features of Colombian 125 cm^3 motorcycles

To analyze an *MM*, the main features of Colombian motorcycles must be discussed.

Table I summarizes the information required to determine the traction performance of 13 of the country's top-selling motorcycles in the 125 cm^3 Street–Sport class [1]–[5], [10]–[16], [23], [24], [26]–[28], [41].

Table I. Main features of 13 of Colombia's top-selling 125 cm^3 Street–Sport motorcycles

Feature	Value	
Cost for 2022 in COP $ (EUR – 12/05/2022)	Average: 5 525 273 – S: 634 679 (1295 – SD: 148.8)	
Motor		
Times	4	
Cylinders	1	
Distribution	SOHC, OHV	
Power (hp @ rpm)	10-12.82 @ 7500-9000	
Torque (N-m @ rpm)	9.2-11 @ 5000-8000	
Displacement (cm^3)	124.1 to 124.6	
Compression ratio	9.4 to 10.0	
Bore x stroke (mm)	50 x 63 to 57 x 48.8	
Cooling	Air	
Starting method	Electric and kick	
Idle speed (rpm)	1400 ± 100	
Starting system	CDI	
Power transmission		
Gears	4-5	
Mechanical/automatic	Mechanical	
Front suspension	Telescopic hydraulic fork, 130-155 mm	
Rear suspension	Double shock absorber, swingarm	
Front brakes	Disc	
Rear brakes	Drum	
Clutch	Oil-bathed multi-disc	
Chasis		
Front tire mm (inches)	69.85, 80.01, 100.08/431.8, 457.2, 482.6 (2.75, 3.15, 39.4/17, 18, 19)	
Rear tire mm (inches)	76,2, 89,92, 100,08 / 406,4, 431,8, 457,2 (3,0, 3,54, 3,94 / 16, 17, 18)	
Tank capacity (including reserve) (cm^3)	12 800 to 14 500	
Total length (mm)	1900 to 2037	
Total high (mm)	800 to 1210	
Total width (mm)	704 to 780	
Length between axes (mm)	1255 to 1330	
Chair height (mm)	780 to 815	
Net weight (kg)	113 to 138	
Engine – ground separation (mm)	160 to 240	
Chassis type	Tubular: Semi-double cradle/open cradle	
Speed ratio	**Average**	**SD**
Primary ratio (engine-clutch)	**3.25 to 405**	
Final ratio (Chain)	**0.319**	0.0106
1st gear	**0.383**	0.0486
2nd gear	**0.560**	0.0365
3th gear	**0.785**	0.0779
4th gear	**0.966**	0.0750
5th gear	**1.111**	0.0904
Chain type	ISO 08-B1. 18 kN	

Source: Author

Engine and transmission

The motorcycle presented in [31] and [34] has a four-stroke mono-cylinder engine, a wet multi-disk clutch, a five-speed sequential gearbox, and a final reduction using two sprockets and a roller chain.

The crankshaft power flows in constant mesh through the first couple of gears to the primary axle, which is supported at the clutch and on the gearbox case. Its gears transmit the power to the secondary axle pinions. All parts are movable and engage sequentially (Fig. 1).

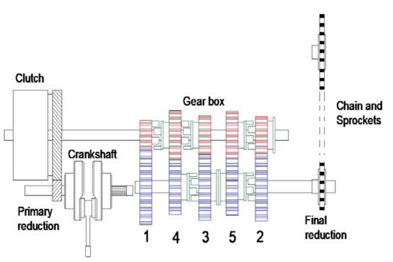


Figure 1. Average power train of a 125 cm^3 motorcycle
Source: Author

Chassis

A new chassis was added to the motorcycle's rear part, removing the rear wheel and implementing a second speed reduction using a roller chain, which moves one axle joined to two wheels with agricultural tires of a smaller diameter. In [31] and [34], the original front and rear rims of the prototype measured 457 mm (18 in), while the *MM's* rear rim is 381 mm (15 in). The rear bar of the new chassis has a drawbar (Figs. 5 and 6). Currently, these modified motorcycles are only able to pull machines through their drawbar because a three-point linkage requires major modifications, hydraulic circuits, and a more robust and complex chassis. The current linkage is a single first-grade support, where there is no reaction to bending.

The chassis of the motorcycles analyzed is of the backbone type, comprising steel pipes welded to each other that connect the steering hub to the rear swingarm. This approach maintains the original rear wheel and its shock absorber. The structure holds the fuel tank and the driver's seat, and it embraces the engine and the steering hub. It combines a central column in the upper part with other elements that form triangular and trapezoidal units to improve rigidity with regard to torsion and flexion.

The chassis of the 125 cm^3 street motorcycles sold in Colombia is characterized in Table II.

Table II. Chassis of the best-selling 125 cm^3 street motorcycles in Colombia

Simple open cradle	Unfolded single crib (semi-double crib)
AUTECO	
TVS striker 125	Bajaj Platino 125
TVS max 125	Boxer CT 125
Bajaj Pulsar NS 125	Bajaj Discover 125 ST-R
YAMAHA	
Yamaha Ybrz 125	
AKT	
NKD 125 Led	TTR 125
cr4 125 unishock	
HONDA	**HERO**
CB125F	Ignitor 125

Note: Other structures include the double crib and the single closed crib.
Source: Author

The center of gravity of a motorcycle with a driver lies along a line at 45° from the horizontal and approximately midway between the front and rear axle [22]. With the new chassis, the center moves to the rear and down.

Pull capacity as a function of the chassis and mass

It is important to determine the weight transfer to the rear axle when the *MM* is pulling one implement.

Following Zoz and Grisso

Based on the analysis conducted by [42] for tractors, the force distribution is shown in Fig. 4a.

$$RWD = RWS + P.\left[\frac{DH}{WB}COS(\theta) - \frac{WB+B}{WB}Sin(\theta)\right] \quad (1)$$

Eq. (1) allows finding the dynamic weight transfer to the rear axle without considering the torque from the engine.

Following McMillan for draught implements

Some assumptions to bear in mind include the absence of inertial forces, the symmetric vertical plane, the radial or tangential forces over the tires, the negligible forces stemming from changes in the fluids or air resistance, and the forces allowing external work that do not cause acceleration.

Methodology

To determine the *MM's* stability and pull capacity, we conducted a static analysis of the complete forces using the geometry, motor, and chassis of a modified 2013 AKT EVO 125.

The center of gravity was measured and calculated as shown in Fig. 2. Unlike a tractor, the driver of the motorcycle does affect the general dynamics [29].

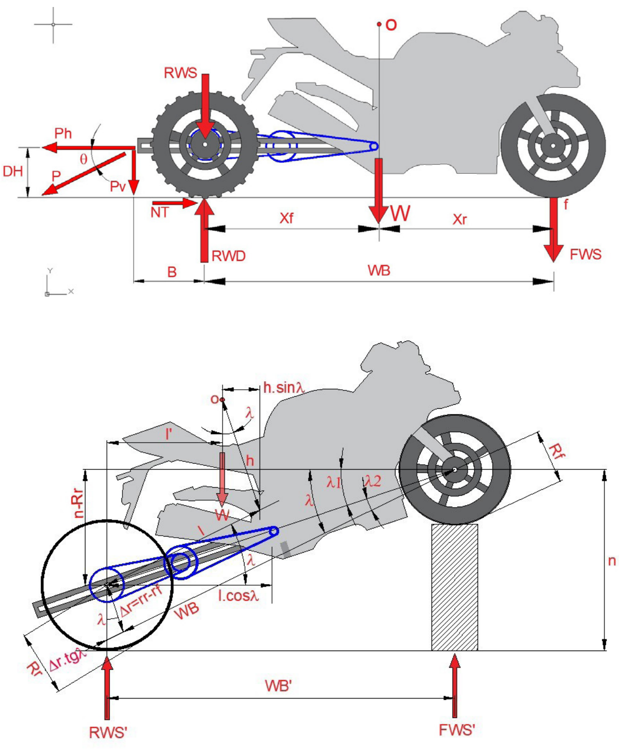


Figure 2. Center of gravity for a *MM:* a) horizontal, b) vertical view
Source: Adapted from [29]

$$\frac{x_f}{WB} = \frac{FWS}{W} \quad (2)$$

$$h = \frac{W_t.l - FWS'.WB}{W.tg(\lambda)} - \frac{FWS'.\Delta r}{W} \quad (3)$$

$$\lambda = \lambda_1 + \lambda_2$$

$$tg(\lambda_1) = \frac{n}{WB'}$$

$$tg(\lambda_2) = \frac{\text{Är}}{WB}$$

$$WB' = \left(WB + \text{Är}.tg(\lambda)\right).\cos(\lambda)$$

To determine the pull capacity, Zos and Grisso and McMillan analyses were conducted. Here, the weight of the *MM* with the driver was considered, as well as the torque from the engine to the new rear axle, as shown in Fig. 3.

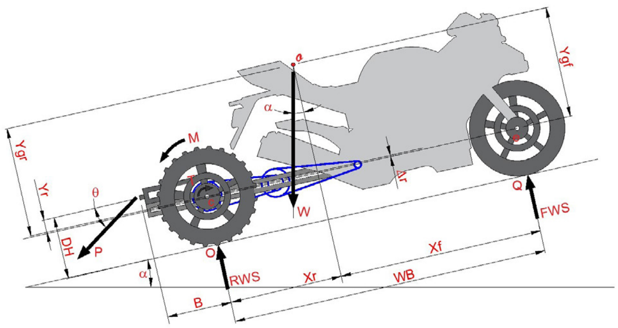


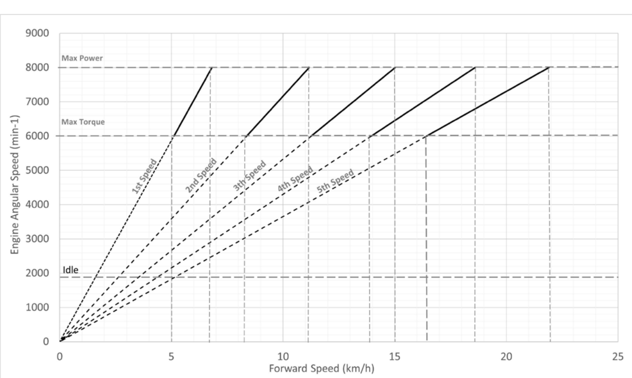
Figure 3. Force distribution in the modified motorcycle including the torque to the rear axle
Source: Author

Results and discussion

125 cm³ street-sport motorcycles in Colombia belong to a very homogeneous segment, with similar power and torques under a similar engine regime, which is high (5000-9000 rpm) in contrast to that of tractors (2500-3000 rpm on average). They feature four- and five-speed gearboxes and very similar transmission ratios. In the manuals, there is no information about the primary ratio, so the value range considered corresponded to only two motorcycles.

With a mechanical value of 0.98 for every two gears in the gearbox [33], the efficiency was 0.96. As for the chain reduction, the mechanical efficiency was 0.98 [38]. Thus, the global mechanical efficiency from the engine to the rear axle of the *MM* was 0.92.

Considering the speed ratio as well as the power and torque for the engine regime of a *MM* based on the AKT EVO 125, [6], [31], [34], the performance of the forward speed and torque is shown in Fig. 3 [32].



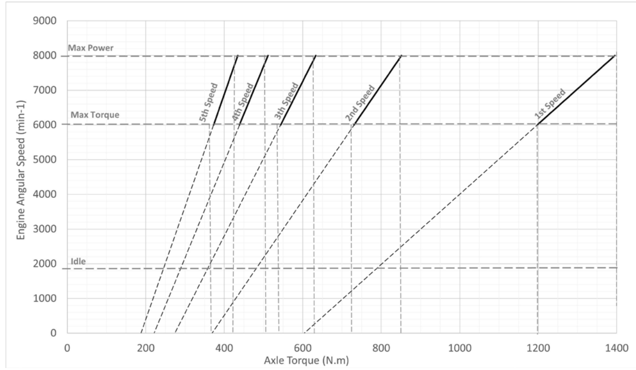


Figure 4. a) Forward speed and b) final axle torque in a modified AKT EVO 125
Source: Author

Fig. 4 depicts the theoretical forward speeds and torques at the *MM*'s rear axle at sea level and without losses in the power train, among other conditions. This allows calculating the gross performance of the *MM*, which is affected by the pulled implement and the soil.

Center of gravity

Based on Fig. 3, for a given **λ** angle, **h** varies with the diameter of the rear wheels. When the rear and front wheels have the same diameter, a rim measuring 431.8-482.6 mm (17 and 19 in), and a diameter between 544 and 645 mm (Table 1), the expression for **h** is given below:

$$\Delta r = 0$$

$$h = \frac{W.l - FWS'.WB}{W.tg(\lambda)} \tag{4}$$

$$\lambda = \lambda_1$$

$$tg(\lambda_1) = \frac{n}{WB'}$$

$$WB' = WB.\cos(\lambda)$$

Eqs. (3) and (4) demonstrate that, when the wheels are equal in diameter, the center of gravity is higher than that of a motorcycle with a larger rear wheel. It is desirable to have a low center of gravity in order to maintain stability and have a more horizontal pull line concerning the pulled machines. On the other hand, **Δr** (=**Rr**-**Rf**) could have so high a value that the center of gravity would be below the line of the rear axle.

For the gravity center to be in line with the rear axle (**h**=0) under the conditions presented in the test scheme (a measured **FWS'** and a given **λ**), the following expression must hold:

$$\Delta = \frac{1}{tg(\lambda)} \cdot \left(\frac{W}{FWS'} . l - WB \right) \tag{5}$$

The *MM* developed by [31], and [34] has the geometric characteristics shown in Fig. 5.

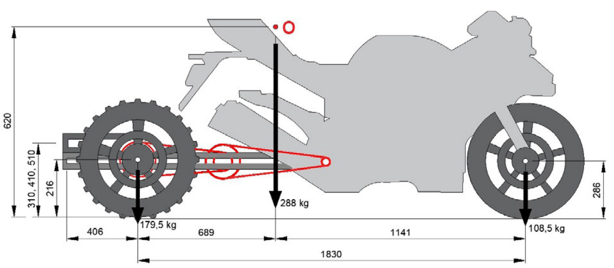


Figure 5. Mass and size of an *MM* based on a 2013 AKT EVO 125
Source: Author

The original weight is 125 kg (203 kg with a driver). Thus, **Ygr** + **Rr** = 620 mm.

Stability and pull capacity

MacMillan assumptions

Machines pulled by the *MM* must be selected in such a way that they can be moved with the available traction force provided by the new rear tires. In doing this, the information in Fig. 3 is considered.

These motorcycles have a four-stroke, high-revving engine with a useful range (maximum torque to maximum power) between 1000 and 2000 rpm, as well as transmission ratios from 0.319 to 1.111 in the gearbox.

Furthermore, as is the case with tractors, the engine rotation regime must be fixed by some device when working the field. This allows for near-steady-state operation. Since the throttle control is sensitive to the rotation of the accelerator on one side of the rudder, significant changes in engine speed can be achieved with small rotations of the command. Keeping a constant working speed for any agricultural task that lasts some hours requires a device to fix the engine regime at a given rpm value, so that the driver's hand is not forced at all times.

The prototypes presented in [31], [34], [17], [21], and [7] propose a chassis that connects to the rear swingarm, forming a tricycle (Fig. 6) in which the rear tires are equidistant from the center of the motorcycle.

The chassis of [17], [21], and [7] features two support points in the swingarm, while the designs of [31] and [34] have a large support point using clamps. In both cases, the new chassis and the swingarm move as one element around the pin that connects the latter to the rear of the chassis by means of a hub. Moreover, the rear suspension system has not been modified (shock absorber).

In these proposals, a second speed reduction using chains, two sprockets, and an intermediate axle is introduced. The tension in the original chain is transmitted to the motorcycle chassis, while the tension of the second one goes to the rear wheels. The least possible distance must be kept between the two sprockets in the intermediate axle in order to reduce the torque about the vertical axis of the motorcycle, which could generate instability. This is analyzed in Fig. 6.

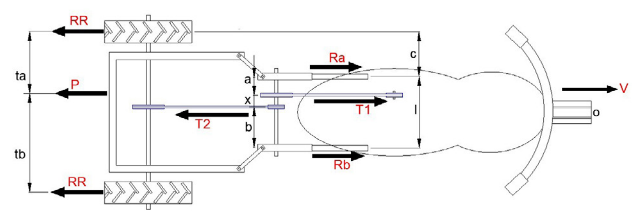


Figure 6. Lateral forces analysis – Medina and Pinzón model
Source: Author

With the vehicle moving and pulling a force P

Moments around point b:

$$\sum Mb = 0: \; RR.c - RR.(s-c) - T_2.lb + T_1.(x+lb) + R_a.L - P.(sb-c) = 0$$

$$R_a.L = RR.(s-2.c) + T_2.lb - T_1.(x+lb) + P.(sb-c) \tag{6}$$

Moments around point a:

$$\sum Ma = 0: \; RR.(s-c) - RR.c + T_2.(la+x) - T_1.la - R_b.L + P.(sa-c) = 0$$

$$R_b.L = RR.(s-2.c) + T_2.(la+x) - T_1.la + P.(sa-c) \tag{7}$$

Since **Rb** – **Ra** must be minimal, based on Eqs. (6) and (7), the following is obtained:

$$(R_b - R_a).L = T_2.(la+x-lb) + T_1(lb+x-la) + P(sa-sb) \tag{8}$$

Considering that

$$L = la + lb + x$$

$$(R_b - R_a)L = T_1.(L-2.la) + T_2.(L-2.lb) + P(sa-sb) \tag{9}$$

For Eq. (9), there is one special case, *i.e.*, when there is no charge, **P** = 0.

This creates a vertical torque on the chassis due to the tension in the chains.

$$(R_b - R_a)L = T_1.(L-2.la) + T_2.(L-2.lb) \tag{10}$$

Moreover, if **la** = **lb** ≈ L / 2,

Ra = Rb

and, when **la** = **lb**,

$$\left(R_b - R_a\right)L = (T_1 + T_2)\left(L - 2.la\right) \tag{11}$$

In general, note that the vertical torque on the motorcycle chassis increases with the separation between the two sprockets in the intermediate axle, as well as with its eccentricity concerning the links to the rear swingarm.

The tension of the chains, as a function of the engine speed, is shown in Fig. 7.

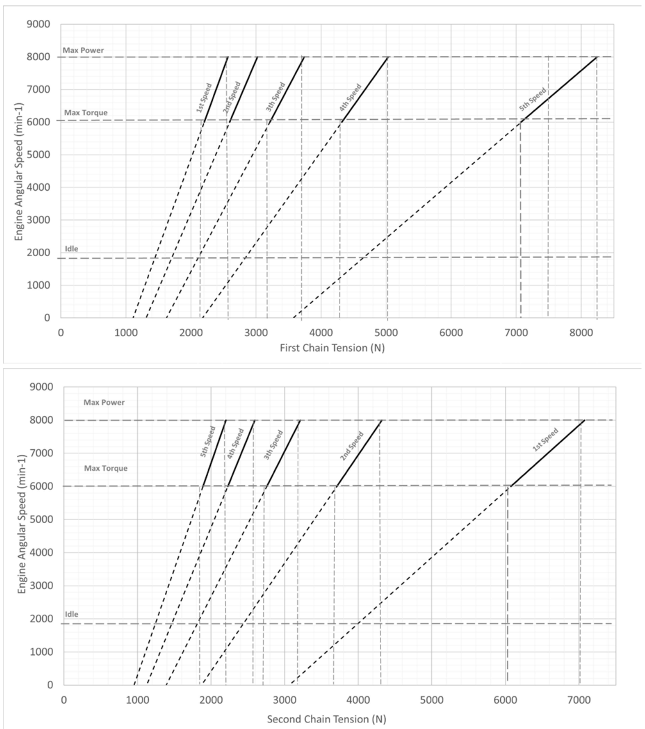


Figure 7. Chain tension as a function of the engine regime: a) first chain, b) second chain
Source: Authors

For the AKT EVO 125, the highest sum of tensions, between 13 150 and 15 320 N, is reached in the first gear.

Fig. 7 was elaborated using the maximum tension in the first gear and at 8000 rpm. The resulting torque changes due to the forces on the two chains for different sprocket locations in the intermediate axle and several **la – lb** separations (Fig. 6), which are expressed as a fraction of the length **L**, *i.e.*, the distance between the supports of the swingarm. This torque is exerted on the chassis and tends to rotate it to the left in the forward position.

In reality, the length **la** is fixed because the driven sprocket in the first reduction is parallel to that at the output of the gearbox. Fig. 8 shows that, as the separation **x** between the sprockets in the intermediate axle grows, the vertical moment of the chassis increases, but it decreases as the first sprocket moves away from the left brand of the swingarm.

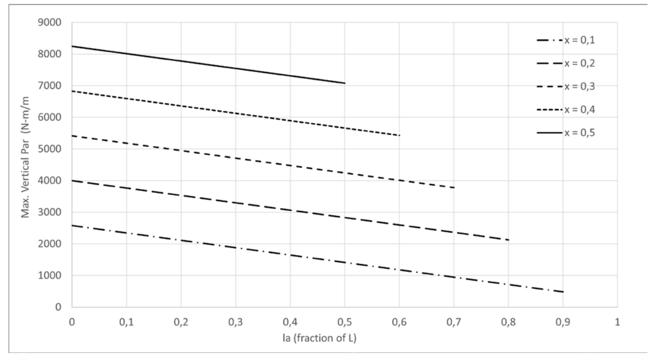


Figure 8. Vertical torque on the motorcycle chassis as a function of the distance between the intermediate sprockets separation for the first gear and at 8000 rpm. *la* and *x* are expressed as a fraction of *L*.
Source: Authors

Considering the force **P** required to pull any implement, as shown in Eq. (6), the drawbar must be attached to the rear bar, so that the two moments acting on the chassis are balanced. Therefore, the following must hold:

$$\left(R_b - R_a\right)L = 0$$

Thus,

$$sb - sa = e = \frac{T_1.\left(L - 2.la\right) + T_2.\left(L - 2.lb\right)}{P} \tag{12}$$

Dimension **e** is the left deviation in the direction of the motorcycle's movement, measured from the center of the rear bar since the right side of Eq. (12) is always positive (Fig. 5).

Eq. (12) and Fig. 8 show that this eccentricity cannot be equal for all the implements pulled by the *MM*; in every forward gear, different chain tensions are generated, and the pulling forces of the machine are different for each implement.

The forces on the tires can only be radial or tangential, even in the case of tractors' larger tires. With the less wide and smaller-diameter tires of the *MM*, and due to its low weight, this assumption can also be made.

At the low working speeds of the *MM*, air resistance may well be negligible. However, a change in the driver's position could affect the center of gravity, as well as the weight transfer. Some field tests must be conducted in order to determine the extent of this influence.

There are two possibilities for the diver's position: sitting down or standing on the footrests. The seat and footrests are fixed to the central part and the bottom of the motorcycle chassis, respectively, using a tubular structure and screws. When the driver is standing up, the center of gravity rises by a few centimeters frontward and upward, reducing the weight transfer calculated with Eqs. (1) and (6).

Dynamic weight transfer and pull capacity as functions of the MM’s chassis and mass

Considering the above, the free-body diagram shown in Fig. 3 was elaborated in oder to analyze the *MM*’s stability. The driver was not included.

For this purpose, the *MM* was assumed to be ascending on a slope with an angle of inclination α, pulling a load inclined at an angle θ with respect to the ground surface. The moments around the front and rear axles were calculated. In each case, the effect of having the drawbar above or below the rear axle line was considered.

Front wheel: To find the weight transfer to the front wheel.

- *When the drawbar is above the rear axle:*

Moments around the rear axle :

$$FWS.WB + W.Y_{gr}.\sin(\alpha) + P.B.\sin(\theta) - W.X_r.\cos(\alpha) - P.Yr.\cos(\theta) + T = 0 \quad (13)$$

- *When the drawbar is under the rear axle:*

$$FWS.WB + W.Y_{gr}.\sin(\alpha) - W.X_r.\cos(\alpha) + P.B.\sin(\theta) + P.(-Y_r).\cos(\theta) + M = 0 \quad (14)$$

In the rear wheel, the torque (T) that comes from the engine is applied, as well as the rolling resistance (Rr) against the surface.

Moments around the rear wheel:

$$T = NT.Rr \quad (15)$$

Forces parallel to the ground:

$$NT = P.cos(\theta) + W.\sin(\alpha) \quad (16)$$

The above yields the following expressions:

Drawbar above the rear axle:

$$FWD = FWS - \frac{W.(Y_{gr} + R_r).\sin(\alpha)}{WB} - \frac{P.(R_r + Y_r).\cos(\theta)}{WB} - \frac{P.B.\sin(\theta)}{WB} \quad (17)$$

Drawbar under the rear axle:

$$FWD = FWS - \frac{W.(Y_{gr} + R_r).\sin(\alpha)}{WB} - \frac{P.(R_r + (-Y_r)).\cos(\theta)}{WB} - \frac{P.B.\sin(\theta)}{WB} \quad (18)$$

Rear wheel: To find the weight transfer to the rear wheel.

Moments around the front axle

- When the drawbar is above the rear axle:

$$RWD = RWS + \frac{W.(Y_{gr} + R_r + \Delta R).\sin(\alpha)}{WB} + \frac{P.(R_r + \Delta R + Y_r)\cos(\theta)}{WB} + \frac{P.(WB + B)\sin(\theta)}{WB} \quad (19)$$

- When the drawbar is under the rear axle:

$$RWS.WB + P.\cos(\theta).(Y_r - \Delta R) - W.X_f.\cos(\alpha) - P.(WB + B).\sin(\theta) - W.(Y_{gr} + \Delta R).\sin(\alpha) + M = 0 \quad (20)$$

$$RWD = RWS + \frac{W.(Y_{gr} + R_r + \Delta R).\sin(\alpha)}{WB} + \frac{P.(R_r + \Delta R - Y_r)\cos(\theta)}{WB} + \frac{P.(WB + B)\sin(\theta)}{WB} \quad (21)$$

Moreover,

$$\begin{aligned} \Delta R + Y_r &= Y_f \\ R_r + (\Delta R + Y_r) &= R_r + Y_f \\ R_r + [\Delta R + (-Y_r)] &= R_r - Y_f \\ Y_{gr} + \Delta R &= Y_{gf} \end{aligned} \quad (22)$$

To summarize, the dynamic weight in the rear and in the front wheels responds to Eqs. (23) and (24).

$$FWD = FWS - \frac{W.(Y_{gr} + R_r).\sin(\alpha)}{WB} - \frac{P.(R_r + Y_r).\cos(\theta)}{WB} - \frac{P.B.\sin(\theta)}{WB} \quad (23)$$

$$RWD = RWS + \frac{W.(Y_{gf} + R_r).\sin(\alpha)}{WB} + \frac{P.(R_r + Y_f).\cos(\theta)}{WB} + \frac{P.(WB + B)\sin(\theta)}{WB} \quad (24)$$

In the therms for FWD and RWD, the height of the drawbar concerning the front axle **Yf** could be:

- ***FWD***: **Yr**: (+) when the drawbar is above the rear axle; (-) when the drawbar is under the rear axle.
- ***RWD***: **Yf**: (+) when the drawbar is above the rear axle; (-) when the drawbar is under the rear axle.

These cases were analyzed for a positive slope, *i.e.*, with the motorcycle ascending. The diameter of the rear wheel affects the weight transferred to each axle.

If the rear and front wheels have the same diameter, the right third term changes from **Yf** to **Yr**.

Models [7], [17] and [21] propose rear wheels smaller in diameter than the front ones in order to reach a higher traction force. [31] and [34] also feature smaller rear wheels.

Maximum force required to prevent overturning

Eq. (23) calculates the maximum pull load required to avoid the loss of the front wheel’s steering effect.

For a flat terrain, **α** = 0, and considering that no weight is transferred to the front wheel to reach an imminent overturning, **FWD** must be equal to zero.

Thus, based on Eq. (14), there is overturning when

$$W.X_r < P.Cos(\theta).(Y_r + R_r) + P.B.Sin(\theta) \quad (25)$$

Expressing the load **P** as a fraction of the weight **W,**

Pull ratio: **A** = **P** / **W**.

Based on Eq. (25):

$$A < \frac{X_r}{(Y_r + R_r)Cos(\theta) + B.Sin(\theta)} \quad (26)$$

For example, for the modified AKT EVO 125,

$$A < \frac{689}{(310 + 216)Cos(\theta) + 406.Sin(\theta)} \quad (27)$$

For instance, when pulling a car by only applying a horizontal force (**θ**=0), **A** = 1.31, 1.10, and 0.95 for the different available drawbar heights **Yr** = 310, 410, and 510 mm (Fig. 5). With the total *MM* weight of 288 kg, the limit pull is 377.3, 316.8, and 273.6 kg in each case. These values do not correspond to the weight of the car, but to the rolling resistance of its wheels.

For a flat terrain, it is possible to find the maximum angle **θ** of the force **P** that causes the overturning. To this effect, d**A**/d**θ** must be equal to zero in Eq. (26):

$$\frac{dA}{d\theta} = \frac{-\left[-(Y_r + R_r).Sin(\theta) + B.Cos(\theta)\right]}{\left[(Y_r + R_r).Cos(\theta) + B.Sin(\theta)\right]^2} = 0 \quad (28)$$

This yields the following:

$$tan(\theta) = \frac{B}{Y_r + R_r} \quad (29)$$

For the modified AKT EVO 125, **θ** max = 37.1°, so **A** = 1.04. This means that, for this *MM*, a pull of 299.5 kg inclined at a maximum angle **θ** of 37.1° implies imminent overturning.

Based on Eq. (23) for **FWD**, the maximum angle **α** of the ground slope in the forward direction can be estimated regardless of the force pull angle **θ**. With the pull ratio **A** = **P/W**,

$$FWD = \frac{W.X_r.Cos(\alpha)}{WB} - \frac{W.(Y_{gr} + R_r).\sin(\alpha)}{WB} - \frac{A.W.\left[(R_r + Y_r).\cos(\theta) + B.\sin(\theta)\right]}{WB} \quad (30)$$

Now, without weight transfer to the front wheel, **FWD** = 0. Based on Eq. (30),

$$X_r.Cos(\alpha) = (Y_{gr} + R_r).\sin(\alpha) + A.\left[(R_r + Y_r).\cos(\theta) + B.\sin(\theta)\right] = 0 \quad (31)$$

Thus, the pull ratio **A** is given by

$$A = \frac{X_r.Cos(\alpha) - (Y_{gr} + R_r).\sin(\alpha)}{\left[(R_r + Y_r).\cos(\theta) + B.\sin(\theta)\right]} \quad (32)$$

For any angle **θ**, the maximum angle **α** can be obtained when d**A**/d**α** = 0 in the interval **α** between 0 and 90°.

$$\frac{dA}{d\alpha} = \frac{-X_r.Sin(\alpha) - (Y_{gr} + R_r).\cos(\alpha)}{\left[(R_r + Y_r).\cos(\theta) + B.\sin(\theta)\right]} = 0 \quad (33)$$

Since the denominator is non-zero for **θ** between 0° and 90°, the maximum value of **α** is independent of the value of **θ**:

$$-X_r.Sin(\alpha) - (Y_{gr} + R_r).\cos(\alpha) = 0 \quad (34)$$

$$tan(\alpha) = -\frac{(Y_{gr} + R_r)}{X_r} \quad (35)$$

The pull ratio **A** shows a maximum **α** of 130.53° for the modified AKT EVO 125, which is outside the 0-90° range. This means that,

- When **α** = 0°, **A** = 1.31
- When **α** = 90°, **A** = 1.53

A = 0 if

$$\tan(\alpha) = \frac{X_r}{(Y_{gr} + R_r)} \quad (36)$$

This means that the **MM** cannot pull any force **P** when the terrain slope is parallel to a line that joins the center of gravity with the point of contact between the rear wheel and the ground.

Conclusions

Considering the *MM* prototypes developed in Colombia, this work conducted some theoretical analyses regarding power, transmission, geometry, and forces. It was found that there is a range of load and pull forces that these prototypes can carry, in addition to stability improvements. Further studies are required which evaluate the performance and size of the machines to be pulled by the proposed *MM*.

Given the large number sport motorcycles with a 125 cm^3 engine in Colombia, we found a new use for them by adding a rear chassis that enables both transport and agricultural use.

The diameter of the new rear wheels must be such that the system's center of gravity is low and the pull line is below the rear axle, in order to allow the *MM* to pull more load.

The pull capacity depends on the *MM* and the driver's weight. Since these machines are light equipment, loads that cause an imminent overturning must be calculated, tested, and avoided. Similar calculations could also be made to keep the **FWD** at 30% of the total weight, in order to maintain steering control.

The new transmission generates a vertical torque on the motorcycle that affects the transverse location of the drawbar for each implement.

Field evaluations similar to the Nebraska tests must be conducted to obtain a better selection of agricultural implements and predict the *MM*'s performance. In addition, force, speed, and torque sensors must be added to verify the predictions presented herein.

In general, it seems possible for the *MM* to pull agricultural implements in flat and slightly sloped terrains. This depends on the final geometry of the motorcycle and its weight distribution.

References

[1] AKT Motos, "Catálogo de partes. 125 SLR – NKDR," 2011. Accesed: Aug. 18, 2025. [Online]. Available: https://www.aktmotos.com/sites/default/files/parts_catalog/pdf/AK%20125SLR-NKDR%202011%20CATALOGO%20DE%20PARTES.pdf

[2] AKT Motos, "Catálogo de Partes. 125 SL/SL /NKD," 2011. Accesed: Aug. 18, 2025. [Online]. Available: https://www.aktmotos.com/sites/default/files/parts_catalog/pdf/AK%20125S-SL-NKD%202004-2011%20CATALOGO%20DE%20PARTES.pdf

[3] AKT Motos "Manual de servicio. AK 125/150 NE," 2011. Accesed: Aug. 18, 2025. [Online]. Available: https://www.aktmotos.com/sites/default/files/parts_catalog/pdf/AK%20125-150NE%20New%20EVO%202011%20CATALOGO%20DE%20PARTES.pdf

[4] AKT Motos, "Catálogo de partes 125/150 R3," 2014. Accesed: Aug. 18, 2025. [Online]. Available: https://www.aktmotos.com/sites/default/files/parts_catalog/pdf/AK%20125-150%20-%20R3%202014%20CATALOGO%20DE%20PARTES.pdf

[5] AKT Motos, "Catálogo de partes. AK 125 EVO," 2012. Accesed: Aug. 18, 2025. [Online]. Available: https://www.aktmotos.com/sites/default/files/parts_catalog/pdf/AK%20125-150EVO%202008-2012%20(2)%20CATALOGO%20DE%20PARTES.pdf

[6] AKT Motos, "Catálogo de partes. AK NKD 125," 2024. Accesed: Aug. 18, 2025. [Online]. Available: https://www.aktmotos.com/sites/default/files/parts_catalog/pdf/NKD125%20-2024.pdf

[7] A. A. Rodríguez, A. "Adaptación de una motocicleta para la actividad agrícola," BS thesis, Universidad de los Andes, Bogotá, Colombia, 2020.

[8] Agricultural machinery management data, ASAE D497.7.2011, St. Joseph, MI, USA, 2011.

[9] Asociación Nacional de Industriales, "Las motocicletas en Colombia: aliadas del desarrollo del país. Estudio del sector," 2019. [Online]. Available: https://www.andi.com.co/Home/Noticia/15607-las-motocicletas-en-colombia-aliadas-de

[10] Auteco, "Catálogo de partes. Discover 125 ST," 2015. Accesed: Aug. 18, 2025. [Online]. https://es.scribd.com/document/324715768/Discover-125st-manual-partes

[11] Auteco, "Catálogo de partes. Discover 125+/ 125 Sport." 2018. Accesed: Aug. 18, 2025. [Online]. Available: https://es.scribd.com/document/383119307/Discover-125-125-Sport-18

[12] Auteco, "Catálogo de partes. Platino 125 Comfortech. DRL Light Tech," 2019. Accessed: 14.12.2022. [Online] Available: https://es.scribd.com/document/467184475/PLATINO-125-DRL

[13] Auteco, "Catálogo de partes. Pulsar NS 125," 2019. Accesed: Aug. 18, 2025. [Online]. Available: https://es.scribd.com/document/437773100/Manual-de-Partes-Pulsar-Ns-125

[14] Auteco, "Manual de garantía y Mantenimiento. Platino 125 Comfortec. DRL Light Tech," 2019. Accesed: Aug. 18, 2025. [Online]. Available: https://www.manualslib.es/manual/113836/Bajaj-Platino-125-Comfortec-Drl-Light-Tech.html?controller=view&page=3#manual

[15] Auteco, "Catálogo de partes. TVS Striker 125," 2023. Accesed: Aug. 18, 2025. [Online]. Available: https://blog.auteco.com.co/wp-content/uploads/2023/12/CATALOGO-DE-PARTES-STRYKER-125-IND-NOV-MY23-FINAL.pdf

[16] Auteco, "Catálogo de partes. TVS MAX 125," 2022. Accesed: Aug. 18, 2025. [Online]. Available: https://es.scribd.com/document/620403347/CATALOGO-DE-PARTES-TVS-MAX-125-SEPT-2022

[17] D. A. Carvajal Yustres, "Diseño de un toma de fuerza mecánico para una motocicleta," BS thesis, Universidad de los Andes, Bogotá, Colombia, 2020.

[18] Cesvi Colombia, "Así es el parque de motocicletas en Colombia," Revista Auto Crash, 2017. [Online]. Available: https://www.revistaautocrash.com/asi-parque-motocicletas-colombia/

[19] The International Commission of Agricultural Engineering, *CIGR handbook of agricultural engineering. Volume III. Plant production engineering*. St. Joseph, MI, USA: The American Society of Agricultural Engineers, 1999.

[20] Departamento Nacional de Estadísticas, "Colombia - Tercer censo nacional agropecuario. 3er CNA. Reporte," 2021. [Online]. Available: https://www.dane.gov.co/index.php/estadisticas-por-tema/agropecuario/censo-nacional-agropecuario-2014

[21] M. A Díaz Caviedes "Desarrollo de una adaptación de motocicletas para desarrollar actividades agrícolas". BS thesis, Universidad de los Andes, Bogotá, Colombia, 2018.

[22] T. Foale, *Motorcycle handling and chassis design. The art and science*. Victoria, Canada: AbeBooks, 2002.

[23] Grupo Uma, "Discover 125 STR," 2022. Accesed: Aug. 18, 2025. [Online]. Available: https://grupouma.com/colombia/wp-content/uploads/sites/2/2022/06/MU-Discover-125-STR-2022.pdf

[24] Grupo Uma, "Pulsar NS 125, Catálogo de Partes" 2019. Accesed: Aug. 18, 2025. [Online]. Available: https://es.scribd.com/document/437773100/Manual-de-Partes-Pulsar-Ns-125

[25] Harsh, "Royal Enfield Bullet Tractor is perfect for small farms," CarBlogIndia, 2021. Accesed: Dec. 14, 2021. [Online]. Available: https://www.carblogindia.com/royal-enfield-bullet-tractor-trishul-small-farmers/

[26] Hero MotoCorp Ltd., "Catálogo de partes. Ignitor 125," 2017. Accesed: Aug. 18, 2025. [Online]. Available:

[27] https://es.scribd.com/document/485532435/manual-de-partes-ignitor-9mayo2018-pdf

[28] Hero MotoCorp Ltd. "Manual Ignitor 125" 2018. Accesed: Aug. 18, 2025. [Online]. Available:

[29] https://heromotos.com.co/wp-content/uploads/2023/09/Manual-Ignitor.pdf

[30] Honda Motor Co. Ltd., "Manual CB 125," 2018. Accesed: Aug. 18, 2025. [Online]. Available: https://motos.honda.com.co/manuales/manual-cb125f.pdf

[31] J. B. Liljedahl, P. K. S. Turnquist, and W. H. David Makoto, *Tractors and their power units*, 4th, ed. New York, NY, USA: AVI Books, 1989.

[32] R. H. Macmillan, *The mechanics of tractor – Implement performance. Theory and worked examples*. Melbourne, Australia: Melbourne University, 2002.

[33] https://fsantos.utad.pt/Bibliografia/65851_Macmillan.pdf

[34] W. D. Medina Rubiano. "Adaptación de una motocicleta como fuente de potencia para trabajos agrícolas," BS thesis, Universidad Nacional de Colombia, Bogotá, Colombia, 2020.

[35] F. D. Molina Aiz, *Motores y máquinas agrícolas*. Almería, Spain: Universidad de Almería, 2010.

[36] R. L. Norton, Diseño de maquinaria. Síntesis y análisis de máquinas y mecanismos, 3rd ed. Boston, MA, USA: McGraw Hill, 2005.

[37] S. C. Pinzón Corredor. "Diseño y adaptación de la transmisión de una motocicleta para utilizar en trabajos agrícolas," BS thesis, Universidad Nacional de Colombia, Bogotá, Colombia, 2020.

[38] Redagrícola, "Colombia: mercado de tractores agrícolas crecería 5.6 % al 2024," 2020. [Online]. Available: https://www.redagricola.com/co/colombia-mercado-tractores-agricolas-creceria-5-6-al-2024/

[39] M. A. Sabogal Acero. "Caracterización de los sistemas de mecanización utilizados en la preparación de suelos de ladera en la región del Gualivá," BS thesis, Universidad Nacional de Colombia, Bogotá, Colombia, 2000.

[40] D. R. Savaliya, P. D. Savani, and M. U. Khunt, "Development of two-wheeler use for farming," *Int. J. Res. Eng. Sci. Manage.*, vol. 3, no. 5, pp. 1207–1215, 2020. https://www.ijresm.com/Vol.3_2020/Vol3_Iss5_May20/IJRESM_V3_I5_319.pdf

[41] M. F. Spotts, *Elementos de máquinas*, 7th ed. México DF, Mexico: Prentice Hall, 1999.

[42] Trade Nosis, "Informes Comex. Informes de Comercio Internacional. Colombia, 87 – Automóviles, 8701. Tractores, 2022. [Online]. Available: https://trade.nosis.com/es/Comex/Importacion-Exportacion/Colombia/tractores--tractores-excepto-las-carretillas-tractor-de-la-partida-8709/CO/8701

[43] Trishul Tractors PVT. LTD., "Trishul Mini Tractor," 2022. [Online]. Available: www.trishultractors.com. https://www.trishultractors.com/downloads/brochure-eng.pdf

[44] Yamaha Motor Co. Ltda., "Catálogo de respuestos. YBR 125 ESD 2CD4 Colombia," 2014. Accesed: Aug. 18, 2025. [Online]. Available: https://www.incolmotos-yamaha.com.co/wp-content/uploads/2018/08/YBR_125_ESD_2CD4_2015.pdf

[45] F. M. G. Zoz and D.G. Robert, "Traction and tractor performance. Tractor design No. 27," ASAE, 2003.

Nomenclature

A: pull ratio = pull force/weight
B: horizontal position of the drawpoint concerning the rear axle
C: 6.818 x 10-3 ˚C/m
CF: indicated power correction factor
DH: vertical position of the drawpoint with respect to the ground
FWD: front dynamic weight
FWS: front static weight
H: height above sea level (m)
IP: indicated power
L: distance between the brands of the rear swinging arm
M: rear axle torque
O: gravity center
P: absolute atmospheric pressure (bar)
pv: saturated vapor pressure (bar)
P: Pull force
Ra: air constant: 287.053 J/(kg-K)
Rf: front wheel ratio
Rr: rear wheel ratio
RWD: rear dynamic weight
RWS: rear static weight
S: distance between the rear wheels
T: air temperature (K)
WB: distance between the front and rear axle.
Xf: horizontal distance between the front axle and the center of gravity
Xr: horizontal distance between the rear axle and the center of gravity
Yr: height of the drawpoint with respect to the rear axle
Yf: height of the drawpoint with respect to the front axle
Δr: **Rr – Rf**
α: terrain slope angle
θ: force angle with respect to the ground
Subscript **0**: reference value