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# Development of a Ride-On 2-Bottom Mouldboard Plough for Primary Tillage

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## ABSTRACT
**Background and Objective:** Most single-sided mouldboard ploughs have challenges of needless empty turns and reduced ploughing efficiency. This requires a more efficient plough with reduced empty turns. The study aimed to develop a ride-on 2-bottom MB plough with seating and hydraulic lift jack attachments. **Materials and Methods:** The equipment consists of two major parts: The prime mover (power-tiller) and the accompanying implements, which include, the implement carrier, operator seat, the hydraulic jack pump and two mould board plough units. The machine was developed and fabricated based on standard engineering principles for part-sizing and materials selection. The machine was tested and the performance was evaluated using descriptive statistics. **Results:** The developed machine is dynamically stable and ergonomically suitable for operator comfort and manoeuvrability during field operation. The measured average cutting depth, width and speed parameters are 14.84, 24.56 cm and 3.48 km $h^{-1}$, respectively. The evaluated average field efficiency and theoretical field capacity are 88.23% and 0.096 ha $hr^{-1}$, respectively. The equipment is appropriate for small-scale farmers. **Conclusion:** A ride-on plough was successfully designed, constructed and tested for functionality and field performance. The cost implications showed that the machine is economically affordable for low-income farmers who could purchase the power tiller through joint ownership ventures.

## KEYWORDS
Power tiller, ride-on plough, 2-bottom, width of cut, field capacity, performance efficiency



## INTRODUCTION
Tillage is considered one of the most energy-consuming farm operations with an estimated 16-25% of the total energy available for agricultural production[1]. Tillage is labour-consuming and a difficult operation, compared to all subsequent agricultural operations[2]. The mouldboard plough is the most common tillage implement in the world, ranging from the simplest type for animal traction, up to the highly advanced, large ploughs for tractors. This type of plough is not completely proper for every field condition, desired tillage quality and low fuel requirements[3]. Mechanization of agricultural operations by improved tools/implement design is one of the ways to increase crop productivity. The soil resistance is a basic parameter for the evaluation of tillage implements and significantly influences constructional characteristic features of the bodies, connected with the dimensions and shape of a working surface of the body, particularly: The rake angle and cutting angle of the share, setting angle of the mouldboard etc.[4].

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The power tiller also known as a small tractor, garden tractor, single axle tractor, hand tractor, walking tractor, walk-behind tractor or two-wheel tractor etc. is a multipurpose hand tractor designed primarily for rotary tilling and other operations on small farms[5,6].

Power tillers are mainly used with rotary tines mould board plough and cultivator attachments to prepare seedbeds to prepare land in dry and wet conditions[7-10]. Apart from preparing a seed bed, it can also be used for pumping water, digging potatoes, sowing seeds, spraying pesticides, puddling, forming ridges, threshing, harvesting, transporting goods, post-harvest operations[6,11] etc. Hence, the use of power tillers is increased daily. Furthermore, it has been used for electricity generation, water pumping and transportation purposes[12].

Power tillers come with different attachments (implements) to accomplish many kinds of farm work like tillage, planting, harvesting and transportation. When a tillage implement is attached to a two-wheel tractor, it is called a power-tiller. Non-availability of matching equipment for different farm operations limits its versatility[6]. The initial introduction of power tillers was without a complete range of matching equipment[13].

In recent years, there has been an influx of two-wheel tractors into Nigeria and the demand has particularly been increasing in a place like Niger State where its use for the cultivation of low-land rice is increasingly becoming popular[14]. Due to the economic level of the majority of farmers and the quest for the introduction of intermediate technology in developing countries like Nigeria, appropriate intermediate technology was employed to develop a two-bottom mouldboard plough drawn by a power-tiller. The utilization of the power tiller among farmers has increased recently because of its ease of operation, reduced unit cost of operation and possibility of being used as adaptable multi-purpose machine[15]. Power tiller tractors outperform four-wheel tractors in terms of work performance and precision on mountains[16].

Tillage is a time and labour-consuming operation representing about 20 percent of energy consumption compared to other subsequent field agricultural operations. Furthermore, Rasool and Raheman *et al.*[17] have reported a major reduction in energy and time consumption (up to 10%), when single plough implements were replaced by double-bottom plough bodies. In line with the above discussion, this article focuses on the comprehensive reviews of the versatile use of power tillers over the years. Emphasis has been given to studies related to the development and application of power tiller-operated implements for farm-related operations, post-disaster management and agro-forest management. Furthermore, ergonomic evaluation, status of the power tiller in hilly areas and matching equipment have been discussed. The main objective of this study is to develop a ride-on two-bottom MB plough with seating and hydraulic lift jack attachments.

## MATERIALS AND METHODS

**Study area and duration:** The experiment was conducted at the ABET workshop, Federal College of Agriculture in Ishiagu, Ebonyi State, Nigeria and lasted for 9 months from April 2023 to December 2022.

**Material selection:** The proper selection of materials for engineering purposes is one of the most difficult problems for designers. The best material is one which serves the desired objective at the minimum cost. To ensure appropriate material selection, the following factors were considered: The major engineering considerations for the selection of materials are the strength properties and the power requirements for lifting and lowering the implement for soil engagement.

**Engineering properties:** These include good wear resistance and corrosion resistance, better shock absorption, good strength and availability, availability of the materials, suitability of the materials for the working conditions in service and affordable cost of materials. Other important properties, which determine the utilization of the material, are its physical, chemical and mechanical properties. The materials to be used for design are selected after a careful study of the desired physical, mechanical chemical and even aesthetic characteristics of a number of proposed materials. For this project, due to economic considerations and availability of raw materials, Low carbon steel or mild steel material is selected because it has 0.15 to 0.45% carbon which enables it to be ductile. The ductility of a material is commonly measured by means of percentage elongation and percentage reduction in area in a tensile test.

Low carbon (mild) steel was selected due to economic considerations, availability and ease of machinability. It has 0.15 to 0.45% carbon which enables it to be ductile. Mild steel has the following properties, ultimate strength is 560 MPa, $\sigma_{allowable}$ = 560 MPa/4, $\sigma_{all}$ = 160 MPa, yield strength is 320 MPa, ultimate shear strength is 180 MPa and length of the frame should be less than or equal to the length of plough holder because if the length of the frame decreases the obstacle of the machine decrease which increase capacity of the machine. So, its length should be less than 500 mm because plough holder is 500 mm.

**Factors of safety:** The selection of a correct safety factor for the design of machine components is dependent on the choice of material, mode of manufacture, kind of stress, general service conditions and shape of the parts. The following considerations are important: Reliability of material to changes during service, accuracy of machine parts, extent of applied load, failure mode, localized stress during fabrication and human safety when failure occurs. During the design and manufacturing processes, each of these aspects was thoroughly addressed and analyzed.

## Methodology

**Design considerations:** Several studies have identified plough-bottom surface as the major technical requirement for soil layer movement in the designing of ploughs[18,19]. Movement over the mouldboard. Other researchers have looked into plough surface optimization using different criteria[20,21]. However, they recommend establishing an appropriate plough surface so as to achieve the desired soil layer movement over the mouldboard when engaged.

Other design characteristics include draft and power needs for measuring and assessing tillage implement performance, which is regarded vital when attempting to correctly match tillage implement to a tractor[22,23]. Other studies to determine the draft and energy requirements of ploughs under various conditions created mathematical models to predict plough drafts[24-26]. The amount of energy required by the drawbar is further influenced by tillage depth, forward speed, soil condition and tool geometry[27]. The effects of draft speed on soil and implement type vary. It has been frequently observed that draft forces on implements rise dramatically with speed, with the relationship varying from linear to quadratic[28]. The draft of a mouldboard plough grew by the square of the speed, whereas the draft of many other tillage instruments increased linearly with speed[29]. The type of the plough-bottom surface equally affects the crumbling and turnover of the undercut soil layers. The parameters of the plough-bottom surface and their changes cause the quality and energy intensity of tillage due to the irrational changes in the screw leads which fail to provide a smooth transition from the straight plane of the share to the curved surface of the mouldboard[30].

## Machine design equations and calculations

**Engine selection:** The engine power was computed utilizing the relationship between the drawbar power ($P_d$) and the engine, as shown in Eq. 1 and 2[31]:

$$P_d = P.v \quad (1)$$

Where, $P_d$ is drawbar power (W):

$$P_e = \frac{P_d}{60\%} \quad (2)$$

Where, $P_e$ is engine power (W) and engine power ($P_e$) is 8, 726.66 W.

With the calculated engine power (8.73 kW), a standard 9 kW (12 hp) Sanya motor SY 150-9 engine manufactured in Korea was considered adequate for the machine and used for testing.

**Frame design:** The evluated width (20 mm) of the square-shape iron was found suitable and is available in the market at a lower cost A standard size of 30×60 mm and the condition b >20 mm was selected for use.

**Machine description and fabrication:** To avoid problems associated with single-sided one-bottom mouldboard plough (SMP), a 2-bottom mouldboard plough was designed to increase the width of the cut and reduce timeliness of operation as well as reduce fuel consumption in operation. The machine has two key components: the prime mover (power-tiller) and the developed implement, comprising an implement carrier, operator seat, hydraulic jack pump and two mould board plough units.

**Prime mover:** The prime mover is a single-axle (two-wheel) water-cooled and hand-cranking type diesel engine. The driving wheels are of two types, the pneumatic type for normal traction and the steel wheel for muddy or swampy lands.

**Single-point hitch mechanism:** The hitch mechanism comprises a 50 mm diameter beam shaft on which the reduction gear and the hopper was mounted using two 22 mm diameter bolt and nut. The beam ends in two hitch pins with a locking pin slot at the periphery. The hitch pin attached the machine to the tractor's lower limbs, while the top link was attached to a bracket on the upper hopper end. The hitch mechanism was locally fabricated in the workshop.

**Frame:** The frame is subjected to the dynamic bending weight of the operator and the resisting weight from the plough because it holds the plough holder frame and using the bending of the plough stress formula we can determine the required dimension. The frame was made by 50×50×50 mm hollow square M.S. square section with sufficient strength to withstand various forces acting on it.

**Hydraulic pump:** The hydraulic pump is a 5 ton jack that converts mechanical power into hydraulic energy by generating flow with enough power to overcome pressure induced by the load. Secondly, its mechanical action delivers this liquid to the pump outlet and forces it into the hydraulic system.

**Implement bracket:** The implement bracket was made from a 5 mm thick and 228.6 mm long H-channel MS welded to a 100 mm strip of metal to provide an alternate bracket for each plough unit in each row to keep the distance offset.

**MB plough coupling bracket:** The implement bracket was made from a 5 mm thick and 228.6 cm long H-channel MS welded to a 10 cm strip of metal to provide an alternate bracket for each plough unit in each row to keep the distance offset.

**Mouldboard assembly:** The implement is a three-in-one unit comprising a carrier bar (frame), the seat attachment, hydraulic jack assembly and the 2-MB ploughs. The unit is attached to the single hitch-point of the prime mover. The implement carrier is a tubular square pipe of 50×50 mm dimensions. It has an attached seat attachment where the operator can comfortably sit. The hydraulic pump is directly installed under the operator seat and operated by an extended crank lever arm conveniently operated from the operator seat to lower and lift the plough implement attached. The mouldboard is two units of single-bottom ploughs connected and welded into a single unit of 2-bottom MB with individual adjusters for penetration and levelling. The implement was mounted on two wheels that provided the desired balance, operator comfort and stability during operation. The roller wheel was attached to the gear housing with a bar spring bracket. The machine is dynamically stable and ergonomically designed to provide comfort for the operator and convenience of operation. The part listing, for the power tiller, implement and orthographic drawings are shown in Fig. 1-3.

**Machine field performance experimentation:** The field experiment was conducted in a loamy-clayey soil behind the departmental complex with relevant observations recorded regarding field conditions before and during the ploughing operation. The selected plot was marked into 2000×1000 mm and ploughed using the fabricated machine. The following soil characteristics were obtained.

**Soil characteristics:** Soil bulk density is determined using a core cutter apparatus and evaluated by Eq. 3:

$$\rho\ (\text{g cm}^{-3}) = \frac{M}{V} \tag{3}$$

Where, ρ is soil bulk density (g $cm^{-3}$), M is mass of the soil (kg) and V is volume of the soil ($cm^3$).

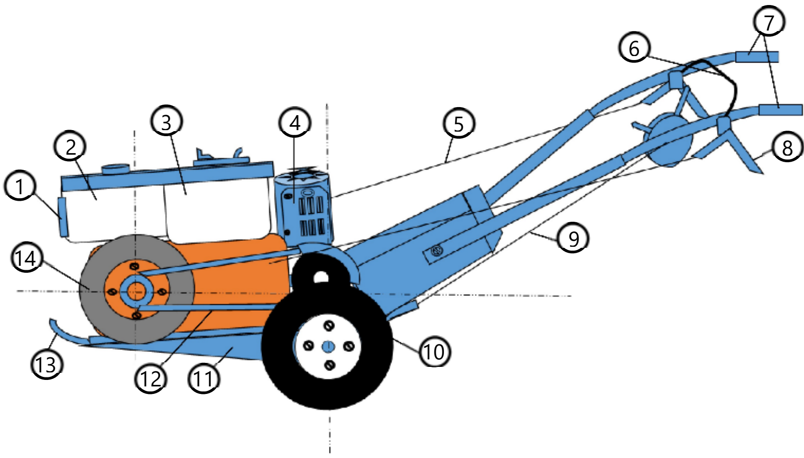
The soil moisture content was determined by oven drying method and the moisture content was determined using Eq. 4[32]:

$$M_c\ (\%) = \frac{m_w - m_d}{m_w} \times 100 \tag{4}$$

Where, Mc is moisture content (%), $m_w$ is mass of moist soil (g) and $m_d$ is mass of dry soil (g).

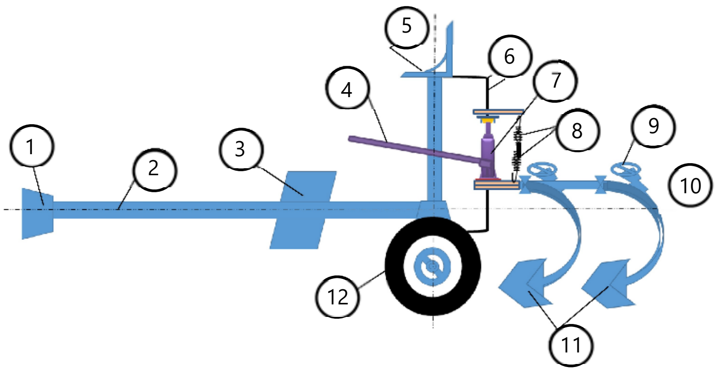
**Implement performance:** Data collected were used to evaluate the performance of the implement: plough characteristics (working depth and width), operation duration (h), volume of fuel consumed (l) and dimensions of the ploughed plot (length and width).

**Effective working depth and width:** In the field, the depth and width of the implement cut were measured by measuring the depth and width of the soil layer tilled by the mouldboard in a row with a




| S/No. | Part list | QTY |
|---|---|---|
| 1. | Head light | 1 |
| 2. | Fuel tank | 1 |
| 3. | Water tank | 1 |
| 4. | Exhaust | 1 |
| 5. | Throttle line | 1 |
| 6. | Stand control | 1 |
| 7. | Handle | 2 |
| 8. | Hand brake | 2 |
| 9. | Stand connector line | 1 |
| 10. | Land wheel | 2 |
| 11. | Chassis | 1 |
| 12. | V-belt | 2 |
| 13. | Front support stand | 1 |
| 14. | Flywheel | 1 |

Fig. 1: Part listing drawing of power tiller



| S/No. | Part list | QTY |
|---|---|---|
| 1. | Implement hitch point | 1 |
| 2. | Implement carrier | 1 |
| 3. | Foot rest | 2 |
| 4. | Jack handle | 1 |
| 5. | Operator seat | 1 |
| 6. | Lift control bars | 2 |
| 7. | Hydraulic jack | 1 |
| 8. | Extension springs | 2 |
| 9. | Depth adjuster | 2 |
| 10. | MB plough shank | 2 |
| 11. | MB plough share | 2 |
| 12. | Transport roller | 2 |

Fig. 2: Part listing drawing of machine

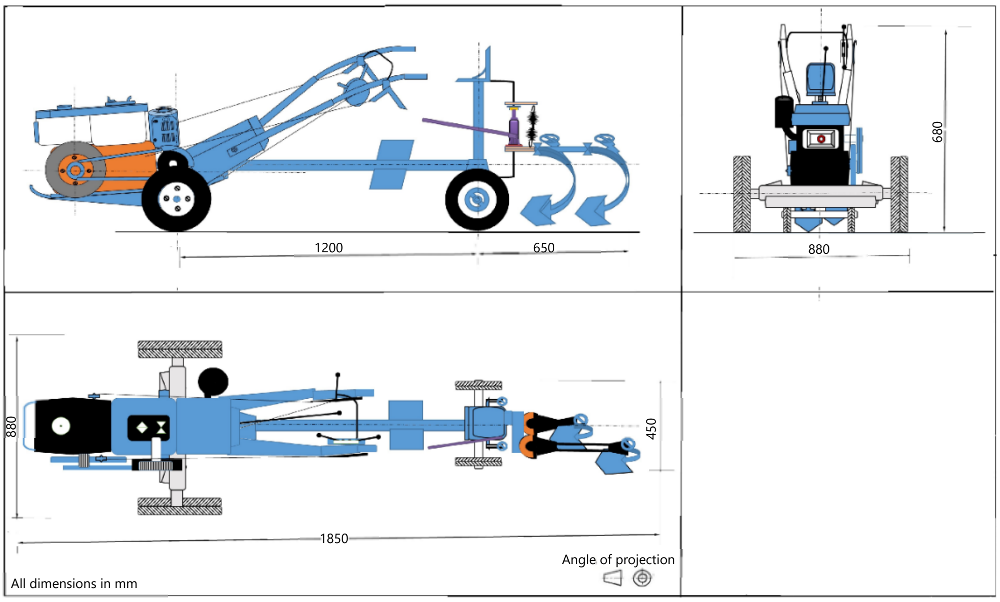



Fig. 3: Orthographic drawing of machine

retractable measuring tape. The mean depth and width of eight ploughing observations were measured in centimeters.

**Operation speed:** The operation speed (ν) is determined by Eq. 5[33]:

$$v = 3.6 \times \frac{20}{t} \quad (5)$$

Where, ν is operation speed (km $h^{-1}$) and t is time taken to cover 20 m (sec).

**Theoretical field capacity:** Theoretical field capacity measured in ha $hr^{-1}$ is determined by Eq. 6[33]:

$$G = E \times \frac{3600}{T_a} \quad (6)$$

Where, G is theoretical field capacity (ha $hr^{-1}$), E is area of field (ha) and $T_\alpha$ is actual time taken in doing the main tillage work (sec).

**Effective field capacity:** Effective field capacity measured in ha $hr^{-1}$ was determined by Eq. 7[33]:

$$X_5 = E \times \frac{3600}{T_t} \quad (7)$$

Where, $X_5$ is effective field capacity (ha $hr^{-1}$) and $T_t$ is total time taken in completing the whole tillage operation (sec):

$$T_t = T_a + T_o \quad (8)$$

Where, $T_o$ is tiller manoeuvring time (without ploughing) to reposition the machine at the end of the working line to change direction.

**Field efficiency:** Field efficiency is the ratio of effective field capacity to theoretical field capacity, expressed in percent. It is expressed mathematically using Eq. 9[33,34]:

$$H\ (\%) = \frac{X_5}{G} \times 100 \quad (9)$$

Where, H is field efficiency (%):

$$\frac{G}{X_5} = \frac{1}{H} = 1 + \frac{T_o}{T_a} \quad (10)$$

The field efficiency shows the level of time wasted during the work. Equation (10) shows that when $T_0$ is low, the field efficiency is 100%.

**Statistical analysis:** Statistical tools of descriptive statistics were used for result analysis.

## RESULTS

**Developed machine parameters:** The developed ride-on 2-MB machine coupled to the power tiller is dynamically stable and ergonomically suitable for operator comfort and manoeuvrability in field operation, To engage the machine in operation, the clutch lever is held to engage the gear. Note that the gearbox of the machine is directly incorporated into the engine to vary the speed of operation. Upon engaging the gear, the clutch lever is released gradually while the acceleration lever is pressed against the steering handle to set the machine in motion. The operator seated on the machine controls the movement of the trailed behind 2-bottom ploughs to cut through the land and invert the cut furrow slice as it drags through the soil.

The technical specifications of the prime mover and fabricated machine are shown in Table 1 and 2, respectively.

Table 1: Technical specification of the power tiller

| Parameters | Observation/declaration |
|---|---|
| Engine | Four stroke, water cooled, vertical, single cylinder, compression |
| Type | Ignition engine |
| Model | DLH 1105 |
| Maximum power (kW) | 12.1@2250 rpm |
| Maximum drawbar pull corresponding to 15% wheel slip (kN) | 3.1@2304 rpm at L-2 gear |
| Maximum drawbar power (kW) | 3.7@2311 rpm at L-3 gear |
| Starting method | Manual, hand cranking |
| Steering system | Steering clutch levers provided |
| Overall dimensions (mm) | 2730 (L)×940 (W)×1360 (H) |
| Minimum ground clearance (mm) | 240 |

Table 2. Technical specification of developed implement

| Specification | Value |
|---|---|
| Working width | 550 mm |
| Number of blades | 2 |
| Depth of ploughing | 9 cm |
| Length of share (L mm) | 217 |
| Rake angle of share | 40 |
| Cutting angle of share (γ) | 39 |
| Angle of mouldboard wing setting (Qs) | 48 |
| Length of mouldboard wing (Lo mm) | 310 |
| Height of body (H mm) | 238 |
| Wheels (2) | 70 |
| Overall dimensions (mm) | 2920 (L)×970 (W)×1300 (H) |

## DISCUSSION

The machine performance tests were evaluated based on its functionality (ability to perform designed functions), components reliability and field performance. The soil moisture content determined on the field is 4.26±0.22%, bulk density 1.53±0.05 g $cm^{-3}$, vertical soil penetration resistance was 10.88±3.55 kg $cm^{-2}$ and horizontal soil penetration resistance determined was 2.26±0.76 kg $cm^{-2}$.

The machine performance evaluation was in terms of operational speed, depth of cut, width of cut (24.56±3.06), effective field capacity (0.075±0.01 ha $hr^{-1}$), theoretical field capacity (0.069±0.02 ha $hr^{-1}$), field efficiency (34.12±0.04%) and fuel consumption (1.13±0.17 l $hr^{-1}$). These results were in line with the results obtained by Ademiluyi *et al.*[5] and Nwakaire *et al.*[16]. The performances of the machine were compared to manual work. It was observed that operational speed, depth of cut, width of cut, effective field capacity and theoretical field capacity of the machine were higher compared to manual work. It was further observed that the field efficiency of the manual work was higher than that of the machines. The performances of the designed machine are linked to the soil characteristics. The ploughing soil with 4.26% moisture has a bulk density of 1.53 g $cm^{-3}$. The low value of the moisture content obtained was due to the period of the test: A peak of the dry season (month of December).

These soil characteristic values are closer to the parameters found in the other work conducted by Kantchede *et al.*[35]. According to Dayou *et al.*[34], the physical properties of soils are important for the proper monitoring of soil function. Their result also showed the range of bulk densities from 1.27 to 1.83 g $cm^{-3}$ and moisture content, from 4.7 to 27.36%.

The maximum ploughing depth of cut of the power tiller was 14.84 cm is higher than 7-8 cm obtained by Pradhan *et al.*[36]. However, the report of Kantchede *et al.*[35], hinted a depth of 15 cm as the best depth for good agricultural yield for maize production.

The effective field capacity of the machine (0.096±0.02 ha $hr^{-1}$), obtained was higher than 0.04 ha $hr^{-1}$ than (0.0075 ha $hr^{-1}$) reported by Bochtis *et al.*[30] and Kantchede *et al.*[35] at a moisture content of 6.3 and 4.26%, respectively. The theoretical field capacity (0.069±0.02 ha $hr^{-1}$) was lower than 0.088 ha $hr^{-1}$ as reported by Bochtis *et al.*[30]. This could be attributed to the soil and the operator's skill. The field efficiency (34.12±0.04 %) was lower than the 47% obtained by Bochtis *et al.*[30]. The fuel consumption (1.13±0.17 l $hr^{-1}$) was lower than the 1.3 l $hr^{-1}$ reported by Bochtis *et al.*[30]. This could be due to the ploughed area coverage and the operator's proficiency.

The total cost of fabricating the machine is approximately NGN 76,500.00. This value is less expensive compared to imported ploughs whose costs (NGN 800,000.00-1,000,000.00) are astronomically high considering the current exchange rate and high cost of import duties. This indicates that the machine is relatively cheap and affordable by small, medium holder farmers.

## CONCLUSION

Based on the outlined objectives of this work, a ride-on 2-bottom mouldboard plough was successfully designed, constructed and tested for functionality and field performance. The depth and width of the cut were 14.84 and 24.56 cm, respectively. The field efficiency and theoretical field capacity were 88.23% and 0.096 ha $hr^{-1}$, respectively. The fuel consumption was 1.99 l $hr^{-1}$. The machine requires one operator comfortably seated to effectively operate the machine. The lightweight of the fabricated plough is a favourable factor for working in wet and dry land conditions and creates the least disturbance to soil structure compared with standard tractors. The following recommendations were made to further improve the performance of the machine. More field tests are required for the versatility and reliability of the machine. Further modifications are ongoing to effectively engage the rear plough body and Ergonomic consideration for the design of depth control mechanism.

## SIGNIFICANCE STATEMENT

Power tiller operation involves a considerable degree of stress, which leads to fatigue during the process. This presented a significant challenge to the operator, thereby diminishing the system's potential for productivity. A ride-on 2-bottom mouldboard plough with a sitting attachment was thus developed and coupled to a power tiller to combat this challenge at the Federal College of Agriculture, Ishiagu. The machine was successfully developed and tested, making power tillers an attractive power source with satisfactory performance.

## REFERENCES


1. Singh, N., G. Singh and V.M. Salokhe, 1991. Cyclic variation in moldboard plow draft and its effect on implement control systems. Soil Tillage Res., 21: 273-286.
2. Tawfik, M.A. and Y.S. Abdellah, 2012. Fabricating a prototype of potato digger to suit small holdings. Misr J. Agric. Eng., 29: 705-724.
3. El-Iraqi, M.E., S.A. Marey and A.M. Drees, 2009. A modified triangle-shape chisel plow (evaluation and performance test). Misr J. Agric. Eng., 26: 644-666.
4. Al-Deen, S., M.A. Ergech and H.T. Tahir, 2008. Comparative analyses of the 4WD tractor performance with two different mouldboard plow bottoms by using FEM. J. Agric. Sci., 14: 183-192.
5. Ademiluyi, Y.S., A.O. Ani, B.O. Ugwuishiwu and O.A. Oyelade, 2007. Performance assessment of two-wheel tractor on a loamy sand soil of Ilorin. Niger. J. Technol., 26: 59-66.
6. Liu, Y., Z. Xu, H. Xu and Y. Chen, 2017. Analysis of rigid-flexible coupling dynamic characteristics for power tiller. Sci. Adv. Mater., 9: 2178-2186.
7. Kumar, R., V. Singh, K. Devi, M. Sharma, M.K. Singh and P.S. Ahuja, 2008. State of art of saffron (*Crocus sativus* L.) agronomy: A comprehensive review. Food Rev. Int., 25: 44-85.
8. Tewari, V.K., K.N. Dewangan and S. Karmakar, 2004. Operator's fatigue in field operation of hand tractors. Biosyst. Eng., 89: 1-11.
9. Hensh, S., V.K. Tewari and G. Upadhyay, 2021. A novel wireless instrumentation system for measurement of PTO (power take-off) torque requirement during rotary tillage. Biosyst. Eng., 212: 241-251.
10. Hensh, S., P.S. Chattopadhyay and K. Das, 2022. Drawbar performance of a power tiller on a sandy loam soil of the Nadia District of West Bengal. Res. Agric. Eng., 68: 41-46.
11. Mujawamariya, G. and E. Kalema, 2017. Limited usage of mechanical equipment in small-scale rice farming: A cause for concern. J. Agric. Environ. Int. Dev., 111: 5-21.
12. Agyei-Holmes, A., 2016. Tilling the soil in Tanzania: What do emerging economies have to offer? Eur. J. Dev. Res., 28: 379-396.
13. Fadel, M.A., 2005. Development of a tractor-mounted date palm tree service machine. Emir. J. Food Agric., 17: 30-40.
14. Erenstein, O. and V. Laxmi. 2008. Zero tillage impacts in India's rice-wheat systems: A review. Soil Tillage Res., 100: 1-14.

15. Karki, E., A. Sharma and B. Brown, 2022. Farm mechanisation in Nepal's Terai Region: Policy context, drivers and options. J. Int. Dev., 34: 287-305.
16. Nwakaire, J.N., A.C. Ezeagba and O.C. Ogoegbulem, 2018. Refurbishment and evaluation of a two-wheeled tractor. Niger. J. Technol., 37: 1168-1175.
17. Rasool, S. and H. Raheman, 2018. Improving the tractive performance of walking tractors using rubber tracks. Biosyst. Eng., 167: 51-62.
18. Ibrahmi, A., H. Bentaher, E. Hamza, A. Maalej and A.M. Mouazen, 2017. Advanced analytical method of mouldboard plough's design. Int. J. Adv. Manuf. Technol., 88: 781-788.
19. Richey, S.B., A.K. Srivastava and L.J. Segerlind, 1989. The use of three dimensional computer graphics to design mouldboard plough surfaces. J. Agric. Eng. Res., 43: 245-258.
20. Formato, A., D. Ianniello, F. Villecco, T. Lenza and D. Guida, 2017. Design optimization of the plough working surface by computerized mathematical model. Emir. J. Food Agric., 29: 36-44.
21. Blednykh, V.V., P.G. Svechnikov and I.P. Troyanovskaya, 2016. Calculation model of technological process of soil crumbling by means of tillage working organs. Tractors Agric. Mach., 83: 22-26.
22. Grisso, R.D., M. Yasin and M.F. Kocher, 1996. Tillage implement forces operating in silty clay loam. Trans. ASAE., 39: 1977-1982.
23. Al-Janobi, A.A. and S.A. Al-Suhaibani, 1988. Draft of primary tillage implements in sandy loam soil. Appl. Eng. Agric., 14: 343-348.
24. Arvidsson, J., T. Keller and K. Gustafsson, 2004. Specific draught for moldboard plough, chisel plough and disc harrow at different water contents. Soil Tillage Res., 79: 221-231.
25. Taniguchi, T., J.T. Makanga, K. Ohtomo and T. Kishimoto, 1999. Draft and soil manipulation by amoldboard plow under different forward speed and body attachments. Trans. ASAE, 42: 1517-1522.
26. Perfect, E., N.B. McLaughlin and B.D. Kay, 1997. Energy requirements for conventional tillage following different crop rotations. Trans. ASAE., 40: 45-49.
27. Upadhyaya, S.K., T.H. Williams, L.J. Kemble and N.E. Collins, 1984. Energy requirements for chiseling in coastal plain soils. Trans. ASAE., 27: 1643-1649.
28. Kheiralla, A.F., A. Yahya, M. Zohadie and W. Ishak, 2004. Modelling of power and energy requirements for tillage implements operating in Serdang sandy clay loam, Malaysia. Soil Tillage Res., 78: 21-34.
29. Kushwaha, R.L. and C. Linke, 1996. Draught-speed relationship of simple tillage tools at high operating speeds. Soil Tillage Res., 39: 61-73.
30. Bochtis, D.D., C.G.C. Sørensen and P. Busato, 2014. Advances in agricultural machinery management: A review. Biosyst. Eng., 126: 69-81.
31. Bowers, C.G., Jr., 1989. Tillage draft and energy measurements for twelve Southeastern soil series. Trans. ASAE., 32: 1492-1502.
32. Tewari, V.K., R.K. Datta and A.S.R. Murthy, 1993. Field performance of weeding blades of a manually operated push-pull weeder. J. Agric. Eng. Res., 55: 129-141.
33. Oyelade, O.A. and K.C. Oni, 2018. Modelling of tractor fuel consumption for harrowing operation in a sandy loam soil. Arid Zone J. Eng. Technol. Environ., 14: 8-19.
34. Dayou, E.D., K.L.B. Zokpodo and L.R.G. Kakaï, 2017. Assessment of the physical and mechanical properties of the soils in the different agroecological zones of Benin. Agro-Science, 16: 37-45.
35. Kantchede, C.N., R.H. Ahouansou, E.A. Ajav and G. Bizimungu, 2022. Development of a small-scale power tiller for farmers in developing countries: A case study of Benin. J. Agric. Food Res., Vol. 10. 10.1016/j.jafr.2022.100441.
36. Pradhan, T.M., K.T. Mahule, V.K.S. Patle, A.K.S. Patle, K.N. Rahulkar, M.M. Nagfasre and Y.P. Nimje, 2021. Solar operated electric power tiller with detachable handle and wheel. Int. J. Innovations Eng. Sci., 6: 64-70.