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# Evaluation of Current Farm Machinery Selection Practices of Wonji Shoa Sugar Factory

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**ABSTRACT**

The Government of Ethiopia is trying to improve sugar industry sector by establishing new factories, expansion projects and rehabilitation of existing ones. The main input in this process is agricultural mechanization; however it has been resulted in a huge number of farm machinery of various types and sizes, without consideration of proper selection and matching between tractors and their attachments (implements). This approach had led to high cost of agricultural operation, resulted in an unbalanced distribution of machinery and the agricultural operations throughout the years. Wonji Shoa Sugar factory is one of the victims of the aforementioned problem. The present study was conducted to evaluate the current farm machinery selection practices of Wonji Shoa Sugar Factory. Three soil types namely; heavy clay, vertisol and sandy loam were selected with four field activities (subsoiling, ploughing, harrowing and furrowing). For subsoiling, ploughing and harrowing, 9410-R John Deer tractor with implements of 5 shank and 3.2 m wide mounted subsoiler, 2.8 m wide double gang offset disc plough, and 3.5 m wide semi mounted four gangs double offset were used respectively. For furrowing YTO-1804 tractor and a four bottom fully mounted 4.5 m wide rider was used. For each experiment, the draft force requirement of the implements, the drawbar power, fuel consumption, overall energy efficiency and power utilization ratio were determined at different tractor travel speeds. Subsoiling, ploughing and harrowing were activities were evaluated at the travel speed of w 3, 4, 5 and 6 km/hr. And a travel speed of 4, 5, 6 and 7 km/hr were used for furrowing operation. Linear regression tests were run to examine the interactions between the factors and determine their significant impact. The results of this study noted for furrowing operation as lowest draft force, drawbar power, fuel consumption and energy efficiency of 14 kN, 12.65kW, 13 lit/hr and 8.7 % respectively in sandy loam soil type. The maximum Draft force of 79.8 kW and drawbar power of 131 kW was noted for subsoiling operation in Heavy clay soil. Moreover the results of all operation in all soil type, as indicated by both overall energy efficiency and power utilization factor shows the mismatch between the tractor and implements, as the tractors were overpowered. That means a less amount of the available power from the tractor is being used to operate the implement. If the tractor had been matched with a bigger and compatible implement a better efficiency and higher productivity of the tractor implement combination could have been achieved.

***Key words:*** *Machinery selection, Optimum travel speed, Drawbar power, Overall energy efficiency*

## Introduction

Wonji Shoa Sugar Factory is found at Oromiya region near Adama City at 110 kilo meters from Addis Ababa. This Factory is the oldest and the pioneer in the history of Ethiopia's sugar industry and started production in 1954 E.C. In a bid to replace the old factory with a new and modern one, an expansion

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project had been carried out both in the cane cultivation field and the factory, since 2005/2006. Factory plant expansion project has come into its completion in July, 2013. Accordingly, the newly built and modern Wonji Shoa Sugar Factory has currently a design capacity of crushing 6,250 tons of cane in a day and producing 174,946 tons of sugar per annum, which with further expansion work will reach up to 12,500 TCD maximizing its production to 220,700 tons of sugar in a year. Its agricultural expansion projects are currently being carried out around the areas known as Wakie Tiyo, Welenchiti and North Dodota areas. The main factory with the help of these agricultural expansion projects had lead 16,000 hectares of sugarcane plantation field in total. Wonji Shoa Sugar factory is a mechanized agro-industry having different types of farm machineries used from early land preparation to cane haulage.

Farm machinery contributes a major capital input cost in most of the agricultural business, since it is a major component of agricultural planning and development strategy in utmost all countries, which requires proper management (Yousif, 2013). Selection of power units and agricultural machines for farming operations, can lead to profit or loss of all or part of the farm enterprise. The use of an oversized fleet of tractors and machines results in a higher costs and loss of fuel use efficiency, inadequate machines sets can extend the time scheduled for the different agricultural operation that can affect yields (Gindo and Kolhe, 2021). The recent increase in fuel prices and decrease in farm income has rekindled interest towards the correct selection and operation of tractor-implement systems that maximize energy input efficiency. The worth of a tractor is measured by the amount of work that can be accomplished and the cost associated with completing the task. An ideal tractor would convert all fuel energy into useful work at the drawbar. However, due to power losses, all fuel energy is not converted into useful work (Grisso, 2010). Therefore, the wrong decision may lead to either over or under utilization of power units and machineries lead to a huge pile of unused scrap of tractors and problem of financial debt Therefore, in the present study, it was decided to evaluate the current farm machinery selection practices of Wonji Shoa Sugar Factory by using four different farm operations in three different soil types.

**Study locations and Experimental set up**

**Description of the study location**

The present study was conducted at the Wonji Shoa Sugar Factory (WSSF), Oromiya region near to Adama City, Ethiopia. The study location (left) and Soil map (right) of Wonji Shoa Sugar Estate is presented in Fig. 1.

**Experimental planning and selected soil details**

Three experimental sites were selected based on soil type: vertisol soil, heavy clay soil and loamy sand soil at different locations. The overall planning of experimental design is depicted in Figure 2, each experimental site has a land area of 10,000 $m^2$, the land area was divided into four plots of 50 x 50 $m^2$, the experimental plot of each soil type was separated by 3 m for performing the planned farm operation. The four operations like; subsoiling, ploughing, harrowing and furrowing were conducted in every planned plot. The compositions of the selected soil types at different experimental are shown in Table 1.

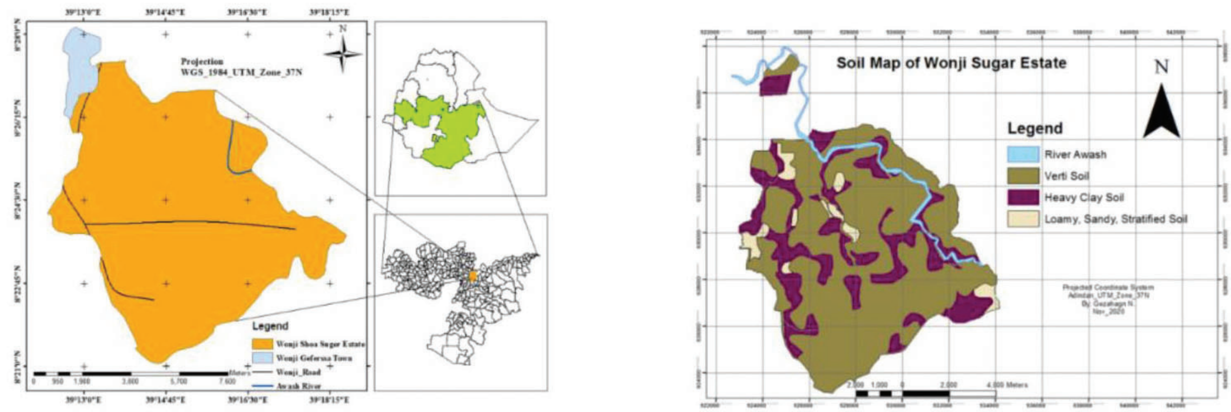



**Fig. 1.** Study location (left) and Soil map (right) of Wonji Shoa Sugar Estate

## Technical specifications of tractor and other farm implements used in this study

9410- R John Deer tractor was used for subsoiling, ploughing and harrowing activities. Its technical specifications are presented in Table 2.

For furrowing operation, YTO -1804 tractor was used and its technical details are presented in Table 3.

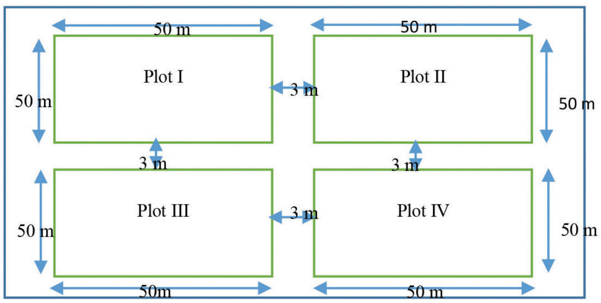



**Fig. 2.** Layout of field experimental design for all soil types

**Table 1.** Compositions of soil types at selected plots

| Sr. No . | Soil Type | Composition (%) Clay | Silt | Sand |
|---|---|---|---|---|
| 1 | Heavy Clay Soil | >70 | 20 | 10 |
| 2 | Vertisol | 62 | 20 | 18 |
| 3 | Loamy sand soil | 10 | 10 | 80 |

## Implements utilization specifications for subsoiling, harrowing, ploughing and furrowing operations

The implements used for various operations during field experiments are as: For subsoiling a 5 shank and 3.2 m wide mounted subsoiler was used. Whereas a semi mounted two gangs offset Heavy Disc Harrow with 16 discs each 42 inch diameter (42′′×16), and 2.8 m wide was used for ploughing experiment for all soil types. For harrowing a semi mounted four gangs double offset with 48 discs each 24 inch diameter (24′′×48) and 3.5 m wide was used. A four bottom mounted 4.5 m wide rider was used. The details of Implements utilization for the experiment (from left to right: disc plough, furrower and disc harrow) are as in Figure 3.

**Table 3.** Technical specification of YTO 1804 tractor

| | |
|---|---|
| Rated Engine power at 2200 engine rpm, kw | 132.3 |
| Max Engine power (97/68 EC) at 1900 engine rpm, kW | 332 |
| Bore and stroke, mm | 110x120 |
| Transmission | 12+4 |
| PTO speed | 540/1000rpm |
| PTO power | 118kw |
| 3-POINT HITCH | Rear lift (at 24"/ 610mm): |
| Wheel Configuration | 4WD |
| Tire Size | 16.9-28/20.8-38 |

## Methodology for measuring Physical Properties, draft measurement, drawbar power, tractive efficiency and tractor wheel slip

### Determination of soil physical properties

The soil's bulk density, porosity, soil structure, and soil moisture content are among the physical characteristics of the soil (or "parameters") that influence draft force, drawbar power, tractive efficiency, and required energy. In vertisol, sandy loam, and heavy clay soil, these characteristics were examined. The soil samples were taken at 10 places at the depths of (0–20 cm, 20–40 cm, and 40–60 cm) for each soil type. (Oduma and Oluka, 2019).

**Table 2.** Technical specifications of 9410- R John Deer tractor.

| | |
|---|---|
| Rated Engine power (97/68 EC) at 2100 engine rpm, kw | 302 |
| Max Engine power (97/68 EC) at 1900 engine rpm, kW | 332 |
| Transmission | 24-speed Manual Shift 40 km/h; 24F 6R |
| Drawbar | Cat 4 w/ Std Drawbar Support, 2470 kg Maximum \ Vertical Load |
| PTO shaft | 1-3/4 in., 20-spline, 1,000-rpm |
| PTO Performance | PTO Horsepower, Basic / Optional/Transmission 238kw |
| 3-POINT HITCH | Category 3/4N with Quik-Coupler – All Axle Diameters Allowed, 6940kg |
| Wheel Configuration | 4WD |
| Tire Size | Front Tire Size or Track Width, MFD/4WD or Track - 710/70 R38 Duals. Rear Tire Size or Track Width - 710/70 R38 Duals |

**Fig. 3.** Implements used for the experiment (from left to right: disc plough, furrower and disc harrow)

**Table 4.** Use and capacity of scientific instruments and equipment's

| Name | Use | Capacity |
|---|---|---|
| Measuring Tape | Used for linear measurement of land, and working width of the implements | 50 meters |
| Steel Ruler | Used for measuring depth of cut for tillage implements | 100 cm |
| Dynamo meter | Used to measure the horizontal pull required by implements | 100 kN |
| A graduated cylindrical container | used to measure the amount of fuel required to refill the fuel tank of the tractor immediately after each operation | 5 liters |
| Smart cell phone | Used to take pictures | 48 Gega pixel |

**Determination of soil moisture contents**

An oven-drying method was used to determine the moisture content of the soil samples at various locations used in the study. The weight of the oven-dried sample of the same soil (dry soil) is taken as the weight of the first soil sample (wet soil) taken in the field was determined in the laboratory and the moisture content was determined by using equation no 8 [6].

$$M_c = \frac{W_s – D_s}{D_s} \times 100\% \quad .. (8)$$

Where, MC = moisture content of the soil, %; WS = weight of wet soil (initial soil sample), kg;

DS = weight of oven-dry soil, kg.

**Determination of soil bulk density**

The cylindrical core-cutter method was used to determine the bulk density of the soil was evaluated using the equation 9 (Danielson and Sutherland, 1986).

$$\rho = \frac{W_S}{V_s} \quad .. (9)$$

Where: ρ = bulk density, g $cm^{-3}$; WS = weight of dry soil sample, g; VS = volume of dry sample of soil, $cm^3$ (equal to the volume of the cylindrical cutter).

**Determination of soil porosity**

The soil porosity was evaluated from equation no 10 [6]

$$\text{Porosity} = 1 – \frac{\text{Bulkdensity}}{\text{average density of soil particles}} \times 100\% \quad .. (10)$$

**Implement draft measurement**

Optimum power requirement, fuel consumption and operating efficiency can be obtained by matching of the tractor and implement properly. Measurement of draft force requirements is the prominent factor to achieve this objective during selection of machinery and power source[6]. Two John Deer 9410R tractors were used to measure the draft of the tillage tools (subsoiler, disc plough and disc harrow). The semi mounted implements under study were attached at the rear side of one tractor with three point hitching system. A pull type100 kN LI-200 PIAB bidirectional load cell dynamometer was attached to the front side of the tractor, which was pulling the implement under test. The other tractor was used to pull the implement mounted tractor through dynamometer. To ensure equal travel reduction of drive wheels, the differential lock was engaged during each test run treatments and the tractor was operated at the respective gear and throttle settings to achieve the required travel speeds as shown in Figure 4.

A test run of 50 m length was allocated for each test block for each operations speed. The implement drafts were measured at travel speeds of 3, 4, 5 and 6 kmh"1 for subsoiling, plouhging and 4, 5, 6 and 7 km/hr harrowing and furrowing activity. The tractor pulling the implement was made in neutral gear with implement in operating condition (operating depth). The idle draft force was also measured with in the same field when implement was in a lifted position. The difference between the draft recorded at operating and idle conditions gave the draft required to pull the implement.

YTO-1804 tractor with rated engine power of 132.3 kW at 2200 engine rpm and 118 Kw PTO power was used for furrowing activity to measure draft force with the same procedure followed for subsoilng, ploughing and harrowing with John Deer tractor except for forward travel speeds (4,5,6 and 7 Km/hr) used for harrowing and furrowing . It is a four wheel drive tractor with 12 forward and 4 backward speeds. Its tire is 16.9-28 / 20.8-38 and minimum operating mass is 6880 kg. A semi mounted 4 bottoms and 4.35 m wide furrower was used for all soil types for this experiment.

### Determination of drawbar power

Drawbar power is the power required to pull or move the implement at a uniform speed, in relation to either a pull – type or mounted implements. Once the horizontal pull force (draft force) is measured, the drawbar can be calculated by using the following the equation 11 [8]

$$DBP = \frac{D \times S}{C} \qquad ..\ (11)$$

Where, D= Draft, kN, C= Constant=3.6, DBP= Drawbar power, kw, S= travel speed km/hr

### Determination of tractive efficiency (TE)

The tractive efficiency of a traction device, or for an agricultural tractor (the ratio of drawbar power output to axle power input), is generally considered to be the most important traction parameter. Ever since the advent of pneumatic rubber tires in the early 1930's, traction research and development has mainly been devoted towards improvement in tractive efficiency [7]. Tractive efficiency was calculated by using the simple expression shown by equation 12 [11]:

$$TE = DTR/GTR\ (1-S) \qquad ..\ (12)$$

Where, TE is tractive efficiency, DTR is dynamic traction ratio, GTR is gross traction ratio and

S is travel reduction (wheel slip)

The DTR/GTR ratio can be thought of as the ratio of useful to theoretical drawbar pull. The ratio of useful drawbar pull to theoretical pull was employed to replace the DTR/GTR ratio in this study. Theoretical drawbar power was obtained from the tractor manufacturer's technical specifications, and useful drawbar pull was computed using the equation above at the desired travel speed. [7]

### Determination of wheel slip

The experimental setup for wheel slip is shown in figure 5, also the wheel slip is calculated by using equation 14 [12].

$$S(\%) = 1 - \frac{S_1}{S_n} \qquad ..\ (14)$$

Where, S is a wheel slip, Sl = distance travelled with load, Sn= distance travelled with no load

### Determination of Power Utilization Ratio (PUR)

Power utilization ratio is calculated by ASAE, 2000 standards as cited by [13] as shown in equation 15.

$$X = \frac{\text{Equivalent PTO power required by the implement}}{\text{Maximum available PTO power from the tractor}} \qquad ..\ (15)$$

### Measurement of fuel consumption

The amount of fuel needed to immediately refill the tractor's fuel tank can be measured using a graduated cylindrical container [14]. This measurement

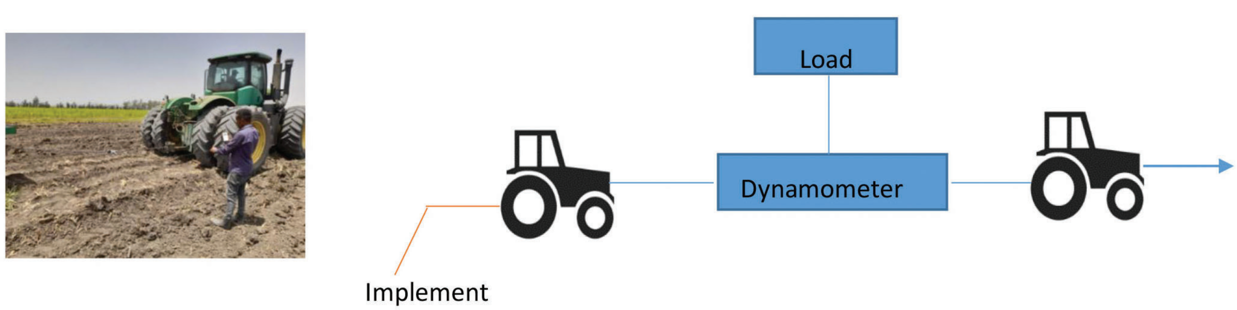



**Fig. 4.** Experimental setup for draft measurement by using pull measurement technique

**Fig. 5.** Tractor wheel slip measurement in the field

will show how much fuel was used throughout any activity. The fuel consumption rates were determined by Equation 16.

$$\text{Fuel consumption rate} = \frac{\text{Reading of cylinde, liters}}{\text{Time taken to cover land area, hours}} \quad .. (16)$$

**Determination of Overall Energy Efficiency (OEE)**
8

The ratio of the specific energy transferred from the tractor to operate the implement to the energy equivalent of the fuel consumption necessary to carry out the operation is known as the overall energy efficiency (OEE). This ratio combines the performance effects of implement and tractor load matching, traction development at the tire-soil interface, and tractor engine operating condition. It was calculated by using equation 17 [15] :

$$OEE = \frac{Va \times D}{10.2 \times Fc} \times 3.6 \quad .. (17)$$

Where,
OEE – Overall energy efficiency (%)., Va – Real forward velocity (km/h).. D – Draft (kN).
Fc – Fuel consumption (L/h) and, 10.2 is calorific value of diesel fuel

OEE is between 10 % and 20 %, and this can be used as a rapid way to verify the accuracy of fuel consumption measurements. Values outside of this range could be a sign of inaccurate fuel consumption statistics, unusual tractor-implement operation, or inadequate tractive efficiency [15].

**Data Analysis**

A statistical method of regression analysis was used to examine the relationship between variables like soil type; travel speed, draft force, drawbar power, fuel consumption and overall energy efficiency studied. Linear regression analysis was used to predict the value of a variable based on the value of another variable. The relationships are modeled using linear predictor functions whose unknown model parameters are estimated from the data. Also the graphical representation was carried out by using MS Excel.

## Results

The results of physical properties of the selected soil types for the evaluation of machinery selection practices are as depicted in Table 5. Also; the results of effect of travel speed on draft force and drawbar power for subsoiling, ploughing, harrowing and furrowing for the three soli types studied (heavy clay soil, vertisol and sandy loam soil) and their comparison are depicted by Figures 6-9.

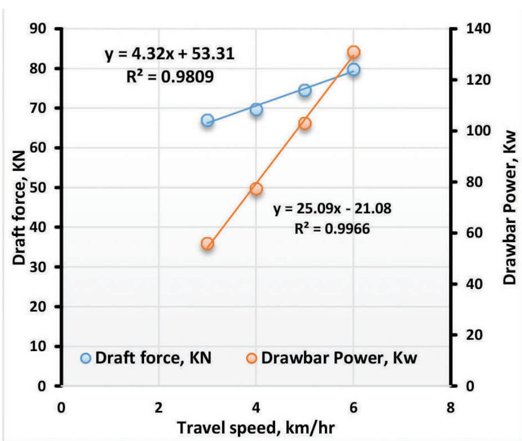
## Discussion

The results of the soil physical properties test conducted before the field experimentation are presented in Table 5. From the results it is observed that for all soil types, soil moisture content and bulk density increases as the soil depth increases, nevertheless porosity decreases as soil sample depth increases. Moreover, it is also observed that heavy clay soil has greater values of moisture content and bulk density for all soil samples throughout soil depths. This is because the higher water retaining capability of the fine particles of heavy clay soil. This nature of clay soil is also the cause for the requirements of higher drawbar power for different field activities. The results also indicated that sandy loam soil has higher porosity because of larger particle size followed by verisol and heavy clay soil. The test result also shows that the soil status of the experimental field were in a good working condition for tillage experiments.

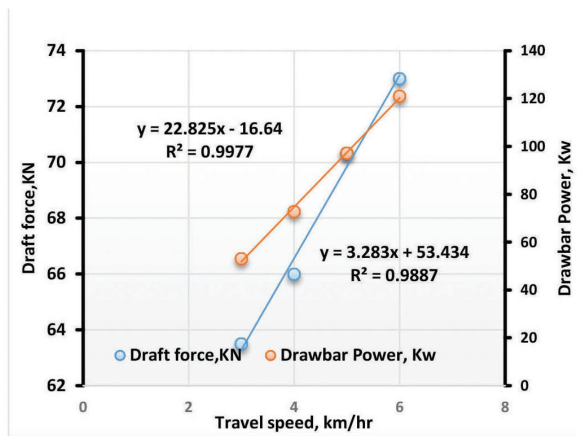
The influence travel speed on draft force and drawbar power requirement in three soil types for sub soiling operation was shown in figures 6 (a,b,c,d). From these figures; it is observed that both draft force and drawbar power increase as tractor travel speed increases. Nonetheless; the values of these draft force and drawbar power for any equal travel speed in all three soil types are different, with highest in heavy clay soil and lowest in sandy loam soil. The difference in the values of draft force and drawbar power is observed due to the nature of soil particles. In heavy clay soil, the result indicates that when travel speed increased from 3 km/hr to 6 km/hr, the draft force increased from 67 kN to 79.8 kN, whereas drawbar power increased from 55.9 kW to 131.4 kW. In vertisol as travel speed increased from

**Table 5.** Result of soil physical properties of selected soil types

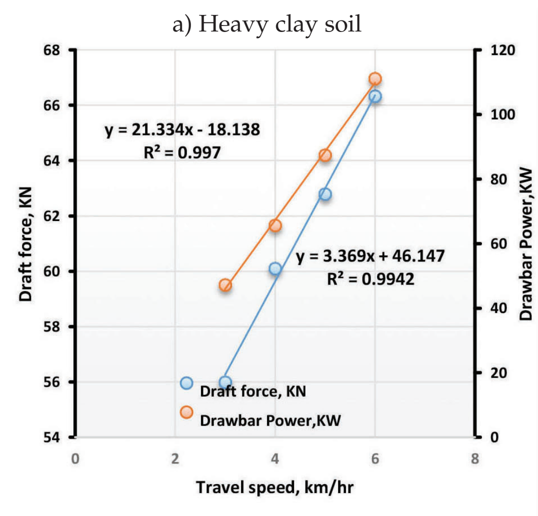
| Soil Types | Depth, cm | Moisture content, % | Bulk density, g/cm$^3$ | Porosity, % |
|---|---|---|---|---|
| Heavy clay | 0-20 | 20 | 1.08 | 42 |
| 20-40 | 22 | 1.12 | 38 | |
| 40-60 | 31 | 1.3 | 30.5 | |
| Vertisol | 0-20 | 18.5 | 1.02 | 43.5 |
| 20-40 | 20 | 1.1 | 39.5 | |
| 40-60 | 31 | 1.25 | 33 | |
| Sandy loam | 0-20 | 16 | 1 | 46.5 |
| 20-40 | 18 | 1.05 | 42.5 | |
| 40-60 | 24 | 1.2 | 39.5 | |



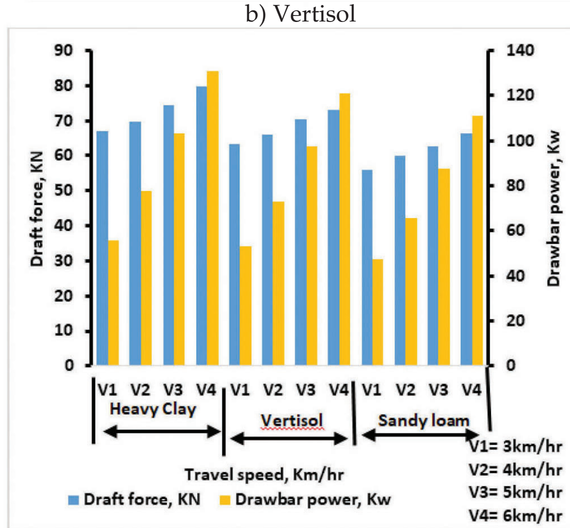

a) Heavy clay soil




b) Vertisol

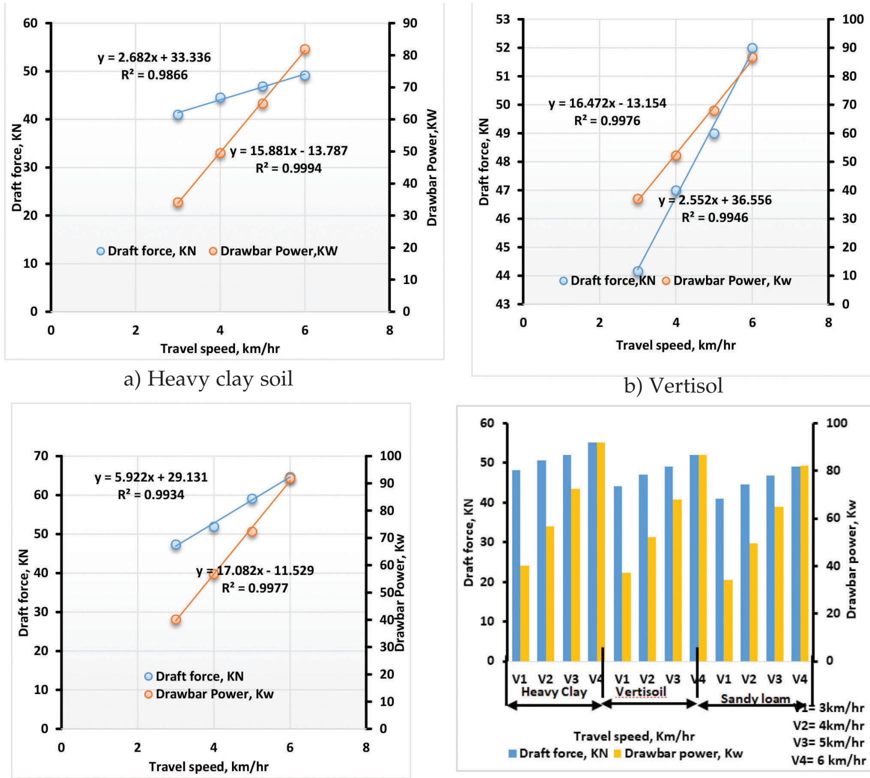



c) Sandy loam soil




d) comparison

**Fig. 6. (a, b, c, d).** Effect of travel speed and soil type, on draft force and drawbar power requirements for subsoiling in three soil types and comparison among the three soil types for the effect of travel speed and soil type on draft force and drawbar power.



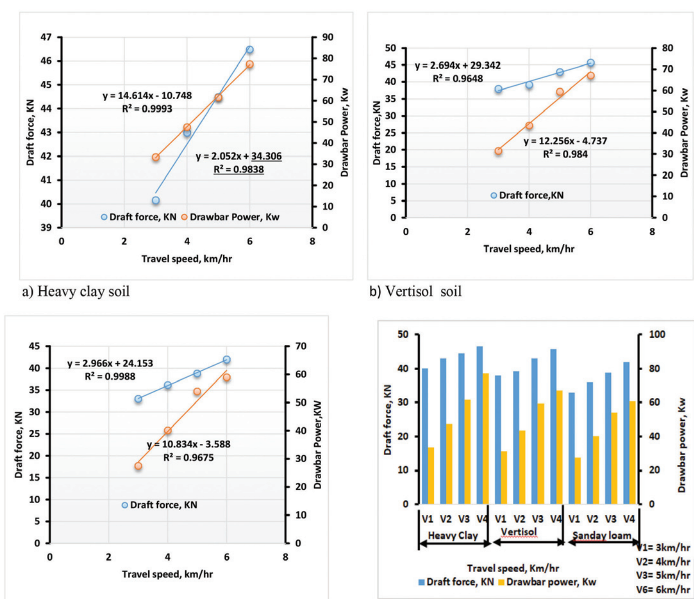

a) Heavy clay soil

b) Vertisol

c) Sandy loam

d) comparison

**Fig. 7 (a,b.c,d).** Effect of travel speed and soil type on draft force and drawbar power requirements for ploughing in three soil types and comparison among the three soil types for the effect of travel speed and soil type on draft force and drawbar power




a) Heavy clay soil

b) Vertisol soil

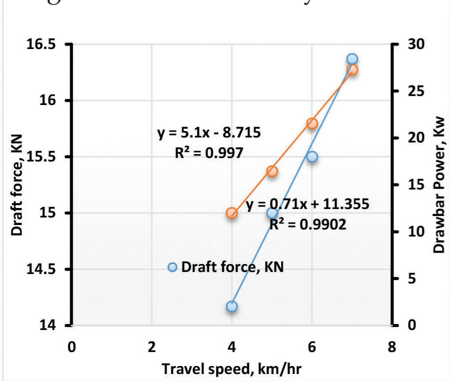
d) Comparison

c) Sanday loam soil

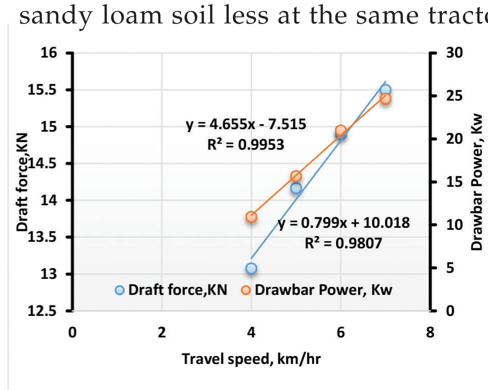
**Fig. 8. (a,b,c,d)** Effect of travel speed and soil type on draft force and drawbar power requirements for harrowing in three soil types and comparison among the three soil types for the effect of travel speed and soil type on draft force and drawbar power

3 km/hr to 6 km/hr, draft force increased from 63.5 kN to73 kN and drawbar power increased from 53.16 kW to 121.1kW. In sandy loam soil it observed that as travel speed increased from 3 km/hr to 6 km/hr, draft force increased from 56 kN to 66.33 kN and drawbar power increased from 47.23 kW to 111.1 kW. Comparison of draft force and drawbar power requirements for subsoiling in three soil types are also presented in figure 6 d. From this figure it is also observed that heavy clay soil requires more draft force and drawbar power than other soil types at any the same forward speed. For example, at 6 km/hr, the drawbar power requirement is 131 kW, 121.1 kW and 111.1 kW for heavy clay soil, verti soil and sandy loam soil respectively.

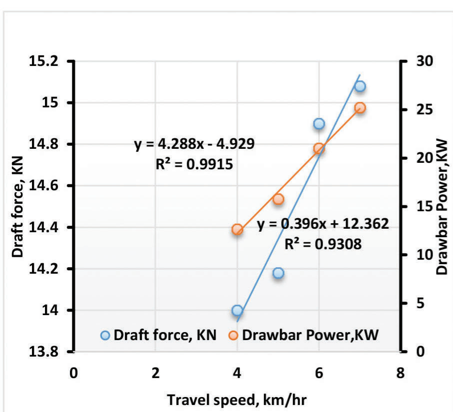
The trend of effect of tractor forward speed on draft force and drawbar power requirement in three soil types for ploughing operation observed is similar with that of subsoiling, but the values are different. The change in values are mainly due to the differences in tillage depth, type and size of the implements and condition of soil during the tillage operations. Hence for ploughing operation, figure 7 (a, b,c), it is also observed that when travel speed increased from 3 km/hr to 6 km/hr in heavy clay soil, the draft force increased from 47.36 kN to 64.7 kN, whereas drawbar power increased from 40.19 kW to 91.94 kW. In vertisol as travel speed changes from 3 km/hr to 6 km/hr draft force increased from 44.16 kN to 52 kN and drawbar power increased from 37 kW to 86.65 kW. In sandy loam soil as travel speed increased from 3 km/hr to 6 km/hr draft force increased from 41 kN to 49.16 kN and drawbar power increased from 34.2 kW to 81.98 kW. Comparison of draft force and drawbar power requirements for ploughing in three soil types are also presented in figure 7 d. From this figure it is also observed that due to the nature of its particles, heavy clay soil requires more draft force and drawbar power and sandy loam soil less at the same tractor forward



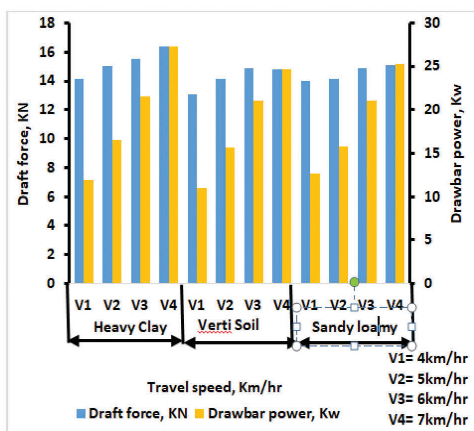

(a) Heavy Clay soil




(b) Verti soil




(c) sandy loamy soil



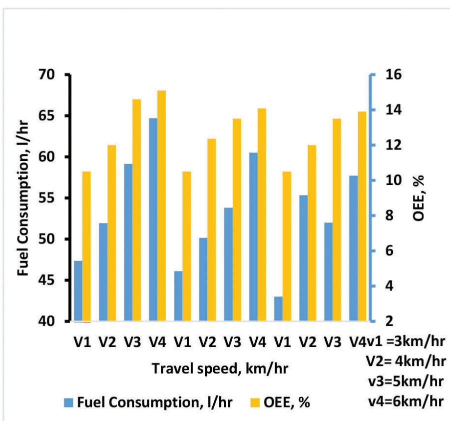

(d) Comparison

**Fig. 9. (a,b,c,d).** Effect of travel speed and soil type on draft force and drawbar power requirements for furrowing in three soil types and comparison among the three soil types for the effect of travel speed and soil type on draft force and drawbar power

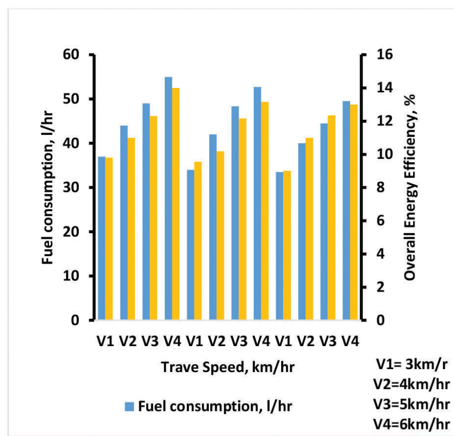
travel speed. For instance, at 6 km/hr the drawbar power requirement is 91.94 kW, 86.65 kW and 81.98 kW in heavy clay soil, vertisol and sandy loam soil respectively.

Harrowing is somehow a lighter field operation, when compared with subsoiling and ploughing as depth of operation is shallower and the soil is well disturbed earlier by ploughing. As depicted in figure 8, the trend of effect of tractor forward speed on draft force and drawbar power requirement in three soil types observed is similar with that of subsoiling and ploughing discussed as earlier, but with different values. From figure 8 a, it is observe that draft force increased from 40.16kN to 46.5kN and drawbar power from 33.4kW to 77.4kW when travel speed increased from 3km/ hr to 6km/hr in heavy clay soil. Figure 8 b indicates that as travel speed changes from 3km/hr to 6km/hr draft force increased from 38kN to 45.7kN and drawbar power changed from 31.56kW to 67.1kW in verisol. Figure 8 c indicates the same trend between travel speed, daft force and drawbar power in sandy loam soil, as travel speed increased from 3km/hr to 6km/hr draft force increased from 33kN to 42 kN and drawbar power increased from 27.5 kW to 59kW. Moreover comparison of draft force and drawbar power requirements for harrowing in three soil types is also presented in figure 8 d. From this figure it is also observed that heavy clay soil requires more draft force and drawbar power and sandy loam soil less at the same tractor forward travel speed. For instance, at 6 km/hr the drawbar power requirement is 77.4 kW, 67 kW and 59kW in heavy clay soil, vertisol and sandy loam soil respectively.

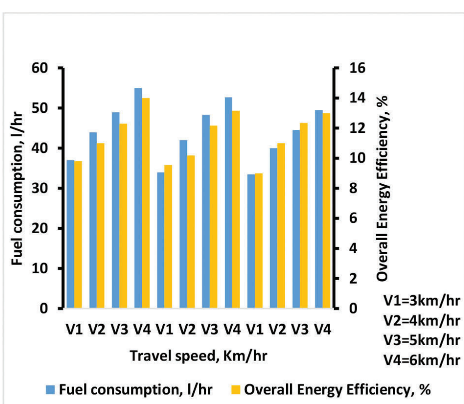
Furrowing is the final and lightest tillage activity which is done immediately after levelling the farm land. Here also the tendency of effect of tractor forward speed on draft force and drawbar power re-



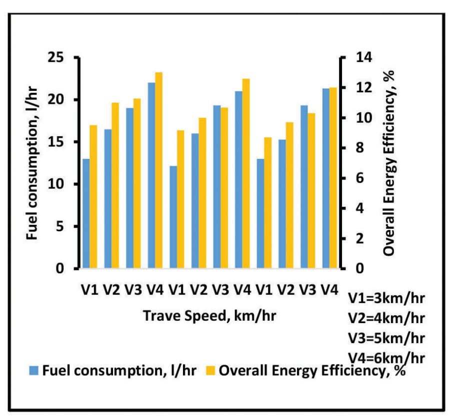

a) Subsoiling




b ) Ploughing




(c) Harrowing




(d) Furrowing

**Fig. 10 (a,b,c,d).** Comparison of effect of travel speed and soil type on fuel consumption and overall energy efficiency for field activities: subsoiling, ploughing, harrowing and furrowing in three soil types.

quirement in three soil types are similar with that of subsoiling, ploughing and harrowing discussed earlier, but with different and less values. Figure 9(a), 9(b) and 9(c) depicted the influence of travel speed and soil type on draft force and drawbar power requirements for this task in heavy clay soil, vertisol and sandy loam soil respectively. For furrowing operation, figure 9 (a) indicates that draft force increased from 14.17 kN to 16.5 kN and drawbar power from 12 kW to 27.3 kW when travel speed increased from 4 km/ hr to 7 km/hr in heavy clay soil. Figure 9 (b) also shows the changes in vertisol. It indicates that as travel speed changes from 4 km/hr to 7 km/hr draft force increased from 13.08 kN to 15.5kN and drawbar power changed from 11kW to 24.7 kW. Figure 9 (c) indicates the same trend between travel speed, daft force and drawbar power in sandy loam soil, as travel speed increased from 4 km/hr to 7 km/hr draft force increased from 14 kN to 15 kN and drawbar power increased from 12.65 kW to 25.2 kW. Additionally, comparison of draft force and drawbar power requirements for furrowing in the given three soil types was also presented in figure 9 (d). From this graph, it is also noticed again that heavy clay soil requires more draft force and drawbar power and sandy loam soil less at the same tractor forward travel speed like for other field activities. If we look at the drawbar power requirement at 7km/hr in heavy clay soil, vertisol and sandy loam soil, it was 27.3kW, 24.7kW and 25.2kW respectively.

Figure 10 shows the effect of soil type and travel speed on tractor fuel consumption and overall energy efficiency in three soil types and four tillage activities namely; subsoiling(a), ploughing(b), harrowing(c) and furrowing(d). A figure shows that tractor fuel consumption (l/hr) increases with tractor travel speed for all soil types and all field activities. Moreover, soil type also affects tractor fuel consumption. It is indicated that highest fuel consumption was recorded in heavy clay soil followed by vertisol and sandy loam soil for all tillage activities Figures 10 also indicates that forward velocity, soil type and interactive effect of them had influence on the overall energy efficiency (OEE). It is also indicated that maximum OEE occurred in all soil types at 6 km/hr and the minimum at 3km/hr that means, OEE increased as forward velocity increased. The relationship between OEE and forward velocity in all soil types was linear for all tillage activities in all soli types with coefficient of linear regression R> 0.95.

Figure 11 depicts the comparison between drawbar power available at the tractor draw bar and the one which is actually required for the specific field operation. From this figure it is observed that for subsioling-1 which is subsoiling in heavy clay soil the available drawbar power was 229 kW but only 131 kW is required for this activity. Here the power utilization ratio 0.57 that means only 57 % of the available drawbar power is utilized. For subsioling-2 and subsoiling-3 the PUR was 0.52 and 0.48 respectively. For ploughing-1, ploughing-2 and ploughing-3 (ploughing in heavy clay soil, ploughing in vertisol and ploughing in sandy loam soil) the PUR was 0.4, 0.38 and 0.36 respectively. For harrowing-1, harrowing-2 and harrowing-3, the PUR were 0.34, 0.29 and 0.27 respectively. The PUR for furrowing-1, furrowing-2 and furrowing-3 were also 0.27, 0.25 and 0.25 respectively. The other point observed here is PUR is somehow better in heavy clay soil but decreased significantly in sandy loam soil for all stated operations. This is due to the effect of soil type in drawbar power requirement, as heavy clay soil requires more and sandy loam soil less.

## Conclusions

From this study following conclusions were made:

1. Soil types and field condition, are highly affected on draft force and drawbar power requirements for the stated field operations, like; Subsoiling, ploughing, harrowing and furrowing etc. Moreover, tractor fuel consumption, overall energy efficiency and power utilization ratio are also affected by soil type and field conditions.
2. Heavy clay soil requires higher draft force, drawbar power and fuel consumption, followed by vertisol and sandy loamy soil. But better overall energy efficiency and power utilization ratio are observed in it.
3. For all the stated soil types, like heavy clay, vertisol, sandy loamy soil and all stated field operations have been noted; less overall energy efficiency (OEE). Moreover;. Less overall energy efficiency is the indicator of the mismatch between the implement and power source (tractor).
4. Power utilization ratio, which is one of the leading requirement to be considered, when making evaluation of tillage systems and is also found bellow standards for this study in all cases.
5. For all the field activities observed, the tractor

was not compatible with the implement attached to it, i.e. the tractor was overpowered.

**Recommendations**

Based on the findings of this study the following recommendations were made for better field and economy performance of tractor and implements;

1. Before planning any field activity, the type and condition of the soil need to be studied for better machinery performance.
2. When subsoiling is considered, the number of bottoms or the width of the implement currently in use at Wonji Shoa Sugar Factory is not compatible with the tractor they are using with. Therefore, either the size of the implement should be increased or the horse power of tractor should be reduced i.e. they have to use a smaller tractor only up to 250 horse power.
3. Regarding ploughing operation, the disc plough attached to a 410 horse power John Deer tractor in heavy clay soil for example requires only 40 % of the available power and could be pulled by a tractor of about 200 hp. Here the case is even worst for vertiso and sandy loam soil.
4. For harrowing operation, the implement attached to a huge 410 hp tractor could be sufficiently pulled with a tractor of about 150 HP.
5. When the lightest field operation, furrowing consumes only 27 % of the available power. So it is the most inefficient and costliest operation observed. A tractor with 100 hp could be used to pull the implement.

**Conflict of Interests**

The authors declare that they have no competing interests; honest efforts are to transfer the technology to the farmer's community and agro industries for the better improvement of agro-production.

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## References

Ashok Kumar, A., Tewari, V.K., Gupta, C. and Pareek, C.M. 2017. A device to measure wheel slip to improve the fuel efficiency of off road vehicles. Journal of Terramechanics, Elsevier Ltd 70: 1–11.

Danielson, R. E. and Sutherland, P.L. 1986. Porosity Methods of soil analysis, Part 1. Rev. Physical and Mineralogical Methods. American Society of Agronomical Science, Monogr 9.;

Domier, K.W. and Willans, A.E. 1977. Maximum or Optimum Tractive Efficiency? American Society Agricultural Engineering. 650–653.

Gindo, D. L. and Kolhe, K. P. 2021. Studies of Tractor and Crop Parameters combinations for optimal Selection of Machinery Sizes: A- Review. *International Journal of Mechanical Engineering, Kalahari Journals*. 6(3) : 3547–52.

Gosaye, C., Mengiste, Z. amd Hailu, A. 2015. Evaluation of the Compatibility of Tractors and Implements at Tendaho Sugar Estate, *ARPN Journal of Science and Technology.* 5(10).

Grisso, R.B. 2010. Predicting Tractor Diesel Fuel Consumption;. Virginia Polytechnic Institute and State University, 442-073

Kastens, T. 1997: Farm Machinery Operation Cost Calculations.; www.agmanager.info, Kansas State University 1-25.

Mclaughlin, N.B., Drury, C.F., Reynolds, W.D., Yang, X.M., Li, Y.X. and Welacky, T.W. 2008. Energy inputs for Conservation and Conventional Primary Tillage Implements in a Clay loam soil. Transactions of the ASABE, *American Society of Agricultural and Biological Engineers.* 51(4) : 1153–63.

Mehta, C.R., Singh, K. amd Selvan, M.M. 2010. A decision support system for selection of tractor-implement system used on Indian farms. *J Terramechanics.* [Internet]. 2011; 48(1) : 65–73. Available from: http://dx.doi.org/10.1016/j.jterra..05.002

Oduma, O. and Oluka, S. 2019. Effect of soil type on power and energy requirements of some selected agricultural field machinery in south-east Nigeria. *Poljopr Teh*. 44(3) : 69–77.

Oduma, O., Oluka, S., Nwakuba, N. and Ntunde, D. 2019. Agricultural field machinery selection and utilization for improved farm operations in South-East Nigeria : A review. *Journal of Agricultural Engineering, University of Belgrade.* 44(3) : 44–58.

Society of Automotive Engineers Cooperative Tractor Testing Committee, 1938. The traction of pneumatic tractor tires (33): 13-26.

Udo DU AC, 2004. Fuel consumption in tillage operations for sandy loam soil. *Niger Inst Agric Eng.* 26: 74–82.

Yousif L, 2013. Crop-machinery management system for field operations and farm machinery selection. *Journal of Agricultural Biotechnology and Sustainable Development.* www.academicjournals.org/JABSD. 5(5): 84–90.

Zoz, F.M. amd Grisso, R.D. 2003. Traction and Tractor Performance. *American Society of Agricultural Engineers*. (27).