Feasibility study of a tricycle mounted draft implement for dry soils: a case of the Motor king tricycle in Northern Ghana

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Abstract

The debate on African agriculture mechanization has never grown as big as in recent years. Solutions are sought to achieve Sustainable Development Goals. In West Africa, farmers have already adopted tricycles as a means of transport. It is the modern horse, bull, and donkey used by farmers. Their spare parts are available; and their maintenance is mastered in rural areas. This paper highlights the realistic possibilities and the technical limits of using this tricycle for plowing by using the reverse engineering method and data collection in a sandy loam field. Since the tricycle was not initially created for fieldwork, data were collected from its application. As a result, this study found that the tricycle is powerful for tillage, and the power transmission system can support fieldwork. The chassis of the tricycle is strong enough for farm work. Light implements are recommended in medium and light soil conditions. Maximum working width of 40 cm is recommended. A quick analysis of the depreciation rate gave a positive appreciation. An experiment with a single furrow moldboard plow in sandy loam soil indicated a working depth of 15 cm, an Effective Field Capacity of 0.15 ha/hr., and a fuel consumption of 0.9 L/hr.

***Keywords**: Farm power, agriculture, Africa, tricycle, tillage, smallholders.*

1.0 Introduction

Agricultural mechanization in Africa is evolving to facilitate the fight against poverty and hunger. Also, it is usually the first technological tactic to fight low life expectancy, high infant mortality, low level of infrastructure, and low level of social welfare (Renius, 2020a). The socio-economic and cultural particularities of Africa make it a case study for which special measures are needed. Among these are African farmers are poor and cannot afford to buy or rent agricultural tractors despite the efforts of the states to reduce the purchasing cost. Africa has about 33 million smallholdings of less than 2 hectares which represent 80 % of all farmsteads in the continent (NEPAD, 2013). Other particularities of African farmers are the lack of qualified technicians for the maintenance of agricultural machinery, lack of spare parts. More than 40 % of the African population live in landlocked countries, a factor that increases the cost of transport (Jones, 2008). In addition, youth and women represent more than 60 % of farmers in Sub-Saharan Africa (Sims et al., 2016). Furthermore, in some countries, up to 80 percent of the total farm labor comes from women (Kormawa et al., 2018). Women and the youth who are the main actors in agriculture cannot have access to bank loans because lands belong to men.

To achieve the Sustainable Development Goals (SDGs), the African Union Heads of State and Government, at their twenty-fourth summit, reiterated their full duty and commitment to Agenda 2063. That program is called "The Africa We Want". It specifies all African ambitions for 2063. The Food and Agriculture Organization (FAO) and the African Union Council (AUC) predicted that African agriculture will be modern and fruitful. Likewise, it will combine traditional knowledge, science, and technology to reach all objectives. By 2025, hand-hoe will be banished; the agricultural sector will be modern, gainful, and attractive to the youth and women across the continent (FAO and AUC, 2018). It is expected that men will go back to the farm. Accordingly, a social balance will be created.

The African Union Commission's goal is to transfer hand hoes to the museum and liberate farmers from backbreaking drudgeries (FAO and AUC, 2018).

As for tillage, people use animal power as an alternative to human power because of its availability, and their breeding is not difficult in rural areas (Braimah et al., 2013). they need full maintenance out of the farm work, affected by the weather, and work slowly . Nevertheless, Clarke and Bishop (2002) predicted farm power availability in South Saharan Africa and estimated that farmers will move through thermal engines. On the other hand, it is interesting to observe the technological progress accepted in recent years in terms of mechanical power.

This paper aims to study the feasibility of plowing with a three-wheel motorcycle.

In this study, we want to answer the question: "Is it possible to add a tilling function to the Motor King tricycle"?

Smallholders will appreciate a plowing function to the tricycle in West Africa and beyond.

2.0 Materials and Methods

This study was conducted in the community of Nyankpala, Tolon District, about 10 miles South-West of Tamale the capital of the Northern Region of Ghana.

The materials used to do this study were:

1. A physical model of the Motor King tricycle,
2. The Manufacture's Technical documents,
3. A Single Furrow Moldboard Plow.
4. Three meters of chain

Since the tricycle was not initially created for fieldwork, we made a technical comparison between the tricycle, and farm work machine and then applied the reverse engineering principle. The reverse engineering in this study (Figure 1) involves the available engine power, power transmission analysis, tire-soil friction analysis, chassis strength analysis, and the depreciation of the tricycle while being used for farm work.

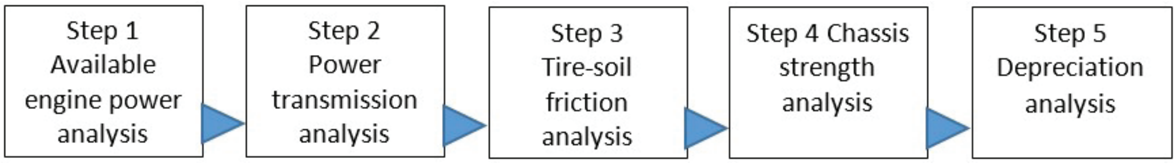


Figure 1: Steps of Feasibility Study

A single furrow moldboard plow is attached to the tricycle by chain and bolt.

3.0 Results

3.1 Feasibility Study

Since the tricycle was not initially created for fieldwork, a technical study was done. This study involved the available engine power, power transmission components, tire-soil friction, chassis strength, and depreciation analysis

3.2 Available Engine Power

Power estimation in the foreword designing method starts with the power requirement for the implement, the power used for self-propulsion, and the power loss in the transmission chain. In reverse engineering and teardowns method, a concrete product or machine is redesigned or optimized (K.N.··奥托 (美) and Otto, 2003). In this study, the product is the engine tricycle, and its power is known. . In Northern Ghana, many brands of engine tricycles with various ranges of engine power are used. These include MOTOR KIA, KAVAKI MOTOR, MOTOR KING among others. The engine power varies from 12HP (the oldest) to 18HP (the most recent). The manufacturers indicate the power output of the engine and the load that the tricycle is capable of carrying. The tricycle used for this study is called Motor King and is one of the most popular. It has 280 cubic centimeters and is capable of carrying load weighing one thousand kilograms (1000 kg). The engine of the tricycle is not touched for this research.

Power loss in the transmission

The gearbox, the propeller shaft, and the differential gearbox are considered.

1. Gearbox performance

It is known that for any vehicle, the first gear ratio has the maximum thrust force, then the second, third, and so on. Maggio *et al.* (2003) explained how gearbox ratios influence driving style.

The inside technology influences the performance of a gearbox. Spur gears are commonly used for motorcycles.

What is the performance of a spur gear system?

Spur gear performance on the Google search engine shows a yield from 95 to 99 %. Anderson and Loewenthal (1981), who worked for the National Aeronautics and Space Administration (NASA), prove that spur gear performance is more than 98 %.

2. Propeller shaft performance

The tricycle propeller shaft has two universal joints. The first one is near the gearbox, and the second is located near the differential. It is known that universal joints allow angle variation in mechanical power transmission. This is important for this study because the original tires that may not be suitable for fieldwork can be changed to 2 WT tires. The tricycle tire size is in the same range as 2WTs of 12Hp. An and Wang, (2017) analyzed the principles and defaults of the double cross universal joint. Vibration, noise, and deformation are the main defaults caused by wear. A problem named “galling” appears when the operating angle is too large. It looks visually like materials are gouged out (Solanke & Bharule, 2014). The performance of a propeller shaft with a universal joint is estimated to be 99.9 % (https://www.techniques-ingenieur.fr) for light angle. This performance decreases very slightly while the angle increases.

3. Differential gearbox

The differential gearbox transmits the power to the wheels. The gear system varies from one brand to another. The performance is difficult to estimate. If the gears have helical teeth, the efficiency is a little lower than spur gears. The number of gears in contact also influences the performance. Some literature not certified estimates a bevel gear performance at 96 %.

Note: Total performance in the power transmission is estimated as η =0.98*0.99*0.96 = 0.93 %.

Tire-soil friction analysis

Renius (2020c) argued that tire-soil friction is the uppermost share of all energy losses between the thermal engine and the tilling implement. It means that particular attention should be made when estimating this power loss. It depends on the soil type, soil moisture, tire load, tire type, tire size, and tire inflation pressure (Febo *et al.,* 2000; Hao Li, 2013). Wright (2012) highlighted that the soil moisture content influences significantly the off-road dynamics of an agricultural machine, even at low speed. Battiato and Diserens (2013) compared the effect of increasing the wheel load and decreasing the tire inflation pressure on the traction performance of a tractor. They found that decreasing the tire inflation pressure produced more improvement in the coefficient of traction, tractive efficiency, power delivery efficiency, and specific fuel consumption than increasing the wheel load.

It is also known that many tractors have rear-wheel bigger than the front ones because studies showed that unequal wheel sizes give more tractive performance than equal wheel size tractors about more than 14 % (Dwyer & Pearson, 1976)a four-wheel drive tractor with front wheels smaller than rear and a four-wheel drive tractor with equal-sized wheels, each having the same 63 p.t.o. kW (84 hp. The tire inflation pressure has a positive and negative impact on the tire-soil system and the drawbar pull depending on the soil type (Yong *et al.,* 1980, Elwaleed *et al.,* 2006)166, 193 and 221 kPa.

From the different types of tires used for tractors (narrow tire, standard tire, low section tire), the standard tire is the most used (Renius, 2020b)**.** There are two basic design principles of tractor tires: the radial-ply tire and the diagonal or bias-ply tire. According to Renius (2020b), the radial design is used far more than the bias ply one. These tire parameters are used to determine the needed coefficient and value to estimate the tire-soil loss.

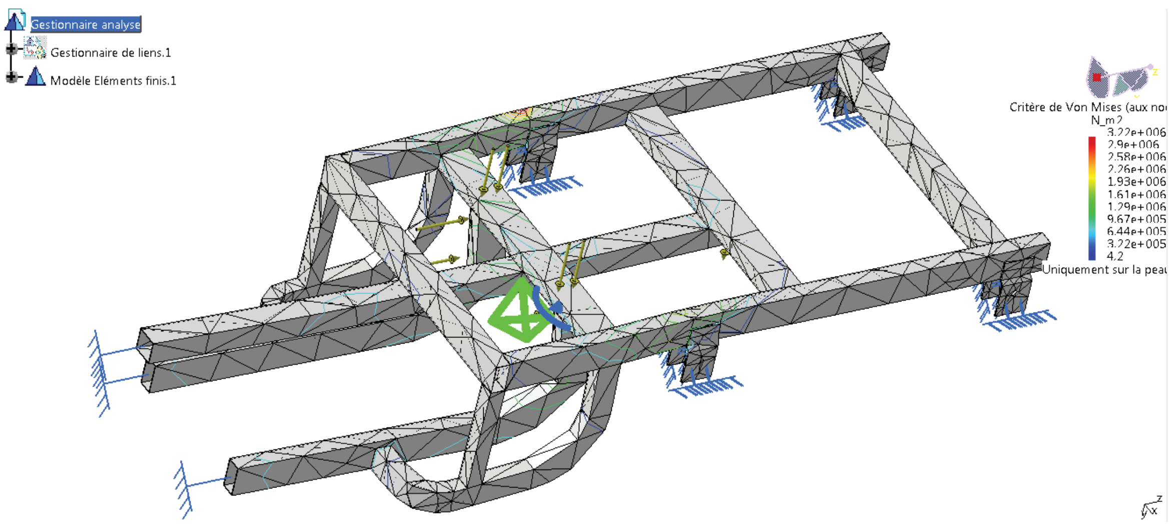
In the same perspective, Elwaleed et al. (2006) **166, 193 and 221 kPa** highlighted that 20% to 55 % of the engine power is lost in the tire-soil interaction.

Note: Regarding all power losses, the total available power for the implement varies from 41.85% to 74.4 % of the engine power.

Chassis analysis

The chassis is made of rectangular tubes of 80×40×2 mm. An analysis of the existing chassis is done. It was redrawn in 3D software (CatiaV5) and applied the estimated forces from Table 1 (horizontal force 4000 N, vertical force 2000 N, and 4000 N of ballasting weight) generated by the implement (Figure 2). In Table 1, for moldboard plow and medium soil, we have a draft per meter of width of 10.30 KN. A single furrow moldboard plow has a width of 20 cm. For this width the draft force should be 10.30/5 = 2.05 KN. Then we multiplied this value with a coefficient of security of 2. This gave 4000 N of horizontal draft force used to simulate the chassis strength. To simulate the chassis strength in a worst-case scenario, we add 2000 N of vertical force and 4000 N of ballasting weight if the wheels slip.

It shows the chassis deformation and highlights the weak part. To validate the chassis strength, a comparison is made between the obtained strength and displacement to the tolerated strength and displacement of the chassis matter. As a result, the chassis can support the forces upon tilling tools because the stress value is 3.22 10^6 MPa. This value is smaller than the steel elasticity limit of 2.5 10^8 MPa.



The position of the gravity center is important in machine design. The center of gravity of an engine tricycle like the motor king, is around 2/5 of the distance between the rear wheels and the front wheel (Austin *et al.,* 2015). It is important to take into consideration the gravity center to avoid creating forces or moments that compromise the driven style. Hence a recommendation is made to consider the attachment point on the chassis near the gravity center.

Depreciation analysis

This section estimates how the added tilling function on the tricycle impacts its retirement. The depreciation analysis helps to understand the new lifecycle.

Many machine depreciation methods exist and examples are the straight-line method, annuity method, diminishing-balance method, and retirement method (Preinreich, 1938). Many of them are based on capital value and usage time. Others are based on units produced, hourly usage, repair costs, and others. The depreciation of a machine depends on the operating conditions (operator skills, maintenance, usage rate, environmental conditions). Perry and Nixon, (1991) emphasized that the usage and repair costs are the most important factors to consider while estimating a tractor depreciation. Daninger and Gunderson, (2017) support this argument.

Dumler et al., (2003) compared the "old" ASAE method, Box-Cox model, NAEDA Official Guide, and the Kansas Farm Management Associations KMAR method. They concluded by classifying the Box-Cox method first and the ASAE method second. Wu and Perry, (2004) also compared so many depreciation methods and confirm that the Box-Cox method is the best.

Wilson, (2010) found that there is no relationship between depreciation and horsepower. A machine depreciates the same way as a small and medium machine as a powerful machine. Pagare, (2019)it requires higher operating and maintenance cost, as a result of this, there is a need to replace them. Decision making about the replacement of used farm equipment with a new similar one is one of the important aspects of farm machinery management. Based on that criterion, the objective of the investigation was decided to estimate the economic operational life of tractors in the central region of Madhya Pradesh, India and to evaluate the effect of different parameters on economic life, which would add value to the profitable management decision. The tractor data collected were from government agricultural centres in the different regions of M.P. and categorized them into different groups based on their horsepower rating. Considering the preventive replacement policy the total annual average costs of tractors were estimated taking account into the repair cost and depreciation cost. The time period (in year confirmed this argument.

Chenarbon *et al.* (2011) determine the suitable replacement age of a Massey-Fergusen 285 based on the "New" ASAE standards and the repair and maintenance cost. They concluded that the suitable replacement age is nine years.

The repair and maintenance cost method is based on collected data from the usage of the tractor. In this study, a new tricycle was used. Hence the ASAE standard 2000a (Equation 1) is used to calculate the tricycle depreciation.

$$V_n = P\left(1 - \frac{x}{l}\right)^n \qquad (1)$$

Where: Vn - remaining value; n - machine age in the year of calculation (assuming after 1 year. n=1); P - purchasing price (US$ 1600); x - depreciation rate 1< x <2 (x=1.5 average value) ;

L - total machine life (limited to 5 years instead of 9 years because of the tilling function)

$$V_n = 1600\left(1 - \frac{1.5}{5}\right)^1 = US\$\,1120 \qquad (2)$$

A depreciation of US$ 480 /year is very acceptable for everyday use machine.

Field Test

The basic scenario is to use the engine tricycle as bulls (Plate 1): the standard single furrow moldboard plow used by bulls is tracked by the original tricycle without any modification. This option needs two operators: the driver and the moldboard operator. Plate 2 shows the soil aspect after tillage operations with the tricycle.

Type of soil	Sandy loam
Plowing Dept	15 cm
Effective Field Capacity	0.15 ha / hr.
Fuel consumption	0.9 liter/ hr.

Plate 1: Motor king tricycle pulling a single furrow moldboard plow

Plate 2: The soil aspect

It is recommended to collaborate with a tillage specialist to validate the success of the tillage. Indeed, the operator for this experimentation is a professional who always uses bulls to plow. In addition, he is a motor king driver for goods transportation. The conclusion was unequivocal. The tricycle plowing speed and fuel consumption were normal. The sandy loam soil used for this test was plowed with a tractor for the first time, one year before but no crop was grown; then the following year the tricycle was used to till when the grasses came out (Plate 2). The soil aspect was good, and the Effective Field Capacity (EFC) was greater than the land tilled with animals .

To conclude this results section, an experiment of the tricycle pulling a single furrow moldboard plow was done. The result was unequivocally positive. It indicated a working depth of 15 cm, an EFC of 0.15 ha/hr., and a fuel consumption of 0.9 L/hr.

If the tricycle is used for fieldwork, it should be compared to the nearest field work technology. Animal Traction (AT) was compared to the tricycle-mounted draft implement because similar tools are used for both. Kabri (2023) found an EFC of 0.41 ha/day for AT and for a single moldboard plough in sandy loam soil. Assuming that he worked six hours the EFC was 0.068 ha/h. He also found a Field Efficiency of 72.5 %, which is between 66.7 – 83.8 % accepted among scientists. A tricycle-mounted single moldboard plough, in sandy loam soil, did better than the animal traction of Kabri's experiment. For the same implement and soil type, the tricycle got an EFC of 0.15 ha/h. while animal traction got 0.068 ha/h., therefore tricycle is 2.20 times better than AT.

Comparing the operational cost between animal traction and tricycle used for farm work for the same tilling implement and soil type, it is observed that both technologies use two operators (same labor cost). Then the tricycle needs GHC79.2 (GHC12/liter) as petrol cost to till one hectare while the feeding cost is free for animal traction. But a tricycle can be used 6.6 hours (1 day) to till a hectare while AT needs 14.7 hours to till the same hectare (3 days required because for AT, it is maximum 6 working hours per day). So, AT needs 2 operators for additional 2 days to plow a hectare. If each operator is paid GHC50 per day, then the additional labor cost is GHC50*2*2 = GHC200 which is much higher than the petrol cost. The tricycle is more profitable than AT.

To reproduce this experiment, one needs to get the motor king tricycle, a single furrow moldboard plow, and three meters of chain. The chain must be attached to the front bar behind the driver.

Discussion

This research is carried out on the technical feasibility of the use of the motor king tricycle for tillage. As a result, we found that the engine of the tricycle is powerful enough for fieldwork. The transmission elements have good performance and can technically support an additional tilling function. However, Renius (2020) argued that the most power loss is in the tire-soil interaction. A hypothesis was made to ballast the tricycle since the tire-soil friction depends on the tires' load. Ballasting the tricycle by adding weight to its container may be important to control wheel slip, increase tire-soil cohesion and compensate for the vertical force upon implements. But carrying that weight consumes a share of power. To resolve the wheel slip problem, one can also change the original wheels (on-road tires) to off-roads. The sizes are almost the same, a small change in wheel size has no consequence on the power transmission system because of the available universal joint. A universal joint tolerates angle variation in mechanical power transmission.

After the 3D simulation, a conclusion was made that the chassis of the tricycle is strong enough to support the horizontal and vertical forces needed by the implement. Another finding was the acceptable depreciation rate of the tricycle. The tilling function will reduce somehow the total life cycle of the machine. Shorting the tricycle usage to five years instead of nine (example of a Massey-Fergusen 285) is still acceptable for users. A recommendation is made for personal usage and small-size farm (farm size < 2ha) cultivation. As a matter of fact, it will only be used for tillage for a few days per year.

Regarding which tillage device can be used with a tricycle, a comparison is made between the real available power for the implement (41 to 74% of the tricycle engine power) and the power needed by a tillage implement (Table 1). As a result, disc harrow, tines harrow, duck foot cultivator, or any device in the same range of energy can be used in a limited width. Total width of not more than 40 cm is recommended. One can also create a medium size of existing tools or indigenous tools that tie in the tricycle power according to the cropping system.

Table 1: Recommended draft for different implement and soil condition

Implement / Equipment	Draft per meter of width (kN)	Typical speed (km/h)	Field efficiency, (%)
Moldboard plough (200 mm depth)			
Heavy clay soil	15.70	4.5	80
Heavy soil	13.73	5	80
Medium soil	10.30	5	80
Light soil	6.87	6	80
One-way disc plough			
Heavy soil	5.90	6	80
Medium soil	4.41	6	80
Light soil	2.94	6	80
Offset or heavy tandem disc harrow			
Heavy soil	5.90	6	80
Medium soil	4.91	6	80
Light soil	3.73	6	80
Duck foot cultivator			
Heavy soil	4.41	6	80
Medium soil	2.94	6	80
Light soil	1.47	6	80
Seed drill			
Heavy soil	1.47	5	70
Medium soil	0.88	5	70
Light soil	0.49	5	70
Planter			
Heavy soil	1.47	5	70
Medium soil	1.72	5	70
Light soil	1.77	5	70

(Source: Jain SC and Philip G (2003), Mehta et al., (2011)).

On the question of which type of soil can be tilled by the tricycle-mounted implement, we recommended medium soil and light soil according to Table 1.

As regards how to apply the horizontal and vertical forces with the tricycle in safe conditions; how to lift the implement when needed and how to control the working depth, Plate 1 shows a single furrow moldboard plow, used by bulls, tracked by the original tricycle without any modification. This option needs two operators. More studies are recommended.

Conclusion and Recommendations

After many failed policies, the debate on African agriculture mechanization has never grown as big as in recent years (Daum et al., 2022). Time passes, and the progress to achieve the development goals for 2025, 2030, and 2063 is behind the previsions. Africa has 33 million smallholdings of less than 2 hectares which represent 80 % of all farmsteads in the continent (NEPAD, 2013). Existing agricultural machines are not suitable for African farmers, and they are not using them as expected. This is why this study applied the reverse engineering method to an existing machine in rural areas. The considered machine is an engine tricycle (18Hp) called mMotor kKing used as a means of transport in Northern Ghana. As a result, the available power is enough for tillage, and the power transmission system can support fieldwork. The tire-soil interaction may be the main challenge and can be optimized by ballasting the tricycle or changing the original wheels to off-roads'. The chassis of the tricycle is strong enough for fieldwork. Light implements are recommended in medium and light soil conditions. Maximum working width of 40 cm is recommended. A recommendation is made to consider a distance of one meter between the tilling instrument and the tricycle. A quick analysis of the depreciation rate gives a positive appreciation.

Authors Contribution

Conceptualization, Hamadou H. Abdoul-Aziz; methodology, Hamadou H. Abdoul-Aziz; software, Hamadou H. Abdoul-Aziz; validation, Felix Kofi Abagale, Shaibu Abdul-Ganiyu, and Hamadou H. Abdoul-Aziz; formal analysis, Felix Kofi Abagale; investigation, Felix Kofi Abagale, Shaibu Abdul-Ganiyu, and Hamadou H. Abdoul-Aziz; resources, Shaibu Abdul-Ganiyu; data curation, Hamadou H. Abdoul-Aziz; writing—original draft preparation, Hamadou H. Abdoul-Aziz.; writing—review and editing, Felix Kofi Abagale, Shaibu Abdul-Ganiyu, and Hamadou H. Abdoul-Aziz; visualization, Felix Kofi Abagale, Shaibu Abdul-Ganiyu, and Hamadou H. Abdoul-Aziz.; supervision, Felix Kofi Abagale, Shaibu Abdul-Ganiyu; project administration, Felix Kofi Abagale; funding acquisition, Felix Kofi Abagale. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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