

IMPROVING FARM TRACTOR-IMPLEMENT MANAGEMENT USING DECISION SUPPORT SYSTEM (DSS): THE CASE OF WONJI-SHOA SUGAR FACTORY, ETHIOPIA



Demelash Gindo Lemi

**A Dissertation Submitted to the Department of Mechanical Engineering,
School of Mechanical, Chemical and Materials Engineering**

**Presented in Partial Fulfillment of the Requirement for the Degree of
Doctor of Philosophy in Mechanical Engineering (Specialization in Agricultural Machinery Engineering)**

Office of Graduate Studies Adama Science and Technology University

November 2024
Adama, Ethiopia

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APPROVAL OF Ph.D. DISSERTATION

We hereby certify that the recommendations and suggestions made by the board of examiners are appropriately incorporated into the final version of the dissertation entitled “**Improving Farm Tractor-Implement Management Using Decision Support System (DSS): the case of Wonji-Shoa Sugar Factory, Ethiopia**” by Mr. Demelash Gindo Lemi

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DECLARATION

I hereby declare that this dissertation entitled “**Improving Farm Tractor-Implement Management using Decision Support System (DSS): the case of Wonji-Shoa Sugar Factory, Ethiopia**” is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials used for this dissertation have been duly acknowledged through appropriate citations.

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Signature

Date

RECOMMENDATION

We, the supervisors of this dissertation, hereby certify that we have read and revised the dissertation entitled “**Improving Farm Tractor-Implement Management using Decision Support System (DSS): the case of Wonji-Shoa Sugar Factory, Ethiopia**” prepared under our guidance by **Mr. Demelash Gindo** and submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Mechanical Engineering (Specialization in **Agricultural Machinery Engineering**). Therefore, we recommend the submission of the dissertation to the department for further review and defense.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
ASABE	American Society of Agricultural and Biological Engineers
ASAE	American Society of Agricultural Engineers
ASTU	Adama Science and Technology University
BM	Breakdown Maintenance
CBM	Condition-based Maintenance
CFRP	Carbon Fiber Reinforced Polymer
CIGR	International Commission of Agricultural and Biosystems Engineering.
CM	Condition Monitoring
CMS	Condition Monitoring Systems
CRF	Capital Recovery Factor
DBP	Drawbar Power
DP	Dynamic Programming
DSS	Decision Support System
EFC	Effective Field Capacity
ESC	Ethiopian Sugar Corporation
ETB	Ethiopian Birr
EWEA	European Wind Energy Association
GAMS	General Algebraic Modelling System
GTP	Growth and Transformation Program

HYV	High Yielding Variety
ICT	Information and Communication Technologies
MCDM	Multi-Criterion Decision Making
MPs	Maintenance Plans
MT	Metric Tones
NTTL	Nebraska Tractor Test Laboratory
OEE	Overall Energy Efficiency
OPGS	Office of Postgraduate Studies
PM	Preventive Maintenance
PTO	Power Takeoff
PUR	Power Utilization Ratio
RAMS	Reliability, Availability, Maintainability, and Safety
RF	Recovery Factor
RV	Remaining Value
TCD	Tons of Cane
TFC	Theoretical Field Capacity
UT	Ultrasonic Testing
VAT	Value Added Tax
WSSF	Wonji Shoa Sugar Factory

ABSTRACT

A huge number of farm tractors and implements of various types and sizes are owned by Wonji-Shoa Sugar Factory. Selection of farm machinery based on soil type, farm size, and crop type is essential to reduce operation and fixed costs which WSSF lacks. The absence of proper farm machinery selection also resulted in an unbalanced distribution of machinery and agricultural operations throughout the years. The other crucial element of farm machinery management is the decision of when to replace the old, worn-out farm equipment with new ones. Piles of scrap indicate a lack of maintenance facilities and farm machinery replacement strategies at Wonji Shoa Sugar Factory. The objective of this study was to improve tractor- implement management system of Wonji-Shoa Sugar Factory by developing the Decision Support System (DSS). To evaluate machinery selection, three soil types; heavy clay, vertisol, and sandy loam were selected with four activities. The draft force, the drawbar power, fuel consumption, OEE, and PUR were determined at different speeds. At a 95 % level of confidence for each approach, the statistical analysis program "IBM SPSS Statistics 26" was used to undertake the ANOVA, correlation, and multiple linear regressions of the obtained data. The results revealed that the furrowing operation had the lowest draft force, drawbar power, fuel consumption, and energy efficiency of 14 kN, 12.65 kW, 13 lit/hr, and 8.7 % respectively in sandy loam soil type. The maximum Draft force of 79.8 kN and drawbar power of 131 kW were noted for subsoiling operation in Heavy clay soil. The results also indicate that surplus tractor power was observed for all field activities. To evaluate the maintenance and replacement strategies, tractors were categorized into different groups based on their make and capacity rating. The period (in years) when the total annual cost reached its minimum value, was decided as the economic life of a tractor. Accordingly, it was observed that the total annual cost is determined to be lowest in the fifth year (17859.63 USD), seventh year (10729.63 USD), sixth year (4502.7USD), and eighth year (4581.6 USD), for John Deere 333, SAME 130, New Holland 80 and Massey Ferguson 150, tractors respectively for optimum replacement years. The field experimental validated DSS result indicated that it was possible to save a total of 5,925 Birr/ha fuel cost and 592.2 Birr/ha lubrication cost for all tillage activities studied. It was concluded that the tractors considered in this study for land preparation were not compatible with the implement attached to them and were overpowered. It is recommended to use the DSS before planning any field activity and study the soil type and condition for better tractor-implement selection as it affects overall machinery management, performance and, operation costs.

Keywords: *Annual cost, Decision Support System, Machinery management, Maintenance, replacement, Selection.*

CHAPTER ONE: INTRODUCTION

1.1. Background of the Study

Ethiopia's sugar industry, which is solely dependent on sugarcane, also contributes in several other ways to the nation's socio-economic growth (Tolera *et al* 2024). The production of sugar for domestic and industrial use, income generation from bioethanol, electric power generation, and other by-products, and the creation of jobs are only a few of its contributions (Tolera *et al.*, 2024; Tena *et al.*, 2013). While it expanded rapidly during the past three decades, the industry also has a deeper history that goes back to when a center of sugarcane production was established in the Awash Valley during the Italian occupation in the 1930s (Zewde, 2008). The sugar industry in Ethiopia has also been characterized by a modernist political and economic strategy throughout its development. In the days of the Imperial Government, the industry had represented sugar as an 'exotic' and 'modern' commodity that fitted with the regime's determination to 'modernize' and 'accustom' Ethiopians to modern tastes (Zikargie *et al.*, 2022). The Imperial Government's second five-year development plan (1962–1967 E.C) invoked agro-industrial projects, including the sugarcane industry, to 'modernize' the 'traditional' livelihoods through the introduction of large-scale mechanized commercial farming (Zikargie *et al.*, 2022). During the rule of the military government, the Derg (1974-1991), the state nationalized and expanded the sugar industry into the Fincha Valley, a development that was completed during the late 1990s. During the period of the EPRDF government (1991–2019), several expansions and new factories were made, particularly after 2004. The government's developmental narrative has justified massive investments in the establishment of a state-led and rapidly expanding sugar industry, which by 2020 earmarked more than 300,000 hectares of land in Lower Awash, Fincha, Beles, and Omo Valleys, as well as in the West and Northwest (Zikargie *et al.*, 2022).

With three successive governments investing in the sugar industry, the question of why sugar has continuously remained a strategic political and economic tool of the state is critical and this question is particularly pertinent since, despite decades of aspiration and effort, the governments have not succeeded in making sugar become a major export, but rather meeting the growing domestic demand for sugar, and exploiting the economic advantages of its by-products including ethanol and electricity (Zikargie *et al.*, 2022). In recent years however, the Government of Ethiopia, through the state-run Ethiopia Sugar Corporation (ESC), has made heavy investments in the

country's sugar sector, among which are the construction of new sugar processing factories, the revitalization of older factories, and the expansion of land under sugar cultivation. These ESC-led efforts have and will continue to increase sugar production levels for the foreseeable future (USDA, 2015).

Sugar production is labor-intensive for almost all operations, from land preparation to harvesting. Mechanization helps in labor-saving and timeliness of operations, improving the quality of work, reducing drudgery and operation costs, and more importantly, increasing the effective utilization of resources (Usaborisut, 2018).

Farm machinery serves as the backbone of modern agricultural activities, a range of tools and equipment essential for efficient crop cultivation (Challa, 2016). From hand tools and, devices pulled by animals to powerful tractors and mechanized harvesters, farm machinery plays a critical role in every stage of the farming process (Pandey, 2004). These machines not only reduce manual labor but also enable farmers to perform tasks with precision and timeliness, ultimately increasing productivity and crop yields. A machine requires an input of physical labor from a source of power; like a human, animal, or mechanical to operate. Asia, Africa, and South America place a high value on animal power. Lawrence and Pearson, R. A. (2002). It also helps for effective use of inputs such as High Yielding Variety (HYV) seeds, fertilizers, pesticides, and irrigation water to increase labor and land productivity. Farm labor is also decreased by the use of machines (Salawu *et al.*, 2023).

Shekhawat, J. S. (2021) also stated that agricultural machinery relates to the mechanical structures and devices used in farming or other agricultural activities. There are many types of such equipment, from small hand tools, and power tools to tractors and the countless kinds of farm implements that they tow or operate (Pandey, 2004). Diverse arrays of equipment are used in both organic and non-organic farming. Especially, since the advent of mechanized agriculture, agricultural machinery is an indispensable part of how the world is fed (Challa, 2016). Agricultural machinery can be regarded as part of wider agricultural automation technologies, which include more advanced digital equipment and robotics. Agricultural robots have the potential to automate conventional motorized machinery to perform the three essential agricultural operations namely; diagnosing, decision making, and performing with humans conducting diagnosis and decision-making based on observations and experience (Bechar and Vigneault, 2016)

The strategies of using Tractors and combine harvesters were first utilized in Ethiopia's south-eastern area, where there were huge numbers of commercial farmers, flat terrain, and two cropping seasons (ATA, 2018). These strategies resulted in a considerable reduction in harvest losses. During this time, the country's first tractor assembly facility was built, representing a significant advancement in agricultural mechanization (ATA, 2018). The Ethiopian government is currently promoting both machinery imports and the establishment of domestic machinery manufacturing firms that produce and assemble tractors, tools, and water pumps (Deribe *et al.*, 2021). In recent years, mechanization in Ethiopia has received increased attention, with a focus on both small- and large-scale farmers. As a result, a mechanization strategy has been devised by the Agricultural Mechanization Service Corporation (AMSC) under the Ministry of Agriculture (MOA), to increase the agricultural mechanization index from 0.13 kW/ha to 1 kW/ha by 2025, (Deribe and Getinet, 2021). The approach consists of four primary components: research and development, manufacture and import, distribution and promotion, and purchasing and use (Fentahun and Amdissa, 2018).

According to Akdemir (2013), the key agricultural mechanization challenges are small-scale and fragmented farming, unnecessary tractor and agricultural machinery selection, lack of expertise on effective and proper utilization, and tractor and agricultural machinery maintenance. Improper tractor selection might result in significant costs. For example, when a small size tractor is chosen for a vast area, it faces lengthy hours in the field, excessive delays, and premature replacement, whereas a huge tractor can result in high operational and overhead costs (Sumner & Williams, 2007). Thus, tractor selection is a complex problem in machinery management due to the wide range of machinery types, different available sizes, capital investment, competent technician labor requirement, timeliness, crop types, unbalanced crop rotation, and other related factors (Osman, 2011). Farmers, farms, or decision-makers must explore many strategies that integrate conflicting criteria to discover the optimal solution, Işık and Adalı, (2016).

To optimize production and boost profitability, the competitive agricultural market of today requires better utilization of resources and reduced operational costs. In the farming industry, machinery and equipment are substantial expenditures (Sumner & Williams, 2007). Larger machines, new technology, higher costs for parts and new machinery, and increased energy prices have all contributed to recent increases in machinery and power expenses (Peng *et al.*, 2022). The optimal farm power machinery components are obtained by matching the amount of tractor

power needed for a field activity, the implement size, and the number of tractors required to finalize field operations at the best time (Mandal *et al.*, 2020).

The key parameters to choose the best tractor capacity include identifying the main field activity of a machine with the highest draft force, estimating the amount of time available to complete the prioritized task, calculating the rate of work (ha/hr), calculating the size of the implement needed, calculating the soil resistance, estimating the required power at the drawbar and calculating the PTO power (Al-Sager *et al.*, 2024)

In Wonji Shoa Sugar Factory, there is no established system to select, measure, and enhance the operational efficiency of the farm machinery management system. The currently existing system and processes are purely traditional practices based on the indigenous knowledge and experience developed over the decades and have remained popular even now. Such practices are inefficient, and costly and result in very low productivity, Zewdie and Fanta, (2019). To alleviate such problems, traditional agricultural machinery management methods must be supported with new technologies and systems as the management of farming operations is currently rapidly changing toward a systems perspective integrating the surroundings in terms of environmental impact, public entities, and documentation of quality and growing conditions.

When we look at the selection of farm tractors in WSSF, the baselines for tractor selection like soil type, nearby repair facility availability, all types of costs and resale value, brand and model name, machine design, and spare parts availability are not analyzed well

Moreover; Wonji Shoa Sugar Factory tries to implement both preventive and corrective machinery maintenance strategies. However, their preventive maintenance practices are not beyond changing lubricants and fast-moving items. Both types of maintenance activities carried out at Wonji Shoa Sugar Factory are the same and lack scientific procedures.

1.2.Statement of the Problem

Large-scale mechanized agricultural fields always need the application of technologies, machinery, and implements (Guan *et al.*, 2023). The application of these technologies in most developing countries in Africa, including Ethiopia with scarce financial resources is limited by factors such as high investment costs, infrastructure, and knowledge preparedness (Cirera *et al.*, 2023). Moreover, due to the absence of scientific machinery management tools like Decision Support

Systems (DSS), the available machinery and implements have been used inadequately or excessively by firms (Relf-Eckstein *et al.*, 2019). Agricultural machinery selection is considered to be the most crucial part among other machinery management elements like machinery maintenance and replacement. A good farm machinery manager should have flexible machinery system combinations to work effectively in different soil, crop, and weather conditions (Talaviya *et al.*, 2020). The flexibility and adaptability of machinery combination systems for different factors often result in reduced ownership and operation costs and enhanced productivity.

The effect of different soil types on tractor draft force requirement, tractor fuel consumption, Overall Energy Efficiency (OEE), and Power Utilization Ratio (PUR) is not well reported by previous studies. Soil types, physical qualities, and field conditions vary per agroecological location. Conducting research in specific agroecological zones is critical if full and genuine performance data for farm machinery selection is to be obtained (Dayou *et al.*, 2018). Moreover, improper machinery selection and matching hurt its maintenance costs and economic life. Properly DSS-supported selected and matched machinery serves a relatively longer time with significantly reduced cost and better efficiency (Thomas and Weiss, 2020).

Tractors in the WSSF and other agro industries of Ethiopia fail before their expected service life due to a poor maintenance plan and insufficient maintenance facilities. Using tractors for several years after their economic life due to a lack of machinery replacement policy and plan is an additional obstacle that the industries are now confronting. Poor machinery maintenance and cost data records were also identified as bottlenecks that needed to be addressed and resolved. In WSSF there are more than 10 different makes and models of tractors with power ratings ranging from 60 to 400 hp. A large number of this machinery were seen out of use and became scrap. Other machineries are also failing frequently and have high downtime. When a machine fails, the company is used to substituting it by borrowing other machines from another nearby sugar factory, especially during peak field operation periods. This type of practice always results in unnecessary costs incurred due to the usage of machine time over the recommended range.

Therefore, this study proposed to first evaluate the current agricultural machinery management system of Wonji Shoa Sugar Factory and develop a decision support system (DSS) to improve farm machinery management system and bring productivity improvement to the factory.

1.3. Objectives of the Study

1.3.1. General Objective

The main objective of this study was to improve tractor- implement management system of Wonji-Shoa Sugar Factory by using Decision Support System (DSS).

1.3.2. Specific Objectives

The specific objectives of the study were to:

- ✓ Evaluate the current farm tractor selection practices of WSSF
- ✓ Appraise the current farm tractor maintenance and replacement strategies of WSSF.
- ✓ Establish a farm tractor-implement selection system using DSS for the existing farm machinery selection (matching) practices of WSSF.
- ✓ Carry out the economic analysis of the established system (DSS) against the existing one

1.4. Significance of the Study

This study has great importance in showing better farm machinery management practices in agricultural enterprises like sugar factories where so many types of agricultural tractors are used to perform different field activities for the company. The outcome of this paper will help, firstly, Wonji-Shoa Sugar Factory to pinpoint major constraints and challenges in the farm machinery management system and hence to devise strategies to improve the system and reduce their machinery ownership and operating costs. Secondly, the study will provide a starter springboard for coming researchers and academicians who want to make further investigations in the study area. Thirdly, this research will be important for concerned government bodies in a way that the policymakers will use the findings for planning similar future projects regarding farm machinery management systems

1.5. Delimitations and Limitations

Wonji-Shoa Sugar Factory has a variety of large number farm machinery including high horsepower heavy-duty bulldozers, grab loaders (used for loading manually harvested sugar cane on carts), different capacity wheel tractors, implements, and pumps. However, this study focused on the study of management practices of farm tractors and implements used only for tillage operations (land preparation). Tillage is the base operation in agricultural systems and its energy

represents a considerable portion of the energy utilized in crop production. In many cases, typical soil tillage including ploughing consumes 25–55% of the total fuel required for the complete technological process (Šarauskis *et al.*, 2017).

Financial constraints to publish papers, and participate in international conferences and symposiums are among many problems encountered while conducting this study.

1.6. Organization of the Dissertation

The research presented in the thesis comprises three stages: evaluation of the current farm machinery selection practices of Wonji-Shoa Sugar Factory, evaluation of the current farm tractor maintenance and replacement strategies of Wonji-Shoa Sugar Factory, and development of a farm machinery management system that will improve the drawback of the existing farm machinery practices of WSSF and evaluate the impact of the newly developed system on the overall operation cost saving and productivity of WSSF's farm machinery department. The study is conducted to achieve the predefined research objectives, and it is reported thoroughly in the dissertation.

The study's activities are divided into four chapters. Chapter one is an introduction to the thesis, providing the readers with an overview of the research work. The chapter begins by summarizing the importance of farm machinery management and its effect on the overall productivity of agroindustry. The relevance of this study for Wonji Shoa Sugar Factory is also discussed in this chapter. The chapter also defines the problem statement, research objectives, significance of the study, and delimitation and limitations of the study. Chapter two is a comprehensive literature review that presents critical findings from previous research and identifies research gaps related to farm machinery selection, maintenance, and replacement strategies. Chapter three focuses on the research methodology and materials. The chapter includes actual field experimentation with four different field activities namely, subsoiling, plowing, harrowing, and furrowing in different soil types. The development of a decision support system (DSS) for farm machinery selection is also included here. Chapter four presents the results and discussion part of the study. Finally, the conclusions and recommendations of the study. The conclusion provides the overall conclusions of the research work, summarizing the findings from each chapter. The recommendation part provides recommendations for future work. Finally, the dissertation includes references and necessary annexes.

CHAPTER TWO: LITERATURE REVIEW

2.1. Agricultural Mechanization

Although there are various definitions of agricultural mechanization, (Rai, 2011) defined it as all-encompassing levels of farming and processing technologies, from basic hand tools to more sophisticated and motorized equipment. It covers any tools, implements, and machinery that can be powered by human, animal, or motorized sources. Mechanization facilitates and reduces hard labor (drudgery), alleviates labor shortages, boosts farm labor productivity, boosts agricultural productivity and timeliness, improves resource efficiency, improves market access, and contributes to mitigating climate-related hazards (Sims and Kienzle, 2017). Increased agricultural mechanization accessibility can help Africa's agricultural and economic development (Diao *et al.*, 2016). Farm mechanization is critical for improving land and worker productivity.

Agriculture productivity in the smallholder sector would continue to stagnate or even drop unless suitable mechanization is implemented, owing to increasing labor constraints (Rai, 2011). Agricultural mechanization is a multifaceted process. From identifying farm operations that should be mechanized and locating, adapting, and/or manufacturing suitable machinery, to providing an enabling and supportive environment and policies (such as markets, finance, and capacity building) along the full value chain (Baudron *et al.*, 2015),

2.2. The Concept of Farm Machinery Management

Agricultural machinery management is the part of farm management that deals with the optimization of the equipment phases of agricultural utilization and production (Yousif *et al.*, 2013). It is concerned with the efficient selection, cost analysis, power requirements, operation, reliability, maintenance, and replacement of machinery (Mohammed *et al.*, 2018). The selection of power units and agricultural machines for farming operations can lead to profit or loss of all or part of the farm enterprise (Wenging *et al.*, 1999). Luo *et al.*, (2016), also stated farm machinery management is an integral but vital aspect of a successful agricultural mechanization scheme irrespective of its scale of operation. Effective machinery management implies effective decision-making and implementation in all aspects of selecting operation, making the right choice on equipment, ownership, appropriate power-implement match, operation financing, and controls on machinery utilization for optimum output. Today's agricultural market is rapidly growing in the face of dwindling oil reserves and ailing capital markets. As such, agriculture becomes

more competitive and requires operating cost minimization and better resource management to maximize profit.

2.3. Farm Machinery Management Procedure

This procedure deals with machinery (implements and tractors). It uses the intended operations, and area to be covered, and implement type that had been specified in the crop production procedure. It consists of 3 sub-procedures; machinery selection, power requirement, and machinery costs. The machinery selection sub-procedure computes the size and the number of implements and power units required to complete field operations during a specific period by computing effective field capacity (ha/h). The required input data include speed of field operation, field efficiency, available working days, available working hours per day, type of soil, and type of crop to be grown. The machinery power requirement sub-procedure determines the required drawbar power (kW), tractor PTO power (kW), and fuel consumption (L/h) for the selected implement. The required input data includes unit draft (kn/m) and soil condition factor (Yousif *et al.*, 2013). The general procedure for farm machinery management is shown in Figure 1. 2. Farm machinery costs refer to the ownership and operating costs of the machine. Operating costs are maintenance costs, lubrication cost fuel cost and labor costs, etc. Operating costs vary depending on the extent the machine is used. In contrast, ownership costs like depreciation cost, tax, housing costs, insurance costs, etc are constant costs despite machinery usage time. Farm machinery operating costs are also used as a basic input to determine their replacement age.

2.4. Farm Machinery Selection

Gindo and Kolhe, (2021), discussed studies of tractor and crop parameters combinations for the optimal selection of farm machinery. They found that wrong decisions on farm machinery investment and machinery selection process will hurt the profitability of the companies, whereas scientific selection and proper utilization of agricultural machinery will enhance profitability by reducing downtime caused by machinery breakdowns, power losses, and implement-tractor mismatching, which can be achieved by performance and cost of farm machinery utilized. They also reported that several kinds of literature focus on tractors, implement variables, and cost parameters by giving less attention to crop parameters. Crop parameters, like; start date, hectare coverage, hours, and soil properties, need further study to get additional valuable data for the selection of optimum size tractor and implement to enhance production efficiency at lower costs.

Yousif *et al.*, (2013), studied a crop-machinery management system for field operations and farm machinery selection. They developed a computer system for farm management and selection of required farm machinery to perform field operations in time for crops grown in rotations. They used Excel and Visual Basic software to develop the program for 3 field operations (seed-bed preparation, seeding, and weeding operations) and 3 farming systems (zerotillage, conventional, and heavy machines farming systems). Six farm implements were used for this study namely, wide level disk, disc harrow, chisel plow, row crop planter, inter-row cultivator, and sprayer. The system they developed estimates the size and number of machines, power requirement, and fuel consumption for the implements and operations. The implement selection sub-procedures of their computer system using parameters like speed of field operation, field efficiency, available working days, and available working hours per day. The power (tractor) selection sub-procedure uses the inputs, unit draft (kN/m), and soil condition factor.

Akinnuliet *al.*, (2014), developed a model for farm tractors and implements selection and optimum utilization based on the concept of obtaining the optimum width of a machine using the power of the tractor and implement and economic optimization method to predict the size of the tractor and implement that can be required to complete the farm operations during a specific time. They reported that the model was found sensitive to tractor travel speed, soil conditions, and cultivable area and not sensitive to purchase price. Siemens *et al.*, (1990) studied a farm machinery selection and management program and developed a program written in the C programming language to run on an IBM-compatible personal computer. The program's input data consists of a list of desired field operations, each with a start date, acres, and hours per day. Other inputs include crop yields, planting and harvesting deadlines, labor availability, and cost, and specific economic data. The program schedules field operations for various machinery sets or a specified set of machinery and computes total machinery-related costs, including machine, labor, and timeliness costs.

Akerele and Nathaniel (2014), developed a mathematical model for selecting machinery. The model was built around the idea of getting the optimal width of a machine by combining the physical power of the tractor and implements with an economical optimization method. The model was created to predict the size of tractor and implements needed to complete farm operations in a specific time frame, to determine tractor and implement compatibility by properly matching available tractor power with the optimum width obtained, and to compute the field

time required for a machine to complete a specific operation, field capacity, and fuel consumption. As a result, the proposed model can be utilized to assist decision-makers in selecting the best tractor machine, implement size, and machinery fleet scheduling.

Sogaard and Sorensen (2004), also developed a model for the Optimal Selection of Machinery Sizes within the Farm Machinery System to support the process of choosing the optimal level of farm mechanization in terms of technical capability. The optimization model was a non-linear programming model implemented by using the programming software suite General Algebraic Modelling System (GAMS) based upon a least-cost concept involving all expected fixed and variable costs (including timeliness costs) for a particular farm size and crop plan. The output from the model was the sizing of each machine, and also the tractor power, and the number of tractors required. According to their report, machinery selection is based upon a farm-oriented matrix involving various types of constraints, such as available man-hours, available machine- and tractor-hours, timeliness and workability of operations, the agronomic window of operations, and sequence of operations.

Natsis *et al.*, (2001), studied farm machinery selection to minimize the cost of agricultural operations by employing linear programming as a mathematical tool for providing the right selection of farm machinery, based on minimizing machinery operational costs, taking into consideration factors like size of the farm, the distribution of crops and crop rotation, cultural practices used throughout the year, farm machinery technical data and consumption costs for each operation. They found 400 ha of agricultural land, allocated for the cultivation of 4 different crops (wheat 200 ha, corn 100 ha, alfalfa 50 ha, and beans 50 ha), considering four different tractor sizes (44, 56, 76, and 148 kW), they found that optimum agricultural machinery selection would include four 76 kW tractors and two 44 kW tractors. Zhou *et al.*, (2020), studied farm machinery use and maize yields in China. They analyzed factors accounting for selection bias and heterogeneity. They examined the potential heterogeneous effects of farm machinery use on maize yields, using an unconditional quantile regression model and survey data from China by employing a control function approach to address the selection bias issue associated with farm machinery use. The empirical results of their findings show that the use of farm machinery significantly increases maize yields for all the selected quantiles (except for the 80th quantile); the

low-productive farmers tend to benefit more from farm machinery use relative to their high-productive counterparts; and farm machinery use reduces the inequality and variability of maize yields.

2.5. Farm Machinery Selection Parameters

Agricultural tasks can be accomplished by several sets of machinery from various brands, each with its size, price, and interchangeability. Machines with varying productivity result in uneven work time and expenditures. Because mechanized works and their implementation conditions differ, each set of machines will be more effective or fully unprofitable when executing one agricultural operation and less effective or entirely unprofitable when performing another. When first scheduling the implementation of a complex of works, sets of machines with a specified composition of MT units available to the firm might be assigned to specific operations in certain agro-technical periods. The initial strategy for tackling an optimization problem, particularly a nonlinear one, strongly influences the result of model computations (Toba *et al.*, 2020). In this regard, the task is to determine the distribution of mechanized works based on methods of execution (sets of machines) within a given fleet (possibly with the option of replenishment), such that all works are completed in the best possible way during the planned period by the established optimization criteria. A technically and economically feasible method of carrying out a given list of tasks should be identified.

A company's farming requirements should be taken into consideration when selecting farming machinery and equipment. It provides agriculturalists with several advantages, including lower operating costs, increased profit margins, and the ability to produce more crops with less labor. The soil and climatic conditions have an impact on the operation of every machine used in farms. Therefore, when choosing the appropriate type of machinery, factors such as land size, soil type, the availability of a service center or repair facility, the resale value, brand and model name, machine design, ease of operation, and human comfort should be taken into account for better outcomes. (Edwards, 2009).

2.5.1 Machine field capacity

Farm machinery performance efficiencies are generally measured by the rate at which they carry out field operations as well as the quality and quantity of output. According to Gbadamosi and

Magaji (2003), machine field capacity is the rate at which a machine can cover a given field operation within a given time limit. Effective capacity is measured in hectares per hour, and the indicators involved are the implement operation width and working speed with the allowance for time loss, in turn at the end of the field, adjustment, and servicing of the machines. Machine/implement efficiency indicates how well a machine can perform its functions. According to Odumaet *et al.*, (2014), an experienced farmer is usually aware of the effective and efficient operation of his/her farm machinery because poor operation or improper utilization of the equipment can result in significant operating losses, reduced production, or total loss of money/productivity.

Sale *et al.* (2013) reported that capacity performance is a factor in how a machine completes a task within the time limits that are allowed. They maintained that the capacity performance of an agricultural machine gave the answers to the question “Will the machine complete the job or task within the allowable constraints of time under a variety of field conditions” or is it a poor investment regardless of its costs? The tractor-drawn implements used for planting, harvesting, and preparing seedbeds while preserving soil moisture, creating good soil aeration and the necessary environmental conditions for crop growth, and protecting the soil against erosion and nutrient losses should all be performed satisfactorily with minimal crop damage.

2.5.2 Theoretical field capacity

Siemens and Bowers (1999), defined the theoretical field capacity of a machine as maximum output at a given speed, provided it is operating at full width. Ajit K.*et al.*, (2006), also stated that when the field efficiency is equal to 1, or when the machine is using 100% of its width without interruption for turns or other idle time, the phrase theoretical field capacity is used to describe the field capacity. The working width of cultivators and other row-working devices is determined by multiplying the number of rows worked in each pass by the row spacing.

2.5.3 Effective field capacity

Odumaet *et al.*, (2014), reported that the actual output produced by a machine is known as its effective field capacity. It depends on the percentage of the machine's width that is being used, the travel speed, and the amount of time spent out in the field. Blockages, working in places like headlands more than once, adjustments, checks, and small repairs all cost time; daily servicing

needs like lubrication are not included. The machine's real effective working width and rate of operation are used to calculate the effective field capacity.

2.5.4 Field efficiency of farm machinery

Torres and Villegas (1993) and ASABE Standards EP496.3 (2006), expressed that the ratio of a machine's actual productivity to its theoretical maximum productivity is known as field efficiency. Field efficiency takes into account field features, time lost due to operator capability, habits, and operating policy, as well as the machine's potential operating width. Field time and field efficiency do not include time spent traveling to and from a field, significant repairs, routine maintenance, or regular servicing tasks. For a given machine, field efficiency is not a fixed value; instead, it depends on the size and shape of the field, the way it is used, crop yield, moisture, and crop conditions. Turning and idle travel, handling of materials (seed, fertilizer, chemicals, water, and harvested material), cleaning clogged equipment, machine adjustment, lubrication, and refueling (aside from daily service), and waiting for other machines are typical factors that account for the majority of time lost in the field.

2.5.5 Crop details

According to Yousif *et al.*, (2013), crop details and sound implement selection criteria should be considered, as the input for the development of a computer system, which allows the user to choose specific crops and required field operation suitable for the selected crop. The design may be possible for various combinations of crops in the computer system. The selected designed options of the computer system for four crop combinations considered were sorghum, sesame, sunflower, and cotton. The system deals with three operations; seedbed, seeding preparation, and weed control; via six implements namely; chisel plow, disk harrow, wide-level disk, rowcrop - planter, inter-row cultivator, and sprayer.

2.5.6 Selection of tractor capacity

There is literature on the selection of optimal implement and tractor combinations for conducting a specific operation or a limited number of operations for a particular farm. Chancellor (1969) created a model for determining the optimal size of a farm tractor. He also applied his model to single and multiple tractor farms and concluded that there exists an economically optimum sized

tractor for single tractor farms and an economically optimum level of rated horsepower per hectare for multiple tractor farms, which applies to tractors of all sizes.

Singh and Kawade (2004) describe the various tractor selection factors. According to them, tractor selection is based on timeliness in operation, horsepower necessary, custom hiring, fuel efficiency, purchase price, special technical features, after-sales service, and resale value, and they also conducted a study on tractor availability in India. They calculated the horsepower range for a 50-acre farm and recommended a tractor with 30-35 PTO HP. Mishra and Dhakad (2004) conducted a study on the optimum sized tractor at some selected farms of Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Jabalpur, and they reported that excess tractors on the farm can be effectively used for crop harvesting by utilizing their power with matching equipment such as tractor driven combine. Concerning farm size, cropping area, cropping pattern, cultural techniques, yield, prevailing trends, and equipment purchase price. The tractor should have enough power to execute the farm activities. Two separate models are used to determine the best tractor size for a farm. They are Hunt's (1983) model, which incorporates transportation activities, and Chancellor's model, which does not.

According to William (2015), when determining reasonable field efficiency for a tillage operation, the effectiveness of the prime mover (tractor) in converting engine power to drawbar power must be considered. There is nothing that can be done to reduce power losses from the engine to the axle. Although proper maintenance can improve the efficiency of converting fuel energy into axle power, little or nothing can be done to reduce energy losses. When considering losses from the farm tractor axle to the drawbar, however, energy is typically lost to create traction force applied to the tool, causing the implements to move through the soil. It is critical to understand that drawbar force or power is the product of pull force and speed, with an infinite number of pull force and operation speed combinations capable of producing the same power. Wheel tractors are designed to operate at higher speeds (greater than 8.0 km/h) and with lower drawbar forces. Track layers should be considered if low forward speeds (less than 5.5 km/h) and large pull forces are to be used regularly. The typical farm tractor efficiencies are shown in Table 2.1. The tractors all had identical crankshaft and PTO powers of 100% and 85%, with maximum drawbar powers ranging from 50 to 75%.

Table 2.1: Typical tractor types and their field efficiency

Tractor Type	Rated crankshaft Power (%)	PTO Power (%)	Drawbar Power(maximum), %	Drawbar power(normal) %
2WD	100	85	50	40-45
FWA	100	85	55	45-50
4WD	100	85	60	50-55
Track	100	85	75	65-70

(Source, William 2015)

2.6 Farm Machinery Maintenance

Productivity is a key strategy for companies to stay competitive in a continuously growing global market. Increased productivity can be achieved through increased availability. Maintenance of production assets is a prerequisite to uphold a high availability. It was reported that as much as one-third of the total maintenance cost was spent unnecessarily due to certain circumstances. These circumstances are e.g. bad planning, overtime costs, poor usage of work order systems, bad use of preventive maintenance, etc (Bengtsson, 2004)

Tomczyk, (2015), reported that an efficient repair and maintenance strategy, which technically avails machines and devices in production processes, has a significant impact on the improvement of farm performance and efficiency in agricultural production processes. Nowadays, with the use of highly sophisticated and expensive agricultural machinery with high structural and quality parameters, users may significantly influence the increase of the degree of their use through the optimization of time devoted to efficient repair and maintenance activities. There are many different types of maintenance strategies, but the most common types of machinery maintenance strategies are, preventive maintenance, condition-based maintenance, predictive maintenance, and Emergency maintenance as depicted in Figure 2. Preventive maintenance is a significant component of the maintenance procedure. It is a vital aspect for minimizing maintenance costs as well as minimizing downtime.

Myaloet *al.*, (2021), studied the feasibility and efficiency of agricultural machinery maintenance. They found that the greatest impact on machine uptime and performance is the timely and high-quality maintenance. They also reported that the main contradiction is inherent in the system of maintenance and use of machines, in the coincidence of the timing of their performance: the more time is spent, the more maintenance operations need to be performed. As a

result, during busy periods of fieldwork, to ensure high operating time, to the detriment of prevention, the mechanic has to virtually eliminate only the consequences of failures, which leads to their increase, in machine productivity and operating costs.

Mishra and Satapathy (2023), studied the Reliability and maintenance of agricultural machinery by MCDM approach. Their study included the evaluation of farmers' knowledge of the maintenance activities of farm-related machinery by using a questionnaire survey in Odisha (India) and found that the maximum number of farmers i.e., 135 (93.75%) out of a total of 144 respondents were found of requiring further guidance for the effective maintenance of tractors in particular. They used the "Step-wise Weight Assessment Ratio Analysis" method to rank the MPs for tractors based on their prioritization, and they found that checking for general conditions ranked first followed by checking for batteries; checking for all fluid levels; and checking for tires and wheels; respectively. Similarly, based on the prioritization of all concerned sub-criteria of all the criteria of MPs for tractors, the corresponding ranking in descending order included checking for secure held-down batteries; checking for broken or cracked parts; checking for clean connection of batteries; checking for a good level of electrolyte in batteries; checking for lug nuts for tightness; followed by checking for leakages or damaged hoses; checking for proper inflation of tires as recommended in operator's manual; checking for loose bolts, nuts, and parts; checking for engine oils; checking for the functioning of all the lights and flashers; checking for cuts and breaks in the sidewalls or tread of tires; checking for fuels; checking of steps for cleanliness of any mud or greases; checking for coolants; checking for hydraulic fluids; and finally, checking for other fluids; respectively.

Maintenance is classified as either preventive or corrective in classical theory. Corrective maintenance, sometimes referred to as unplanned or failure-based maintenance, is carried out when agricultural machinery breaks down or any component fails. There may be a need for immediate part replacement, which will cause unplanned downtime (Ben-Daya and Duffuaa, 2009). Because corrective repair is costly, agricultural machinery operators would prefer to avoid utilizing it whenever possible.

Routine maintenance is the most basic type of planned maintenance, Figure 2.1, but it is quite important. It is performed at regular intervals, as the name suggests. Periodic checks of relevant regions are required. Such checks are performed on an hourly, daily, weekly, and monthly basis,

or as advised by the manufacturer. Routine maintenance lowers fuel costs and increases equipment life. Readings from such checks could be accumulated in a maintenance record over time to provide a behavior history of the equipment. Examples include washing and cleaning, filing the distributor cap, changing the oil, topping up the battery electrolyte, lubrication, inspection, and minor adjustments to pressure, flow, and tightness, among other things (Bello, 2012)

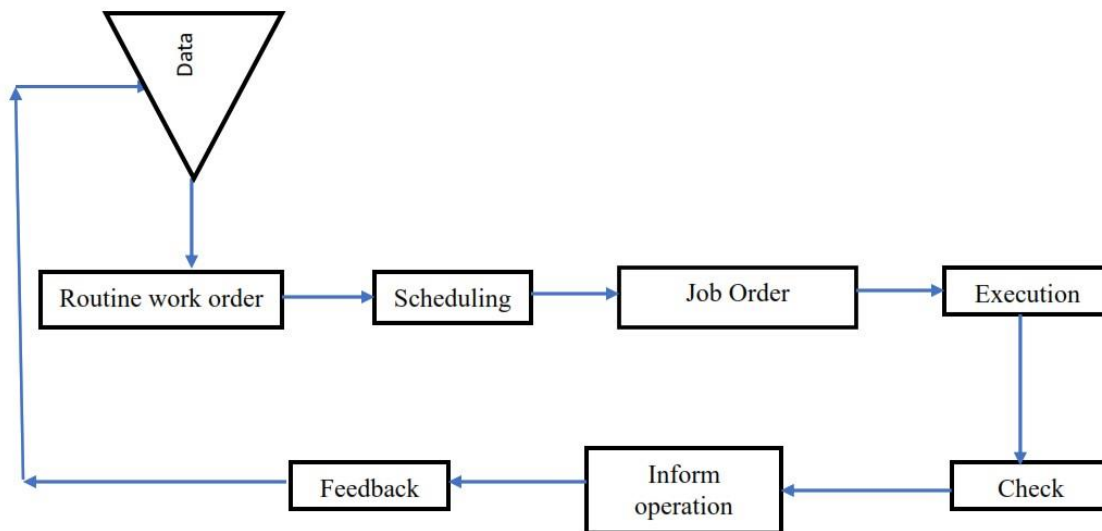


FIGURE 2.1. Block diagram for routine maintenance (Bello, 2012)

Khodabakhshian, (2013), conducted a review of the maintenance management of tractors and agricultural machinery for preventive maintenance systems. He stated that Successful agricultural productivity depends heavily on the maintenance of agricultural equipment. Agricultural productivity seeks to ensure both the availability of machinery and associated equipment for cultivation operations as well as the safety of such operations. It also represents a significant expense for agricultural businesses. Due to the rising competitiveness in agricultural output, maintenance must be improved to save costs while maintaining operational safety

Afsharnia *et al.* (2014) utilized a regression model to predict the annual repair and maintenance expenses of tractors based on failure rate. The findings revealed that increasing the failure rate will increase annual repair and maintenance expenditures. Najafi *et al.* (2015) examined the dependability and availability of the 7000 series chopper harvester for sugarcane at the "Hakim Farabi agro-industry" in Iran. They employed the "ReliaSoft Weibull ++ 6 program" to estimate the parameters of various probability distributions, including the Weibull, exponential, and

lognormal distributions. The feed rollers and hydraulic subsystems were found to be crucial in terms of dependability, while the wheels subsystem and hydraulic subsystem were assessed to be critical in terms of availability.

Tsai *et al.*, (2001), studied Optimizing preventive maintenance for mechanical components using genetic algorithms. They presented periodic preventive maintenance (PM) of a system with deteriorated components by considering two activities, simple preventive maintenance and preventive replacement, which are simultaneously considered to arrange the PM schedule of a system. They found that simple PM is to recover the degraded component to some level of the original condition according to an improvement factor which is determined by a quantitative assessment process. According to their study, preventive replacement is to restore the aged component by a new one. The degraded behavior of components is modeled by a dynamic reliability equation, and the effect of PM activities on the reliability and failure rate of components is formulated based on the age reduction model. While scheduling the PM policy, the PM components within a system are first identified. The maintenance cost and the extended life of the system under any activities-combination, which represents what kind of activities are taken for these chosen components, are analyzed for evaluating the unit-cost life of the system.

According to Lie and Chun (1986), CM is classified as minimum repair (1C) or corrective replacement (2C). 1C-maintenance does not affect system time and restores system reliability when it has failed. 2C- maintenance resets the system time to zero, and the dependability curve is the same as that of a new system. Simple preventive maintenance (1P) and preventative replacement (2P) activities are likewise classified as PM activities. 1P maintenance brings the system's reliability up to date. 2P maintenance is similar to a corrective replacement in that it restores the reliability curve to its original state, but it only occurs in the system state. Figure 2.2 depicts a system's dependability behavior under various maintenance scenarios.

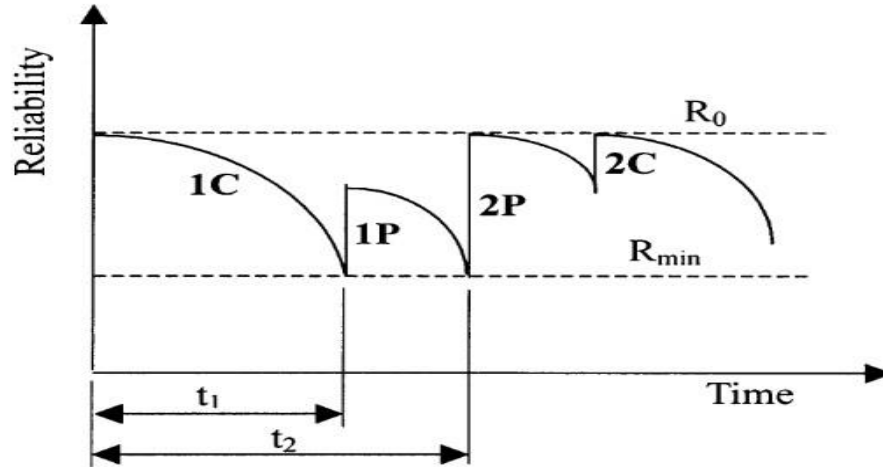


FIGURE 2.2: Reliability changes of a system under various maintenance types (Lie and Chun,1986)

Ben-Daya and Duffuaa (2009), also reported that the objective behind preventive maintenance (PM) is to either repair or replace components before they fail. Preventive maintenance includes periodic and condition-based maintenance. Periodic maintenance may be done at calendar intervals, after a specified number of operating cycles, or a certain number of operating hours. These intervals are established based on manufacturers' recommendations, utility, and industry operating experiences. But decreasing breakdowns in this way comes at the cost of completing maintenance tasks more regularly than necessary and not exhausting the full life of the various components already in service. An alternative is to lessen major component breakdown and system failure with condition-based maintenance (CBM) (Pedregal *et al.*, 2009).

Mobley (2002) also added that machine and equipment maintenance and repair are carried out using one of three strategies: reactive maintenance, preventative maintenance, or predictive maintenance. He further noted that reactive maintenance involves running machines and equipment until a flaw or malfunction arises, which is then repaired. Maintenance is not planned or scheduled with this technique, and components are used as long as possible to reduce spare part costs while making equipment subject to downtime. Preventive maintenance involves replacing equipment before a malfunction occurs.

The utilization interval is often set in terms of operational hours, based on experience or manufacturer-specified maintenance intervals. As a result, components may be replaced before they reach the end of their useful life, raising expenses when compared to reactive maintenance.

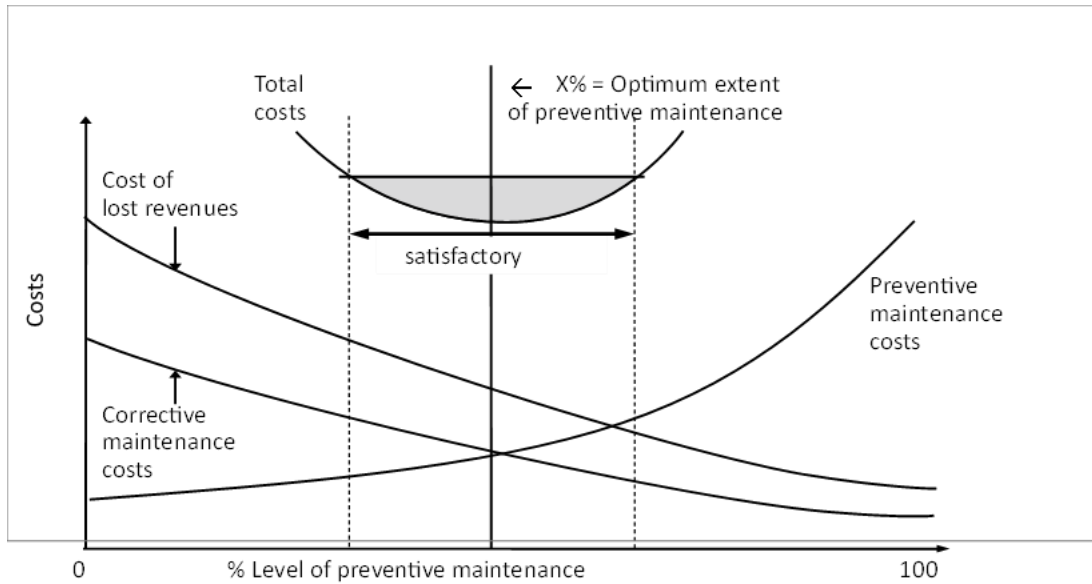


FIGURE 2.3: Total costs of maintenance, depending on the degree of prevention (Mobley, 2002)

Preventive maintenance, on the other hand, avoids or decreases downtime since maintenance tasks can be scheduled before a defect develops. Repairs are scheduled in predictive maintenance based on the condition of a machine or component. Machines or components are used for as long as feasible but are changed before a problem is detected (Nadjet *et al.*, 2016). Predictive maintenance enables the optimal scheduling of maintenance tasks while also lowering spare part prices. Importantly, each maintenance and repair method may be the most cost-effective way to maintain a machine or component (Figure 2.3)

2.7. Farm Machinery Costs

In agriculture, machinery is a significant cost element. Machinery costs represent 20 to 50% of overall costs in wheat production in France, Germany, and Canada. Accurate machinery cost information is thus a critical input for farm management. Depreciation, interest rate, insurance, housing, fuel costs, and repair and maintenance costs are all part of the machinery costs. Except for depreciation and repair and maintenance charges, all of these sub-cost components are simple to compute. In terms of depreciation, studies compare various functional forms (Wu and Perry 2004 and Wilson 2010). Dumler *et al.* (2003) and Wilson and Tolley (2004) evaluate the

accuracy of several depreciation methodologies with prices of used tractors from auction results, and dealer or trade marketing. Wilson and Davis (1998) offer an approach for estimating hourly depreciation and interest charges for tractors based on an estimated depreciation function.

Pishbin (2014), developed a mathematical model to Estimate Repair Costs of Tractors. He stated that the costs of repair and maintenance of agricultural machines and estimating it led to more accurately determining the extent of profit rates that have been received and it is important in determining the optimal economic life of cars. His study aimed to determine the relation between the hours of cumulative operation and cumulative repair and maintenance costs and determine the estimated coefficients of mathematic equations to calculate these costs for the three customary tractors in Iran's Fars province that involves: 1- John Deere 4955 2- John Deere 3350 3- Massey Ferguson 285. He did the fit regression for the final data by using the method of least squares and F tests. Six mathematical models including linear, exponential, inverse, multiplicative quadratic, and third degree for preparation of optimization models and estimating the costs to break down the tractor models were estimated. The results of this study showed that the multiplicative model provides the best fit and performance in predicting the costs even for different tractor models and also for all series tractors. The conclusion from the study indicated constants of mathematic models to estimate the repairing cost of any kind of tractor and for all series of tractors were calculated.

Lips (2017), used a farm survey in Switzerland to investigate repair and maintenance costs for nine agricultural machine types (wagon, harrow, rotary harrow, seed drill, single seeder, field sprayer, solid manure spreader, hydraulic loader, and slurry tanker). Their analysis demonstrates a large influence of annual consumption by assuming complete utilization of the expected service life, represented in work units such as hectares or barrels. The combination of high annual utilization and short lengths of service measured in years reduces accumulated repair and maintenance costs. According to his study, there is some evidence of cost reduction over time despite the restricted comparison of the acquired results for repair and maintenance costs with the literature.

Vafaei et al. (2008) developed a mathematical model for estimating the repair and maintenance costs of New Holland TM155 and Valtra 8400 tractors in the Markazi and Fars Provinces. They

claimed that cost estimation of agricultural machinery repair and maintenance is highly significant for replacement and net return of machinery management, and it is an important factor in presenting a mathematical model for the cost prediction of repair and maintenance. They employed a questionnaire that included information about the drivers as well as technical data about the tractors.

According to ASABE Standards EP496, (2006), agricultural machinery costs can be classified into two main groups: annual ownership costs also known as fixed costs, which happen regardless of how much the machine is used, and operating costs or variable costs, which change in direct proportion to how much the machine is used. Before the machine is sold or worn out, the real cost of these expenses cannot be determined. However by applying a few assumptions regarding equipment life, annual use, and fuel and labor prices, the expenses can be roughly calculated.

2.7.1. Farm machinery fixed costs

Langemeier and Taylor (1998), reported that the annual fixed costs can be computed based on the relationship between fixed cost items and the new value of a machine. Fixed costs are not dependent on how a machine is used. Depreciation, interest (opportunity cost), insurance, taxes, and housing were highlighted as the cost items. Depreciation is a way to quantify how much a machine loses value over time. By deducting the machine's trade-in (or salvage) value from the purchase price, the total amount of depreciation is determined. The estimated worth of the machine at the end of its useful life or trade-in value is known as the salvage value. When an item's worth has dropped to one-third of its initial purchase price, it is said to have reached its maximum life. There are numerous ways to estimate depreciation. Various computational techniques are utilized depending on the goal.

2.7.1.1 Depreciation

There are numerous ways to estimate depreciation. Various computational techniques are utilized depending on the goal (Ronald *et al.*, 2012, Witney, 1988, and Norvel, 2007) using the Straight-line Method. According to their report, it is common practice to calculate depreciation using a straight-line method. For each full year of an item's life, this simple method provides the same annual depreciation.

The straight-line approach of estimation of depreciation has the benefit of being easy to understand and use. It works well for calculating costs throughout the course of a machine's lifetime (Witney, 1988). The amount that must be set aside annually to replace the machine with an identical model after the ownership period can then be viewed as the annual depreciation charged. Naturally, this is based on the supposition that the value of money stays constant, the depreciation fund is not reinvested, and interest and inflation are not taken into account.

2.7.1.2. Interest

Different studies (Ajit *et al.*, 2006, William, 2009, and William, 2015) show that money used to buy a machine can't be used for other profitable endeavors. As a result, the interest earned on the funds invested in the machine is included in the cost of ownership. It is known what the interest rate will be if a loan is used to buy the machine. When a machine is bought outright with cash, the applicable interest rate is the rate that would have been available if the money had been invested rather than utilized to buy the equipment. The amount of the machine's residual value in any given year serves as the principal upon which interest is calculated. Interest charges may be calculated so that the outcome will be constant or equal to yearly charges for the duration of the machine. Interest charges are typically estimated when operational costs are determined. The interest rate may fluctuate, but it often falls between six and twelve percent.

2.7.1.3. Tax

According to Goense (1995), taxes vary by nation, and in the same nations, tractors and self-propelled vehicles may be subject to annual registration plate fees. The purchase price must include VAT and sales taxes. The tax paid on farm machinery can be calculated as a percentage of the purchase price, according to ASAE Standard EP496.2, (2000). The annual tax is expected to be equivalent to 1% of the machine's purchase price if the real numbers are unknown. The expected cost is one to two (1-2%) of the machine's initial purchase price at the start of the year.

2.7.1.4. Insurance

On more expensive equipment, insurance policies are typically carried out, whereas, on simpler, less expensive devices, the risk is typically believed to be also less. According to Bowers (1992), the annual fee for risk or insurance is estimated to be between 0.25 and 0.5 percent of the residual

value. The cost of insurance should be determined by a machine's remaining value. If insurance prices are unknown, 0.25 percent of the machine's purchase price represents an acceptable estimate of annual insurance expenditures. Without insurance, the owner of the machinery assumes the risk of an accident, which is typically close to the insurance premium. If the true insurance rate is known, a different option is employed in the calculation below (Williams, 2009).

2.7.1.5. Housing cost

Maintenance of tools and machinery with proper shelters will lead to fewer repairs, reduced mechanical part deterioration, and less weathering (ASAE, 1999). There is insufficient evidence to demonstrate the economic benefit of protecting farm equipment. However, offering shelter is frequently linked to better machine care and maintenance, which can lead to a machine's longer lifespan, improved look, and higher resale value. If shelter is offered, the price of that shelter can be determined. Without shelter, there would likely be a financial cost in terms of shorter equipment life and worse resale value. Housing costs are predicted to account for 0.75 percent of the purchase price if the actual related data are unknown (ASABE Standards, 2006).

2.7.1.6. Total annual ownership costs

Multiplying the machine's purchase price by the ownership cost percent yields a straightforward calculation of the total annual ownership expenses ASAE Standards, (2003).

2.7.1.7. Capital recovery of farm machinery

According to ASAE Standards EP496.2 (2000), the amount of money that would need to be saved annually only to repay the value lost to depreciation and meet interest expenses is known as capital recovery. A Capital Recovery Factor, or CRF, is a formula used to calculate the capital expenses of ownership, which takes the time value of money into account. The machine's investment is multiplied by the appropriate CRF to produce a series of equal payments over its lifetime that covers both the cost of depreciation and interest.

2.7.2. Farm machinery variable costs

According to Edwards *et al.* (2001), the variable costs of farm machinery are those that change according to how much the machine is used. These costs include labor, fuel, and lubricant costs, as well as repair and maintenance expenses.

2.7.2.1. Repair and maintenance costs

Depending on the care given by the machine's owner, repair, and maintenance costs can vary greatly. It will always cost money to replace broken or worn-out components and/or fix accident damage. According to Ajit *et al.* (2006), repair and maintenance expenses tend to rise as machine size and complexity increase.

According to this equation, the entire cost of all replacement components, materials, shop expenditures, and labor to keep the machine in excellent operating order can be estimated. Due to variations in equipment maintenance, administration, and quality, actual prices may fluctuate significantly. Data should not be projected beyond the machine's anticipated life. The estimated life is the cumulative use at which additional machine repair is typically not justifiable. For machines utilized past their expected life, it is reasonable to predict that accumulated repair and maintenance expenses will rise steadily at a rate equal to that of the machine's estimated life.

2.7.2.2. Fuel cost

Fuel is a substantial expense for rural enterprises and agriculture. Actual fuel usage will vary based on factors including the size and power of the machine being used, the depth of operation, the proper calibration and maintenance of the machinery, and the speed and care with which it is operated Kara (2017). To create budgets, it is common practice to estimate the typical yearly fuel consumption for a particular make and model of the tractor using the ASABE Standards (2006, 2009).

2.7.2.3. Lubrication cost

To prevent the early failure of a machine and make it run properly, the role of lubricants is paramount. Lubricants also help in reducing power loss due to high temperatures and wear and tear of machine parts. Gopalakrishnan and Benerji (2006) also reported that the formation of rust, friction, wear, seizure, and scoring can be highly reduced and machine life can be increased

by properly lubricating the machine parts. Machinery power source (engine) for instance requires crankcase oil changes periodically. Goense (1995) reported that tractors of 25 kW and 150 kW power need one liter of lubrication oil for every 300 and 600 liters of diesel fuel respectively. Tractors test data of Nebraska indicates a general rule of thumb for power machinery is that 15 percent of fuel cost is taken as lubricant cost. For non-power machinery/equipment, 5% of the purchased price is used.

2.7.2.4. Labor cost

The total sum of money paid as salary and other benefits to persons in charge of machinery operation and services is known as labor cost. Actual hours of labor usually exceed field machine time by 10% to 20% because of travel time and time required to lubricate and service the machine

2.8. Farm Machinery Replacement

One of the biggest investments a farm business can make is a full line of machinery. However, unlike buildings or structures, machinery needs ongoing inspection, maintenance, and replacement. The timing and method of equipment replacement can alter yearly production costs by thousands of dollars. One of the reasons to replace machinery is cost minimization. The standard rule for minimizing the long-run cost of equipment is to make a change when the annualized total cost of owning and operating the machine begins to increase. The second reason for replacing farm machinery is connected with reliability. In addition to machinery costs, most owners and operators also consider timeliness costs in their replacement decisions. Crops that are not planted or harvested at the best time incur timeliness costs. Timeliness costs can be very significant if a machine goes down during a crucial period. The third reason to replace farm machinery is when higher capacity is needed. Operators may need to swap out their machinery for new ones with a higher capacity if the number of hectares being produced increases considerably to finish planting and harvesting without suffering severe delays. Similarly, if the size of the farm is decreased, it would be able to minimize expenses by reducing the amount of machinery (Edwards, 2019).

Regarding the replacement strategies, there are at least four general strategies that farmers can follow for replacing machinery. Replacing machinery frequently is the first strategy. This approach minimizes the risk of breakdowns and costly repairs by trading key machinery items every few years. Even when repairs occur, they often will be covered by the original warranty. Operators who cover a large number of acres each year and would be severely inconvenienced by extended downtime are most likely to follow this strategy. Although this is probably a more expensive approach over the long run, some of the extra costs are offset by fewer timeliness losses, the ability to farm more acres, and less need to invest in repair and maintenance tools and facilities. Replacing one or two pieces of machinery annually is a second strategy. The objective is to spend roughly the same amount on new equipment. This way, a significant financial investment need not be made in a single year. On the other hand, it might also lead to replacing machinery earlier than necessary. A third strategy is to wait to make large machinery purchases until a year with above-average cash income. This prevents money required for other expenses like supporting a family and paying off debt from being diverted towards the purchase of machines. Finally, some operators just keep their machinery running until it reaches a point where it is no longer useful and should be renovated. While this might be the most economical option over time, there's a chance that a machine will break down at a critical moment and that finances will need to be arranged quickly (Edwards, 2019).

Leu and Ying (2020) stated that internal and external factors, such as material deterioration, maintenance, operation, and so on, usually have an impact on a machine's performance. The machine's reliability will deteriorate with time, eventually leading to failure. Maintenance plans are normally carried out regularly to ensure that the machinery operates reliably. Corrective maintenance is performed on deteriorating machines as needed. Furthermore, the machine may need to be replaced for a variety of reasons. For starters, the machine becomes inoperable due to physical deterioration. Second, the machine's reliability deteriorates, perhaps leading to a catastrophic breakdown. Finally, the overall maintenance cost will exceed the cost of a new building. Many studies have been undertaken since the decision between replacement and maintenance is critical and difficult.

Hunt (2001) developed two models for determining the best timing to replace farm machinery. The first model's premise is fundamentally based on an accounting method. That example, the

question of when to replace a machine can be answered by assessing the machine's accumulated expenditures over time. The machinery manager can calculate the total cost of any specific implement using the machinery cost information. As a result, maintaining systematic cost information for each machine is the essential key for the current model to be viable.

Taha (2007) developed a mathematical model that was fundamentally different from earlier models in that it used the deterministic dynamic programming (DP) technique to construct a model that predicted the most cost-effective replacement year for various machines over a period of years. In DP, computations are done recursively, so that the best answer to one subproblem is utilized as an input to the next. When the last sub-issue is solved, the best solution for the overall problem is found.

Soliman and Khater (2014) created a computer model to support farm machinery replacement decisions to assist farm machinery decision-makers in determining the best replacement time for an individual unit. Their model relied on Microsoft Visual Basic® to solve a series of mathematical equations to make the correct conclusion. The key input data consists of the machine's purchase price, date, and age at the time of purchase, annual inflation and interest rates, yearly repair and maintenance expenditures, and operating hours over the machine's life. They discovered that the values of computed average accumulated expenditures over a period of years were the most important criterion for keeping equipment in service or replacing it. Rohani *et al.*, (2014), studied the prediction of combine economic life based on the repair and maintenance cost model. Their study aimed to identify a regression model that can adequately represent the repair and maintenance costs in terms of machine age in cumulative hours of use by using field data collected from 11 John-Deer 955 combine harvesters used in several western provinces of Iran. The regression model can predict the repair and maintenance costs for longer periods.

Bakht *et al.* (2010) investigated the optimum life for an MF285 tractor based on repair and maintenance costs: a case study in Iran's central region. They noted that one of the most significant aspects of farm machinery management is the decision to replace used farm equipment with new equivalent equipment. They also stated that evaluating repair and maintenance cost models for farm machinery is critical for determining replacement time and lowering total costs. Proper performance in this situation can lead to timely, high-quality farm operations, which

results in significant reductions in product expenses as well as increased income. Their analysis was based on this to establish the optimum life or economic life for MF285 in the western part of Isfahan province. Repair and maintenance costs for the tractor under consideration were explored in order to develop an adequate mathematical model for predicting these costs. In their study, they estimated the quoted price of the tractor, annual depreciation, and the Internal Rate of Return (I.R.R). They eventually discovered that these goods, along with their repair and maintenance costs, were utilized to determine their economic life.

Bwambale (2016), studied the appropriate replacement time for farm tractors using economic analysis to build up a module. The goal of his replacement module was to determine the optimal amount of time that a tractor should be kept before being replaced. The technique they used to implement the replacement module was based on economic analysis; otherwise, they would have developed a repair and maintenance plan to keep the unreplaced tractors running. The model was created with the MS Access package and the Visual Basic package (version 2010). Repair and maintenance costs, annual depreciation, and interest on investment in the study period were computed based on the study in order to identify the optimum life or economic life for MF385 at Farm Engineering Industries Limited. The tractor's entire annual holding expenses were obtained and used to calculate the economic life.

Borowski *et al.*, (2023) created a mathematical model for calculating the period between preventive replacements in the agricultural machinery servicing system with minimal repair. It was proposed a semi-Markov model for calculating the ideal time for preventive replacements based on the age of technological objects. They researched how technical objects (sets of agricultural tractors with trailers) should carry out the prescribed functions of carrying crops without interruption in their system due to the continuous functioning of combine harvesters. They reported that the effectiveness of the function of the tested technical objects is analyzed by two criteria functions, which are very important for the system managers. These are profit per unit of time and availability. In the analyzed case, it is the availability to carry out the assigned transport tasks. The conditions for the existence of a maximum of criterion functions have been written for the assumptions. The analyses carried out, which are presented in their work, were illustrated with sample calculations. It has been proven that, under general assumptions, the criterion functions considered in the paper have exactly one maximum. On the basis of the conducted analysis,

sufficient conditions for the existence of a maximum of these functions were formulated. According to their finding, in the analyzed transport system, it is possible to increase the efficiency of the function of the technical facilities in use as a result of planning additional preventive replacements (increasing the frequency of these replacements).

Nair and Hopp, (1992), reported that one of the most crucial strategic decisions that manufacturing and service companies must make is whether to replace productive equipment. This is due to the fact that purchasing new equipment can be expensive and might have long term effects on the company's productivity and competitiveness. The physical deterioration of the current equipment is highlighted in the conventional approach to the problem of equipment replacement. The primary concept is to replace the equipment when its operating and maintenance costs reach a level that, in terms of net anticipated present value, justifies a replacement. There are at least five replacement strategies that businesses might use for their agricultural equipment. The optimum course of action from a profitability standpoint is to replace equipment when the yearly cost of the equipment in a given year starts to surpass the equipment cost from replacement (Perrin, 1972).

Businesses maximize long-term revenues by reducing equipment costs. However, from a cash flow standpoint, this approach might not be the best, since certain equipment might need to be replaced in years of low profitability, which would cause farmers to have cash flow issues. Edwards W., stated the four other approaches to replace things frequently, annually, when money is available, or keep the equipment forever (Edwards, 2019)

Changing out machinery every few years or less is a tactic for reducing malfunctions, repairs, and maintenance. If repairs were required, they would probably be free for the farmer because they were covered by the warranty. The second strategy is to replace the item each year in order to keep spending roughly constant. With this approach, farmers can avoid needing to make significant financial investments every year. The drawback of this approach is that machinery may be replaced before it reaches the point of cost reduction, which could result in less-than-ideal long-term profitability. The third strategy is to replace when cash is available. This strategy has the benefit of flattening cash flow since farm equipment is purchased when there is more money available, and not purchased when there is less money available. This strategy may level out

cash flow from year to year, but it won't be as profitable in the long run because certain equipment may need to be replaced before or beyond the ideal time (i.e. when the cost per year is lowest) (Edwards, 2019)

2.8.1. Machinery replacement theory

Simply put, a farm machine should be replaced when the expense of keeping the old one is greater than the cost of buying a new one. The current machine is referred to as the "defender" in replacement theory nomenclature, and the new machine is referred to as the "challenger." Although the replacement theory is a simple idea to explain, calculating the associated costs is significantly more challenging. This is important to compare the estimated costs of the suggested replacement machine with the future expected expenses of the current machine. The defender and challenger both have different future lives, therefore it is vital to compare the options based on annual costs to determine which will be, on average, less expensive.

2.8.1.1. Holding-cost approach to machinery replacement

Dunford and Rickard (1961) suggested using the holding-cost concept to determine the ideal moment to replace a machine. This strategy is based on a secondhand market notion that was previously put forth. The initial investment, repair, and maintenance expenses, and running costs are the three main expenses related to owning and using a machine. The presumption is that if repairs and maintenance are justified in keeping running costs at a constant level, running costs can be ignored when determining whether to replace them. Therefore, the capital and total cost of repairs are the issue. The holding cost is the total of these two expenses. The holding cost (PH) for a machine with starting and replacement costs that are believed to be constant throughout time is shown in Figure 6.5. The holding cost curve (PH) has an increasing slope since it is expected that repair costs rise as a machine gets older. Now it is possible to calculate the holding cost for maintaining the machine till a specific age. For instance, IS provides the holding cost at age OS. The tangent to PH taken from the origin provides the best timing for replacement, assuming no secondhand or scrap value. In this instance, OT provides the ideal time for replacement, and at this time, the average rate of holding cost per unit of life will be at its lowest. The minimal holding cost to machine life ratio shall be RT/OT . In this instance, this sum is provided

given by IJ. Any replacement time that is longer than the ideal point is justified using the same logic.

The capital costs of owning the machine may potentially include investment allowances if these were added every year. Such allowances have the effect of encouraging the farmer to update equipment more regularly. The simple model presented can also be used to take into account technological innovations that may be present in the new machine. If the same type of machine is being purchased, then the new machine will depress the trade-in value of the obsolete older machine. Thus, the trade-in value received can be taken as encompassing the obsolescence effect caused by the technologically superior new machine. In addition, if a decision is made to replace the machine without receiving the trade-in necessary to be restored to the minimum-cost curve, then the shortfall represents the amount the owner is prepared to pay for the technological improvements offered by the new machine.

2.8.1.2. Group replacement theory

A group replacement policy is the replacement of several related objects at regular intervals. This strategy frequently works when there are plenty of identical, inexpensive things that get worse as they age and when the value of each item is modest (Ackoff and Sasieni, 1968). The nozzle tips on sprayer booms and the tines on cultivators are two examples of things that may be installed on many agricultural machines. A group replacement model assumes that all things are replaced at some interval, regardless of when an individual item was last replaced, and that all pieces that fail within a certain time frame are replaced separately. To evaluate (1) if group replacement is beneficial (i.e., preferable to individual replacement) and (2) the ideal group replacement interval that minimizes costs, the system under consideration must be analyzed.

Table 2.2: Summary of the main literature

No	Article	Author/s	Findings
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1	Crop-machinerymanagement system for field operations and farm machinery selection	Yousif et al., (2013)	Developed a computer system for farm management and selection of required farm machinery to perform field operations in time for crops grown in rotations
2	Studies of tractor and crop parameters combinations for the optimal selection of farm machinery	Gindo and Kolhe, (2021),	wrong decisions on farm machinery investment and machinery selection process hurt the profitability of the companies
3	Development of a model for farm tractors and implements selection	Akinnuli et al., (2014),	Developed a model sensitive to tractor travel speed, soil conditions, and cultivable area and not sensitive to the purchase price
4	Farm machinery selection and management program	Siemens et al., (1990)	The program schedules field operations for various machinery sets or a specified set of machinery and computes total machinery-related costs, including machine, labor, and timeliness costs
5	Model developed for farm tractors and implements selection for optimum utilization	Akerele and Nathaniel (2014),	Developed a model sensitive to tractor travel speed, soil conditions, and cultivable area and not sensitive to the purchase price
6	A Model for Optimal Selection of Machinery Sizes within the Farm Machinery System	Sogaard and Sorensen (2004	Sizing of each machine, and also the tractor power, and the number of tractors required.
7	Farm Machinery Selection to Minimize the Cost of Agricultural Operations	Natsis et al., (2001)	Selection of farm machinery, based on minimizing machinery operational

			costs, taking into consideration factors like the size of the farm, the distribution of crops, and crop rotation
8	Farm machinery use and maize yields in China: an analysis accounting for selection bias and heterogeneity	Zhou et al., (2020),	Examined the potential heterogeneous effects of farm machinery use on maize yields, using an unconditional quantile regression model
9	Selecting the optimum-sized tractor	Chancellor (1969)	Determining the optimal size of a farm tractor. This model is also applied to single and multiple tractor farms.
10	Studied on how to purchase a right tractor	Singh and Kawade (2004)	Tractor selection is based on timeliness in operation, horsepower necessary, custom hiring, fuel efficiency, purchase price, special technical features, after-sales service, and resale value.
11	Selection of optimum sized tractor for some selected farms of J.N. Krishi Vishwavidyalaya, Jabalpur	Mishra and Dhakad (2004)	Excess tractors on the farm can be effectively used for crop harvesting by utilizing their power with matching equipment such as tractor driven combine
12	Feasibility and efficiency of agricultural machinery maintenance	Myalo et al., (2021)	The main contradiction is inherent in the system of maintenance and use of machines, in the coincidence of the timing of their performance: the more time is spent, the more maintenance operations need to be performed.
13	Reliability and maintenance of agricultural machinery byMCDM approach	Mishra and Satapathy (2023)	By method to rank the MPs for tractors based on their prioritization, they

			found that checking for general conditions ranked first followed by checking for batteries; checking for all fluid levels; and checking for tires and wheels; respectively.
14	Maintenance management of tractors and agricultural machinery: Preventive maintenance systems	Khodabakhshian, (2013)	Successful agricultural productivity depends heavily on the maintenance of agricultural equipment
15	The Effect of Failure Rate on Repair and Maintenance Costs of Four Agricultural Tractor Models	Afsharnia et al. (2014)	Increasing the failure rate will increase annual repair and maintenance expenditures
16	A computer model for field machinery selection under multiple cropping	Haffar and Khoury, (1992).	A field machinery selection model has been developed to assist farmers in selecting an optimal machine set for multiple cropping production systems.
17	Optimizing condition-based maintenance decisions	Jardine, (2002)	Reviewed common strategies for implementing smart condition monitoring decisions such as trend analysis that is rooted in statistical process control, expert systems, and the use of neural networks.
18	Predicting Draft Requirement of Tillage Implements Using Pull Type Load Cell in Southern Region of Andhra Pradesh, India	J yoti et al., (2019)	Availability of draft requirement data of primary and secondary tillage implement is necessary to implement selection, tractor-implement matching, and determination of fuel consumption for different tillage systems

19	ACHoice: a Decision Support System for agricultural machinery management	Cunha and Gonçalves, (2019)	Developed MACHoice, a decision support system (DSS) used to estimate a farm machinery cost and break-even analyzer of alternatives for agricultural operations, developed using user-driven expectations and in close collaboration with agronomists and computer engineers.
20	A device to measure wheel slip to improve the fuel efficiency of off-road vehicles	Kumar <i>et al.</i> , (2017)	Introduced a hall sensor-based simple technique to measure wheel slip and a microcontroller-based embedded digital system to display wheel slip data and warn the operator
21	Length of Operational Life and Its Impact on Life-Cycle Costs of a Tractor in Switzerland	Lips, (2017)	Found an additional year in service increases LCCs by 4.5% of the tractor's purchase price.
22	Comparison between the draft force requirements and the disturbed area of a single tine, parallel double tines, and partially swerved double tines subsoilers	Aday and Ramadhan, (2019)	Conducted field experiments to compare the field performance of three subsoiler combinations using the draft force requirement and the disturbed area as comparison parameters
23	Prediction of Specific Fuel Consumption of a Tractor during the Tillage Process Using an Artificial Neural Network Method	Al-Sager <i>et al.</i> , (2024)	Investigated the construction of an artificial neural network (ANN) model for tractor-specific fuel consumption predictions for two tillage implements: chisel and moldboard plows

2.9. Research Gap Analysis

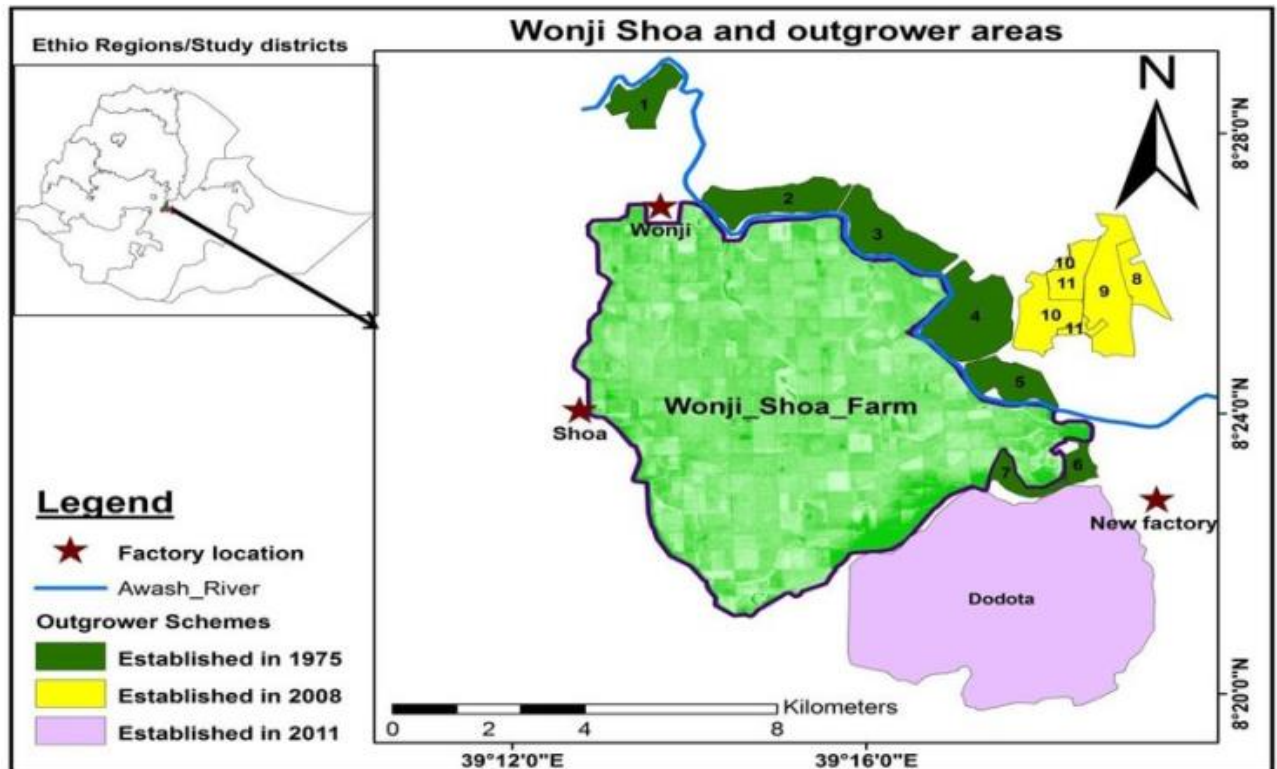
A review of farm machinery management mainly focusing on a tractor, implement selection, and its utilization for improved farm operations was done from the available published literature.

Several pieces of literature focus on crop production practices, weather conditions, machine performance, machinery costs, labor costs, and estimated field capacities. Crop parameters, like; start date, hectare coverage, and available hours, have been also focused on by several studies for the selection of optimum-size tractors and their implements. However, the effect of different soil types on tractor draft force requirement, tractor fuel consumption, Overall Energy Efficiency (OEE), and Power Utilization Ratio (PUR) is not well reported by previous studies. It is known that Soil types, soil physical properties, and field conditions vary from one agro ecological area to the other. It is very crucial to conduct studies at specific agro ecological areas if comprehensive and genuine performance data for farm machinery selection is required. Moreover, improper machinery selection and matching hurts its maintenance cost and economic life. Properly selected and matched machinery serves a relatively longer time with significantly reduced cost and better efficiency. Hence, the motive behind this study was to investigate farm machinery management (machinery selection, maintenance, and replacement) strategies of Wonji-Shoa Sugar Factory. In addition, a decision support system (DSS) has to be developed to make a scientific choice to tackle this challenge.

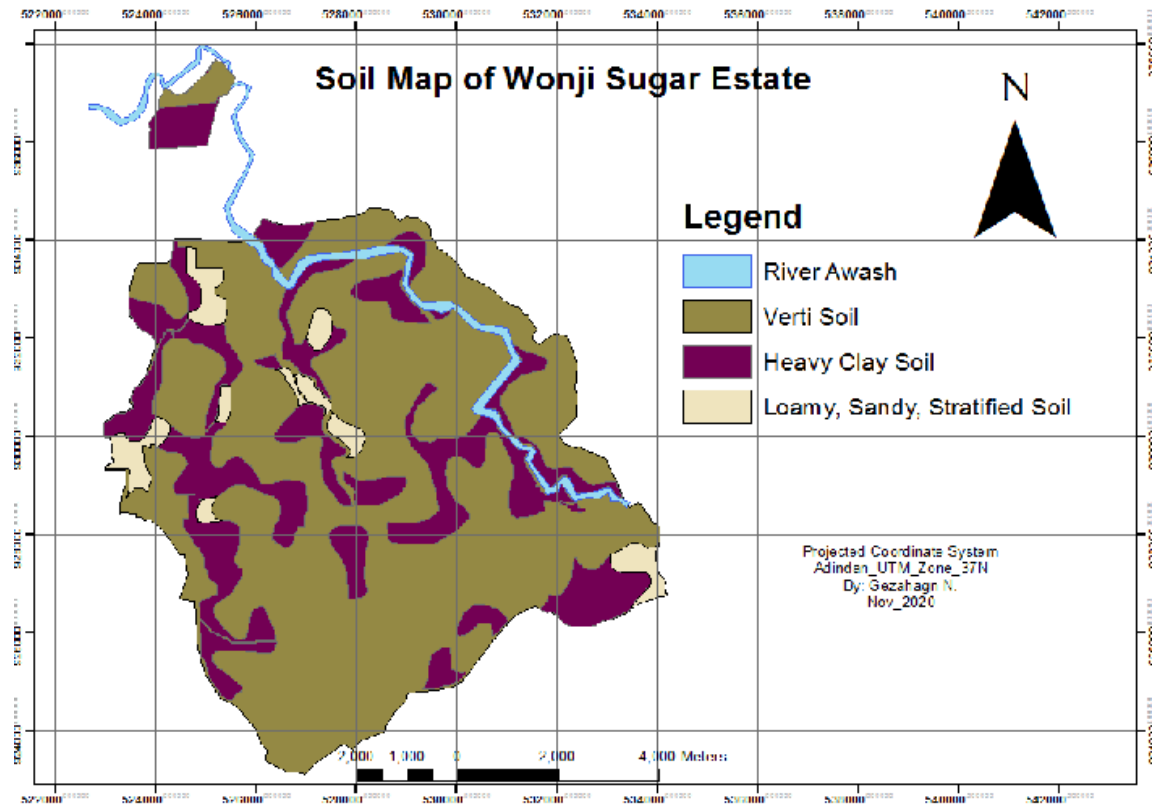
CHAPTER THREE: MATERIALS AND METHODS

3.1. Description of the Study Area

Wonji-Shoa Sugar Factory is found in the Oromiya region near Adama City at 110 kilometers from Addis Ababa. It is located in the central part of the main East African Rift Valley at $8^{\circ} 30'$ to $8^{\circ} 35'$ longitude and $39^{\circ} 20'$ latitudes and at an altitude of 1540 m. The annual precipitation, and mean maximum and minimum temperature of the area are 831 mm, 27 and 15 degrees centigrade, respectively. Wonji Sugar Factory began production in 1954 and is Ethiopia's oldest and pioneering sugar factory. Shoa Sugar Factory followed in 1962. It is the second oldest, and both Wonji and Shoa have been obsoleted since July 2012 and July 2013, respectively.



a). Mape of the Study location (WSSF)



(b). Soil map of the study location

FIGURE 3.1: (a, b). The study location and soil map of the selected experimental plot

The Enterprise has adopted a team management approach, and the organization is divided into four basic sectors: agricultural operations, factory and logistics, finance, and human resources, as well as support and advisory services. Agricultural operations include a variety of tasks such as topographic survey, site preparation, sugar cane growing, and harvesting, all of which are critical to the estate's long-term supply of sugar cane.

3.2. Materials

3.2.1. Soil

Three experimental sites were selected at Wonji-Shoa Sugar Factory for the presented study based on its soil type; heavy clay soil, vertisol, and sandy loam soils as per the soil map depicted in Figure 3.1.b.

3.2.2. Tractors used for the experimental work

9410- R John Deere tractor and YTO -1804 tractors are the main machines used for most of the land preparation activities in WSSF and were used for field experiments; for subsoiling, ploughing, harrowing, and furrowing activities as shown in Figure 3.2. The technical specifications of those tractors are presented in Table 3.1.



(a).9410-R John Deer



(b) YTO-1804

FIGURE 3.2 (a,b): Tractors used for field experimentation

Table 3.1: Technical specifications of tractors used for the field experiment

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 40 km/h; 24F
Drawbar	Cat 4 w/ Std Drawbar Support
PTO shaft	1-3/4 in., 20-spline, 1,000-rpm
PTO Performance	Basic / Transmission 238kw
3-POINT HITCH	Category 3/4N with QuikCoupler

Wheel Configuration	4WD
YTO 1804 Tractor	
Rated Engine power at 2200 engine rpm, kW 132.3	
Max Engine power 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

The other categories of tractors were selected for the study of maintenance and replacement evaluation shown in Figure 3.3. The specification of these tractors was presented in Table 3.2. Only four tractor brands with a suitable amount of data were included in the data set: John Deere, Massey Ferguson, SAME, and New Holland. Because it was difficult to obtain data on purchase pricing and repair and maintenance costs, tractors bought before 2006 were omitted. Year of purchase, number of tractors of specific make, and capacity (hp) of tractors were collected for the specified duration as indicated in table 3.2.

Table 3.2: Tractors used to Analyze Maintenance and Replacement Strategies

Category	Make (HP)	Duration of data collection (years)	No tractors observed
A	John Deere (330)	2011-2020	5
B	SAME (130)	2011-2020	7
C	New Holland (80)	2012-2021	9
D	Massey Fergusson (150)	2006-2015	4



(a).330-R John Deer



(b).SAME 130



(C).New Holland (NH 80)



(d).MF 150

FIGURE 3.3: (a, b c, d): Sample of tractors used for maintenance and replacement studies

Table 3.3: Technical specs of tractors used for maintenance and replacement evaluation

New Holland (NH 80) Tractor	
No. of cylinders / Aspiration / Displacement (cc)	4 cyl / Turbo w/intercooler / 4156 cm ³
Bore x stroke (mm)	105 x 120
Power at a rated speed of 2300 rpm (kW/hp)	60/80
Maximum torque @ engine speed (Nm @ rpm)	286.5 @ 1400-1600

Optimum fuel consumption (g/kWh)	228
Transmission type	30 kph, 12-speed Synchronesh
No. of speeds with Synchro Shuttle - fwd / rev	12 x 4 / 12 x 12 O
Road speeds at rated erpm - fwd / rev (km/h)	1.8 - 29.7 / 4.9 - 14.8
PTO power (kW/hp)	52/70
SAME (130) Tractor	
Model	TCD 2012 L06 2V
Cylinder/Displacement (cc)	6/6057
Power at rated engine speed (ECE R120)	93/126
Max. power (ECE R120) (kW/hp)	95/129
Maximum torque @ 1600rpm	491
Torque rise	27
Synchronized speeds x mechanical ranges	4x3
Number of speeds with splitter	24+12
Maximum speed	40
Hydrostatically operated clutch	TCD 2012 L06 2V
PTO 540ECO/1000	6/6057
Massey Ferguson (MF 150) Tractor	
Model	Massey Ferguson 150
Length	3,340 mm (131.5 in)
Width	1,610 mm (63.4 in)
Engine model	Perkins AD3.152
Cylinders	4
Displacement	2.5 L, 2,507 cm ² , (152.0 cu·in)

Bore and stroke	91.0 mm X 127.0 mm (3.58 in X 5 in)
Compression ratio	17.4:1
Horsepower	46.1 PS (33.9 kW) at 2,000 rpm
Torque	155.9 N·m (15.9 kg·m,) at 1,200 rpm
John Deer (330)	
Rated Engine power (97/68 EC) at 2100 engine rpm, kw	302
Max Engine power at 1900 engine rpm, kW	332
Transmission	24-speed Manual 40 km/h; 24F
Drawbar	Cat 4 w/ Std Drawbar Support
PTO shaft	1-3/4 in., 20-spline, 1,000-rpm
PTO Performance	Basic / Transmission 238kw
3-POINT HITCH	Category 3/4N with Quik-Coupler
Wheel Configuration	4WD

3.2.3. Implements utilized for field experiment

The implements used for various operations during field experiments were presented below: A 5-shank and 3.2 m wide mounted subsoiler was used for subsoiling. Whereas a semi-mounted two gangs offset heavy Disc plough with 16 discs each 42-inch diameter (42"×16), and 2.8 m wide was used for ploughing experiments 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 implements utilized for the experiment are shown in Figure 3.4



(a).Disc plough



(b).Disc harrow



(c) Subsoiler

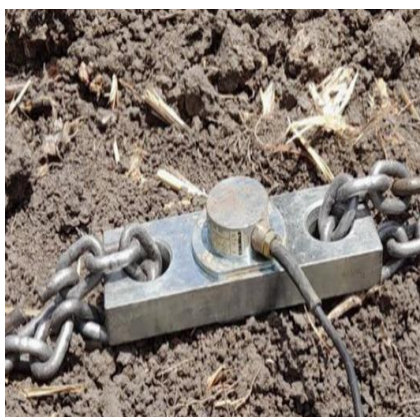


(d). Ridger(furrower)

FIGURE 3.4: (a, b, c, d). Implements used for field experiment

3.2.4. Measurement tools used for experimental work.

For field experimental activities done at each selected site, different tools and equipment were used for recording field results. The various tools and equipment are presented in Figure 3.5. The working width of implements, size of farm plots, tractor fuel consumption, implement draft, and soil textural class were determined with the help of this scientific equipment. The name, use, and specification of this equipment are presented in Table 3.4.



(a). Load cell dynamometer



(b). The display

FIGURE 3.5: (a,b). Tools and scientific equipment used for experimental work

Table 3.4: The details of utilized equipment

Name	Use	Capacity
Measuring Tape	Used for linear measurement of land, and working width of the implements	50 meters
Steel Ruler	Used for measuring the 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
Core sampler	Used to take soil samples at the desired location	0.02m ³
Thermostatically controlled oven	Used to dry soil samples	250 deg C +/- 1 deg C
Weighing balance	Used to weigh Soil samples	2kg
Plastic bags	Used to store soil samples	1/4 th kg
Tongs	To hold hot soil samples	-
Soil Sieves	Used to separate soil particles	0.05mm, 0.25mm, 0.5mm,

3.3. Methods

Figure 3.6 shows the general methodology followed while conducting this study. The detailed description of each method was indicated subsequently.

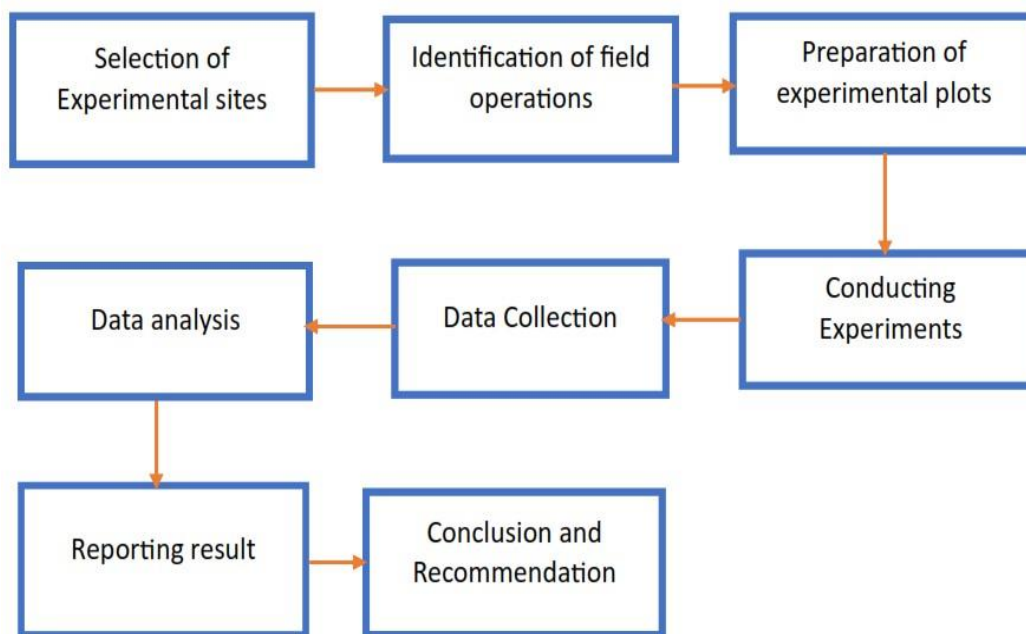


FIGURE 3.6: General study procedure

3.3.1. Soil sampling and determination of its physical properties.

Three experimental sites were selected at Wonji-Shoa Sugar Factory for the present study based on their soil type; heavy clay soil, vertisol, and sandy loam soil as per the soil map depicted in Figure 3.1.b. A core sampler was used to take the samples from the exposed soil at 0- 20 cm, 20 – 40 cm, and 40 - 60 cm depths. The samples were collected into plastic bags and labeled with the necessary information. The first activity with the soil samples was making a sieve analysis to know the soil's textural class (the amount of clay, silt, and sand particles). Soil sieve analysis was performed by taking a 500-gram sample for each soil type. The soil samples were oven-dried to 105 degrees, crushed and pulverized. Then the sieves were assembled as those with larger openings (lower numbers) were placed above those with smaller openings (higher numbers) and the pan was placed under the last sieve. The soil samples were then poured from above the stack of sieves and a cover was placed on it and shaken very well. Finally, the soil sample retained on each sieve and pan was weighed and its percentage was calculated based

on the total weight of the initial sample by the following formulae (Aluvihara *et al.*, 2020, Rasmin, 2009, Diaz, 2007).

- ✓ % Sand = mass of sand / total soil mass x 100
- ✓ % Silt = mass of silt / total soil mass x 100
- ✓ % Clay = mass of clay / total soil mass x 100

To determine the bulk density and moisture content, the sample was placed in a container with known volume and weighed again (M_t). Then the container was placed in an oven at 105 degrees centigrade for 24 hrs. After drying, the container was removed from the oven and allowed to cool. The container and the soil sample were weighed again (M_s). The difference between the two weights was taken as the mass of water present in the soil (M_w)

The physical properties of the selected soils like soil moisture content (MC), bulk density (ρ_b), and porosity (f) were determined by the following equations (Phogat *et al.*, 2015).

The bulk density (ρ_b) of soil refers to the oven-dried mass (M_s) per unit volume (V_t) of the soil, including pore space

$$\rho_b = \frac{M_s}{V_t} \dots \dots \dots 3.1$$

The total porosity (f) is defined as the volume of pores (V_f) per unit volume of soil (V_t). It is a percentage-based measure of soil's relative pore volume.

$$f = \frac{V_f}{V_t} * 100 \dots \dots \dots 3.2$$

The soil moisture content (MC) is the amount of water (M_w) per unit mass of oven-dried soil (M_s). It is commonly referred to as gravimetric water content and is represented in fractions or percentages.

$$MC = \left(\frac{M_w}{M_s} \right) * 100 \dots \dots \dots 3.3$$

3.3.2. Field experimental planning for evaluation of tractor-implement selection

Field experiments were performed under actual agricultural production conditions, using the 9410- R John Deere tractor and YTO -1804 tractors, implements, and equipment. Various settings for the angle between disc gangs and combinations of engine regime-gear selection that would allow varying forward speeds were evaluated ahead of each test. Five forward speeds were used, ranging from 3.0 to 7km/hr.

The overall experimental design is depicted in Figure 3.6, each experimental site had a land area of 10,000 m² for the three soil types (heavy clay soil, vertisol, and sandy loam soil), and the land area was divided into four plots of 50 x 50 m². The experimental plot of each soil type was separated by 3 m for performing the planned farm operation. For subsoiling, ploughing and harrowing field experimental activities in each soil, the forward speeds of 3, 4, 5, and 6 km/hr were taken and each replicated 3 times as depicted in Table 3.5. For furrowing activity, 7km/hr travel speed was also taken as it was the lighter field activity performed at a higher forward speed. For each type of soil, some selected physical properties that affect the energy and power consumption rate of machinery were determined. These properties were soil textural class (soil type) which was taken from the factory fields' soil map and confirmed in lab tests, soil moisture content, soil bulk density, and porosity. Experimental field activities to be performed at each site were subsoiling, ploughing, harrowing, and furrowing. Data collected and calculated during each activity of all treatments were: tractor fuel consumption, draft force, drawbar power, Power Utilization Ratio (PUR), and Overall Energy Efficiency (OEE).

Figure 3.7 (a,) indicates the variables to be measured and calculated and their interactions. For all the selected travel speeds, draft force, drawbar power, fuel consumption, PUR, and OEE were determined in all soil types. The general study procedure is depicted in Figure 3.8. The first activity was the selection of the experimental sites based on soil types. For the three soil types mentioned above, three separate experimental sites were selected and planned as indicated in Figure 3.6. The next step was the identification of field operations to be experimented with. Accordingly, four field activities namely; subsoiling, ploughing, harrowing, and furrowing activities were selected for this study. In the third step; the preparation of field plots was done. Finally, field experiments were conducted on each plot and the primary data like, draft force requirement, and fuel consumption were collected. Drawbar power, Overall Energy Efficiency

(OEE), and Power Utilization Ratio (PUR) were computed from the previous directly measured data sets. "IBM SPSS Statistics 26, 2022" was used to assess the ANOVA, correlation, and multiple linear regressions of the obtained data.

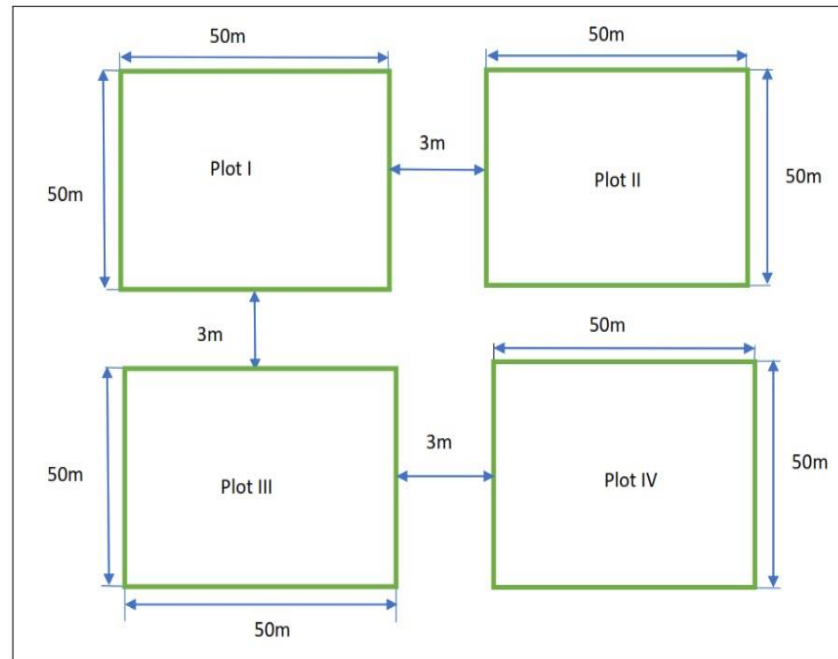
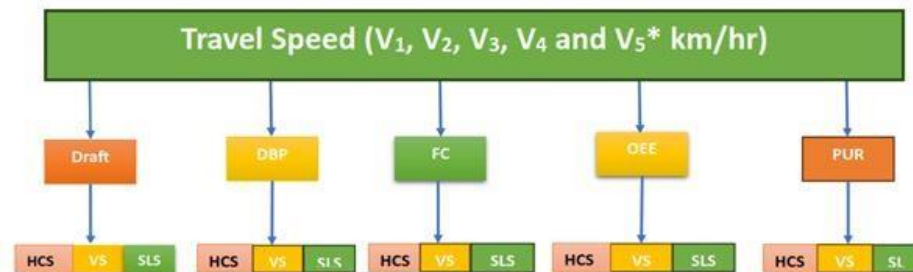
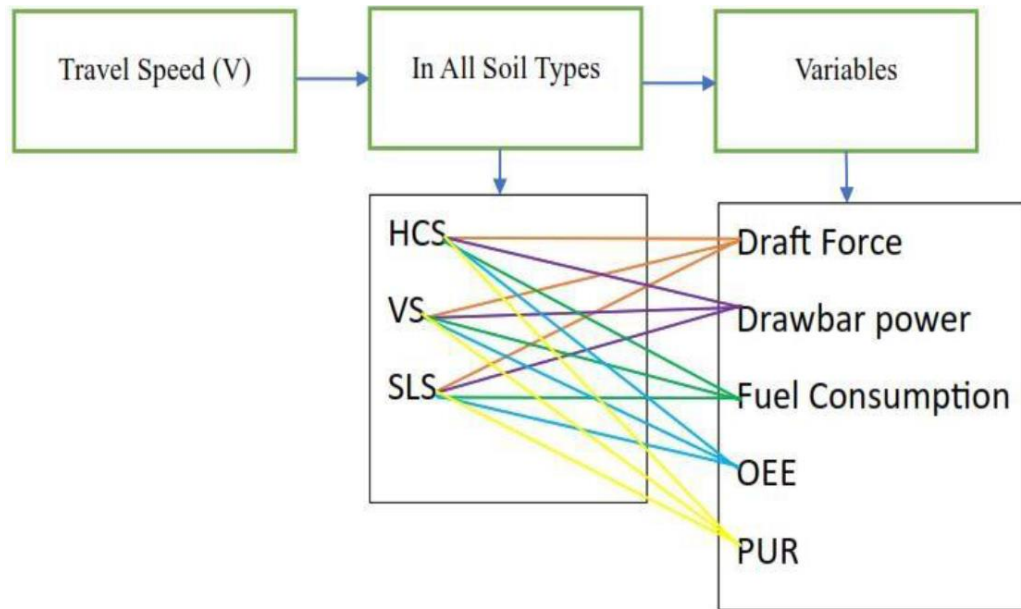


FIGURE 3.7: Field experimental design



V1 = 3 km/hr	DBP = Drawbar Power
V2 = 4 km/hr	FC = Fuel Consumption
V3 = 5 km/hr	OEE = Overall Energy Efficiency
V4 = 6 km/hr	PUR = Power Utilization Ratio
V5* = 7 km/hr	
HCS = Heavy Clay Soil	
VS = Vertisol	
SLS = Sandy Loam Soil	
*Travel speed used for furrowing activity	

a). Variables to be measured and calculated



b). Interaction of variables measured and calculated.

FIGURE 3.8: (a, b): Field experimental details

Table 3.5: Field Experimental design

Activ-ity	Travel speed, km/hr (treat-ment)	Replica-tion	Draft force, kN	Drawbar power, kW	Fuel cons. l/hr	OEE, %	PUR
	3	1					
		2					
		3					
	4	1					
		2					

SPHFH	5	3					
		1					
		2					
	6	3					
		1					
		2					
		3					
		1					
		2					
SPHFV	3	1					
		2					
		3					
	4	1					
		2					
		3					
	5	1					
		2					
		3					
	6	1					
		2					
		3					
SPHFS	3	1					
		2					
		3					
	4	1					
		2					
		3					
	5	1					
		2					
		3					
	6	1					
		2					
		3					

SPHFH: Subsoiling, Ploughing, Harrowing, Farrowing in Heavy clay soil

SPHFV: Subsoiling, Ploughing, Harrowing, Farrowing in Vertisol

SPHFS: Subsoiling, Ploughing, Harrowing, Farrowing in Sandy loam

3.3.3. Implement draft measurement

Draft or drawbar pull refers to the force necessary to pull an implement in the same direction as the tractor. Draft is primarily determined by the working width of the implement, soil texture,

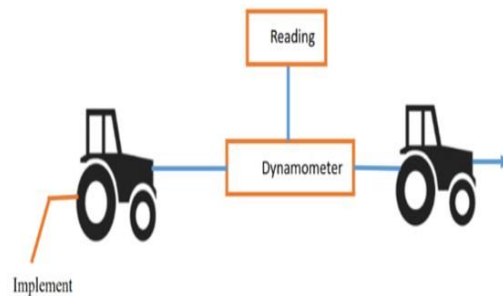
and the speed at which it is pulled. Draft is influenced by soil working depth, organic matter, moisture content, and implement mass (Serrano et al., 2007).

Optimum power requirement, fuel consumption, and operating efficiency can be obtained by matching the tractor and implement properly. Measurement of draft force requirements is the prominent factor in achieving this objective during the selection of machinery and power sources. Two John Deere 9410R tractors were used to measure the draft of the tillage tools (subsoiler, disc plough, and disc harrow), and two YTO-1804 tractors were used to measure the implement draft for furrowing activity with the same experimental setup depicted in Figure 3.9. The semi-mounted implements under study were attached at the rear side of one tractor with a three-point hitching system.

A pull type 100 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 the dynamometer. To ensure equal travel reduction of drive wheels, the differential lock was engaged during each test run treatment, and the tractor was operated at the respective gear and throttle settings to achieve the required travel speeds.



(a). Experimental setup



(b). Schematic representation

FIGURE 3.9: (a, b) Experimental setup for implement draft measurement

A test run of 50 m length was allocated for each test block for each operation speed. The implement drafts were measured at travel speeds of 3, 4, 5, and 6 km h⁻¹ for subsoiling, plowing, and harrowing and 4, 5, 6, and 7 km/hr for furrowing activity. The operation depths were, 60 cm, 30 cm, 25 cm and 30 cm for subsoiling, ploughing, harrowing, and furrowing respectively which were the working depths at WSSF for all soil types. The tractor pulling the implement was made in neutral gear with the implement in operating condition (operating depth). The idle draft force

was also measured within the same field when the 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 Aday and Ramadhan, (2019) and Jyoti *et al.*, (2019).

3.3.4. Determination of drawbar power

Drawbar power is the power available at the drawbar of the tractor. It is required to pull or move the implement at a uniform speed, about either a pull-type or mounted implement. Once the horizontal pull force (draft force) was measured, the drawbar power was calculated by using equation 3.4 at all experimental travel speeds for all field activities (Oduma *et al.*, 2019).

$$DBP = \frac{D * S}{C} \dots\dots\dots 3.4$$

Where,

D= Draft, kN,

C= Constant=3.6,

DBP= Drawbar power, kW, and S= travel speed km/hr

3.3.5. Measurement of fuel consumption

The amount of fuel needed to immediately refill the tractor's fuel tank was measured using a graduated cylindrical container. This measurement shows how much fuel was used throughout any activity. The fuel consumption rates were determined by Equation 3.5 (Gosaye *et al.*, 2015).

$$Fuel\ consumption\ rate(l/hr.) = \frac{Reading\ of\ cylinder, liters}{Time\ taken\ to\ cover\ land\ area, hours} \dots\dots\dots 3.5$$

3.3.6. Determination of power utilization ratio (PUR)

The power utilization ratio is calculated by ASAE, 2000 standards as cited by (Kumar *et al.*, 2017) as shown in equation 3.6.

$$X = \frac{Equivalent\ PTO\ power\ required\ by\ the\ implement}{Maximum\ available\ PTO\ power\ from\ the\ tractor} \dots\dots\dots 3.6$$

Where X is the power utilization ratio

3.3.7. Determination of overall energy efficiency (OEE)

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) (Al-Sager *et al.*, 2024). The overall energy efficiency is dependent on a range of performance factors namely, engine, power transmission, and the interaction of tires with the soil. This last factor implies the definitive influence of the soil as a major factor on the overall energy efficiency. It was calculated by using equation 3.7 (Mehta *et al.*, 2010).

$$OEE = (V_a \times D) / (10.2 \times F_c) \times 3.6 \dots \dots \dots 3.7$$

Where,

OEE – Overall energy efficiency (%), V_a – Real forward velocity (km/h). D – Draft (kN).

F_c – Fuel consumption (L/h) and, 10.2 is the 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 (Mehta *et al.*, 2010).

3.4. Methods to Evaluate Tractor Maintenance and Replacement Strategies

The details for this research embrace quantitative observational types of research to get the necessary data for the evaluation of the existing tractor maintenance and replacement strategies of Wonji Shoa Sugar Factory. The factory's records of the tractors utilized for many years served as the source of the study's data. Four tractor makes with a suitable amount of data were included in the data set as indicated in Table 3.6: John Deer, Massey Ferguson, SAME, and New Holland. Because it was difficult to obtain data on purchase pricing and repair and maintenance costs, tractors bought before 2006 were omitted. Tractors under the age of five were also not considered since there was not enough information that would help to produce reliable and accurate results.

Table 3.6: The present randomly selected available tractors purchased after 2006 in WSSF

Cate- gory	Make (HP)	Duration of data collec- tion (years)	No of tractors observed
A	John Deer (330)	2011-2020	5
B	SAME (130)	2011-2020	8
C	New Holland (80)	2012-2021	12
D	Massey Fergusson (150)	2006-2015	4

A structured questionnaire was prepared and distributed to collect data about the age, work experience, and educational level of farm machinery operators and maintenance personnel of Wonji Shoa Sugar factory.

The Experimental parameters identified for deciding the replacement age of various make tractors at Wonji Shoa Factory were;

- A. Dependent Variable categorized as; Replacement Age,
- B. Independent Variables were; Annual usage (hrs), Repair and Maintenance cost, and Depreciation cost,

3.4.1 Determination of tractor costs

The two primary categories of machinery costs are fixed costs and operational costs. While fixed expenses are unaffected by use, operational costs always rise proportionately as use increases over time. Similar to how the price of fuel, lubrication, daily services, and labor wages are related to the use of machinery, the cost of interest on a machine investment, taxes, housing costs, and insurance are all time-dependent. Only two cost items—the cost of depreciation and the cost of repairs and maintenance—appear to be affected by usage and time. Instead of taking into account all the costs, these two costs are focused on in this research (Pagareet *al.*, 2019).

3.4.2. Determination of depreciation

Depreciation is the phrase used to describe the decrease in a machine's commercial worth throughout its useful life, and it is frequently used to refer to the cost of agricultural equipment

(Calcanteet *et al.*, 2013). The normal deterioration of its irreparable parts, its obsolescence owing to advancements that replace it, or the change in agricultural production that renders it insufficient are the three main causes of the machinery's declining worth over time (Robb *et al.*, 1998).

Several techniques can be used to forecast machinery depreciation, such as the sinking-fund method and decreasing balance (Bakht *et al.*, 2008). Depreciation was calculated using a linear method shown in equation 3.8. (Cunha and Gonçalves, 2019)

$$D = \frac{Vi - Vf}{L} \dots\dots\dots 3.8$$

Where;

D = the value of the depreciation per year

Vi = is the purchase price;

Vf = refers to the value of the machine at the end of service life (L, years) or remaining value.

The remaining value of machinery is, in most cases, not available; a study has been conducted based on equations to depend Vf on machinery list price. Using a constant rate of market value depreciation, it is frequently assumed that a machine's remaining value (Vf) is determined by its age rather than its rate of use, equation 3.9 (Yahya, 2023)

$$Vf = Vi * D1 * D2^{Age} \dots\dots\dots 3.9$$

If age is <1, $Vf = Vi * 0.85$

Where; Vf is the machine's remaining value expressed in function of purchase value (Vi) and D1 and D2 are depreciation factors (decimals with no unit)

Table 3.7: Depreciation factors for calculating remaining value percentages.

Depre- ciati on Factor	Machinery Residual Groups (RG)					
	Tractor (RG1)	Combine (RG4)	Windrowers/ Mowers (RG3)	Forage/ Harvesters (RG2)	Baler (RG3)	Plant- ers/Tillag e (RG4)

D1	0.67	0.65	0.67	0.56	0.66	0.66
D2	0.94	0.93	0.9	0.9	0.92	0.96

(Cunha and Gonçalves, 2019)

3.4.3. Determination of repair and maintenance costs

Any machine's expected yearly repair costs are quite speculative. It represents the total cost of the parts, fuel, oil, and labor. This cost is taken into account in two different situations when reconditioning worn-out parts and replacing defective parts entirely. In this instance, the annual repair and maintenance expenses were gathered from the sources for each tractor for ten years. Several factors, including machine characteristics, purchase price, and maintenance strategy, affect typical repairs and maintenance (R&M) (Calcanteet *al.*, 2013) .

3.4.4. Estimation of the economic life of tractors

The main decision is typically whether to replace an old machine with a new one or keep it in place for at least another year. To make this choice, it is first required to ascertain the ideal replacement time in the context of cost minimization. The (anticipated) long-term unit of time is a more inclusive optimization criterion that has been taken into account here. The price involved in replacing a machine is known as the holding cost or total cost of the machine, which is made up of the depreciation (fixed cost) and cumulative repair and maintenance costs (variable cost). The costs associated with this ideal replacement cycle are then converted into an equivalent stream of costs that are equal every year at the proper rate of time preference. The existing machine should be replaced with a new one to maximize profit if the current cost of maintenance is equal to or close to the equivalent annuity, cost (avg. annual cost) or when the machine's annuity cost is at its lowest value. To estimate the optimum economic life of the tractor considered by this study, a multiple Regression analysis was performed using variables like annual uses(hr), tractor size (measured in horsepower), and repair and maintenance cost (R & M), Pargareet *al.*, (2019).

3.5. The Decision Support System Development

Visual Basic6.0 as the front end and Microsoft Excel as the database were used to develop the system. The system aimed to select the ideal tractor-implement combinations for specific field

activity and specific soil type and field conditions at Wonji Shoa Sugar Factory. The user interface (display) was supposed to be user-friendly and easy to use and select key parameters in deciding to choose the optimum farm tractor that fits the intended field activity (Mehta *et al.*, 2010).

3.5.1. Database of the DSS

Tractors with power ratings ranging from 60 to 400 hp were listed in the DSS's databases. The tractor database included options for adding new tractor model specs and modifying any parameter value that had already been input. The specification table included details on the model, the maximum PTO, no of cylinders, the cylinder volume, forward and reverse speed numbers, the speed of the PTO shaft, the specification of wheels, the turning radius, the mass that was ballasted and unballasted, the maximum engine rpm, etc. Information on standard PTO power, the drawbar power, model, PTO power, SFC, hydraulic capacity, and braking energy were all included in the performance chart.

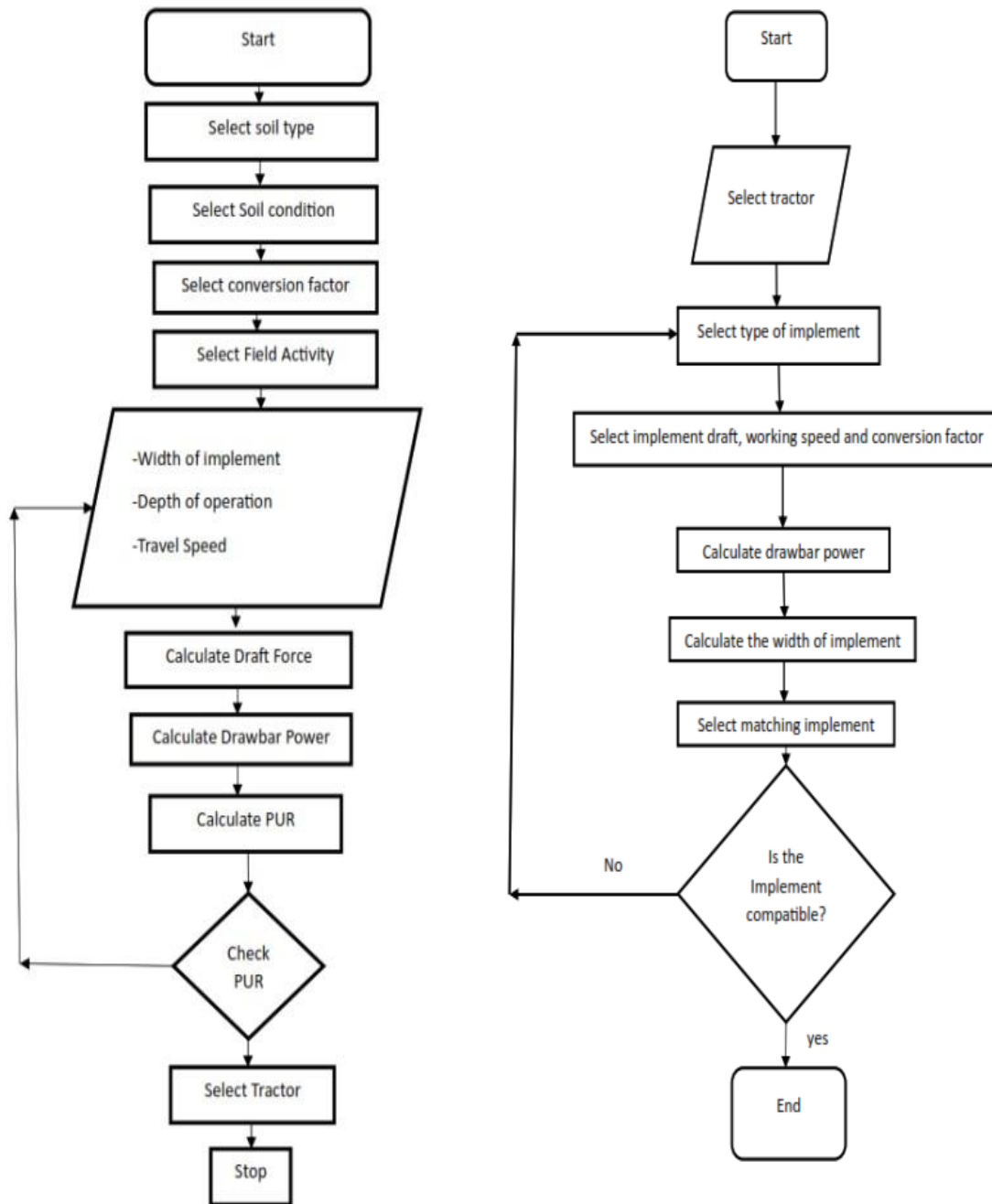
The database about farms had information like types of implements and their sizes found at Wonji Shoa sugar factory and used for this study. It included details such as the name of the implement, its model, width, maker, etc. The database about soils included details on many soil types, including sandy loam, vertisol, and heavy clay soils. For the three aforementioned soil types, the database also included data on the draft force, suggested forward speed, and estimated field efficiency of equipment like the Subsoiler, disc plow, offset or tandem disc harrow, and furrower.

3.5.2. Determination of the size of a tractor

For this study, the DSS provides the ideal tractor and implement size for the activities considered. To determine the tractor size for the selected field operations, an algorithm that produced a Visual Basic computer program was developed. Figure 3.10 (a) shows the program's flowchart. Figure 3.10(b) shows a flowchart for implement selection. The portion of the coding screen is shown in Figure 3.11. The coding screen for tractor selection displays different codes used to calculate the actual drawbar power, required drawbar power, and power utilization ratio (PUR) for the given activity in a specific soil. The inputs of the codes are the implement draft, estimated field efficiency, power conversion factor, travel speed, and width of the implement. The program

computes the required drawbar power for the implement according to the input data for each field activity. Using Eq. (3.4), the program determines the tractor's necessary drawbar power depending on, the working speed, and draft of the implement.

The input parameters for the selection of the appropriate implement size are the size of the tractor (drawbar power), the activity to be performed, and its unit draft force, working speed, and conversion factor. The DSS screen for both the selection of tractor and implement are shown in Figure 3.12 (a,b).



(a). Flowchart for tractor selection

(b). Flowchart for implement selection

FIGURE 3.10: (a, b) Flowchart for selection of tractor and implement

An important parameter, namely, Power Utilization Ratio (PUR) was also calculated by the program to quantify the extent of precision to which the tractor matches the implement. The PUR was calculated by using Eq (3.6). It indicates the comparison between the drawbar power available at the tractor drawbar and the one that is required for the specific field operation.

3.5.3. System Validation

The developed DSS was validated for implement drawbar requirement (DBP), and (PUR), using experimental data collected from the Wonji Shoa sugar factory farm. The DSS's predicted output was compared with the actual field experimental data using a statistical term, relative deviation (RD), which is defined as follows (Kumar and Pandey, 2009, Kimet *al.*, 2022, Efremov *et al.*, 2023, Kurotheet *al.*, 2014,)

$$RD = \frac{1}{N} \sum_{i=1}^N \frac{Pi - Oi}{Pi} * 100 \text{-----} 3.11$$

Where;

P is the anticipated value,

O is the experimental value, and

N is the number of observations

3.6. Economic Benefit Analysis of the Developed System

Depending on the amount of fuel and the amount of time a tractor or machine is used, fuel and lubricant costs will usually represent at least 16 percent to over 45 percent of the total machine

costs (Grisso and Kocher, 2004). For this study, the estimated fuel consumption of the tractor selected by the system was determined by equation 3.12 (Grisso and Kocher, 2004).

$$Q = (2.64X + 3.91 - 0.203\sqrt{738X + 173}) * X * P_{pto} \dots\dots\dots 3.12$$

where

Q = diesel fuel consumption at partial load, L/h (gal/h)

X = the ratio of equivalent PTO power (PT) to rated PTO power (Ppto), decimal

Ppto = the rated PTO power, kW (hp)

Cost-benefit analysis (CBA) was used to evaluate the economic gains obtained by using the DSS. CBA is a method for comparing the entire costs and benefits of a project or investment using a standard metric (often monetary units). This allows us to assess the net profit or expense of the project and decide whether or not to pursue it. The benefit-cost ratio (B/C ratio) is the ratio of benefits to costs (expressed in present or annual value). It is a simple benefit-cost ratio for investment. In the current study, the benefit-cost ratio of the DSS was estimated using the following formula (Acharya *et al.*, 2020, Ward, 2019).

$$\frac{B}{C} ratio = \sum_{t=1}^t \frac{B_t}{(1+r)^t} / \sum_{t=1}^t \frac{C_t}{(1+r)^t} \dots\dots\dots 3.13$$

Where,

B_t = Discounted benefit from the machines

(NRs.) C_t = Discounted cost incurred (NRs)

t= time (years) r= interest rate rate

Decision criteria:

If, the B/C ratio > 1, Accept the system,

If, the B/C ratio < 1, Reject the system,

If, B/C ratio = 1, Indifferent

3.7. Method of Data Analysis

The software IBM SPSS Statistics 26 package was used to undertake the data analysis. From the software package, the explanatory and inferential data analysis method was used for this study. Explanatory analysis is used to find influences. It means explanatory analysis tries to reach the answer to the research questions related to the connections, relations, and patterns between variables Taherdoost and Madanchian (2020).

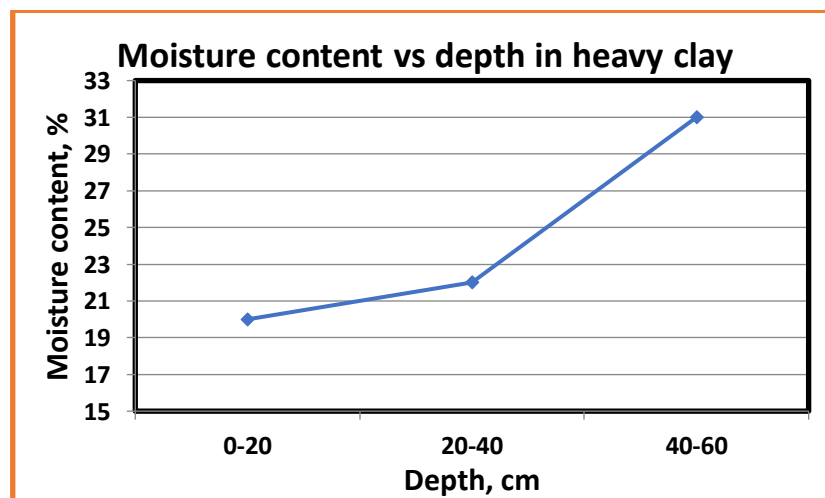
The main tools for these techniques were: Analysis of variance (ANOVA), equation modeling Regression, and correlation

CHAPTER FOUR: RESULTS AND DISCUSSIONS

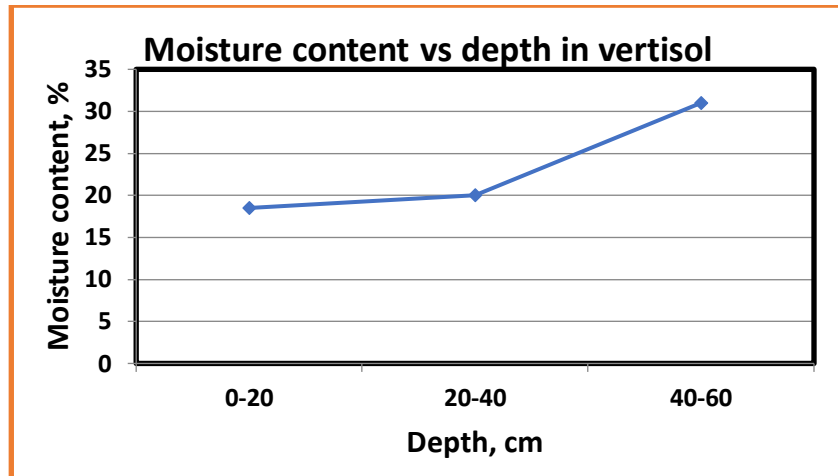
4.1. Effect of Soil Depth on Its Physical Properties

The physical properties of the soil mostly influence implement and tractor performance; like draft force, drawbar power, and fuel consumption. The compositions of the soil types and their physical properties at different depths are presented in Figures 4.1 – 4.3. It was in line with the finding of Tesfaye (2021), who also found nearly similar values of the physical properties of soils at the Wonji-Shoa sugar factory.

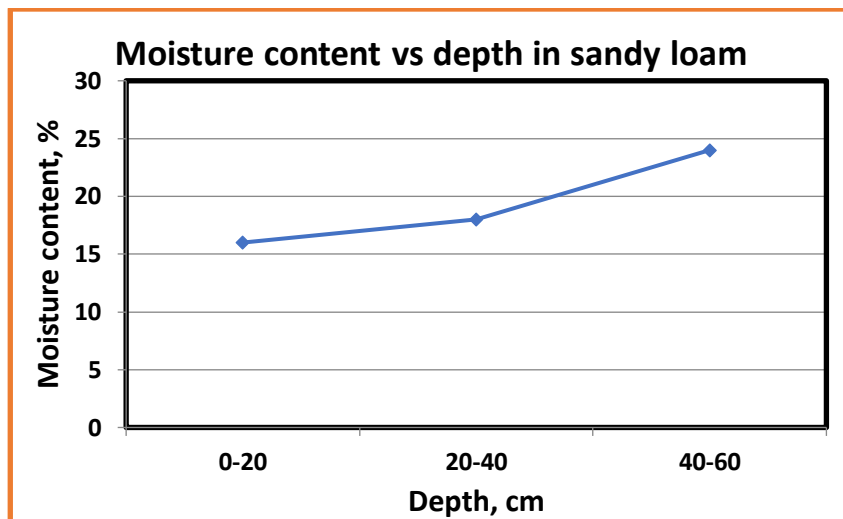
In all the soil types, bulk density was increased with depth in the soil profile. Numerically the highest mean (1.3 g cm^{-3}) value of bulk density was recorded in heavy clay soil at a depth of 60 cm and the lowest mean (1 g cm^{-3}) value was under the top layer of sandy loam soil. The highest value in bulk density in clay soil is attributed to the nature of fine clay particles. One of the reasons for the highest draft force requirement for different field activities in heavy clay soil was therefore due to the highest bulk density recorded in it. Following the variations in bulk density, the total porosity of all the soil types showed a generally decreasing trend with soil depth (Figures 4.1 – 4.3). The higher total porosity in the topsoil layer of the cultivated land is likely attributed to high organic matter and tillage. This is in line with Barzegar et al., (1997), who reported the effectiveness of organic residue in reducing soil compaction. It was also observed that soil moisture content increases with depth. The highest mean (31%) was recorded in heavy clay soil and vertisol and the lowest mean (16%) in sandy loam soil which is attributed to the low water retention capacity of sandy soils



a. Heavy Clay

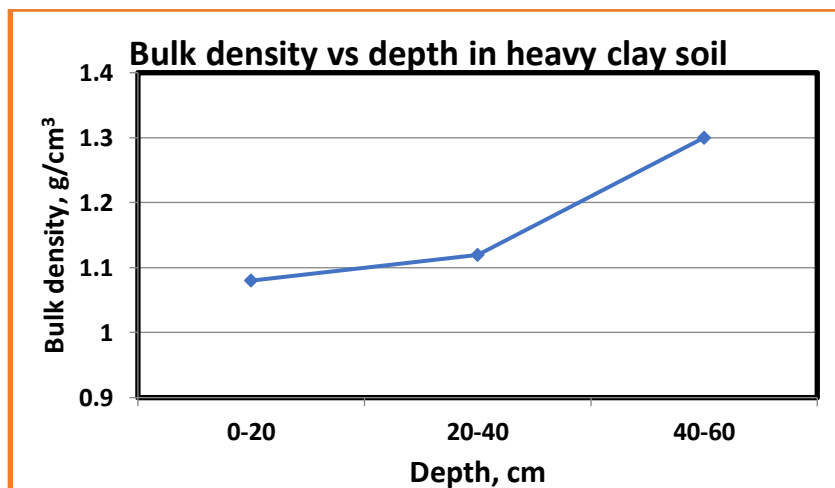


b. Vertisol

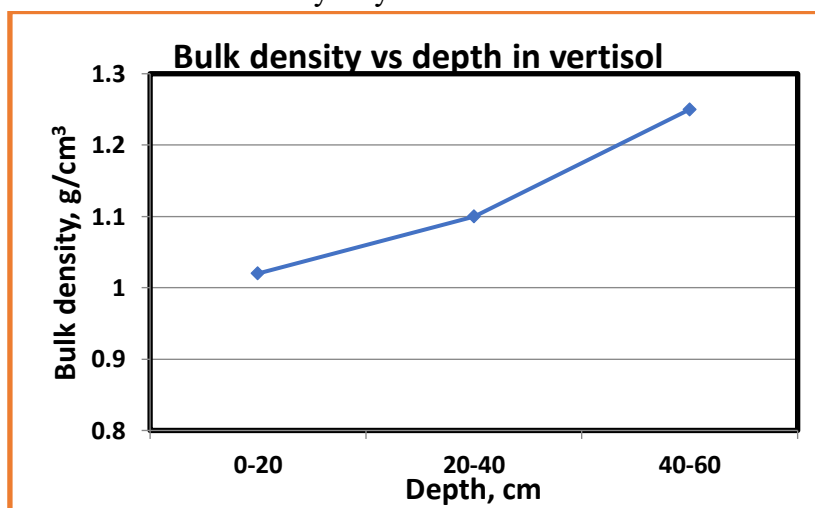


c. Sandy loam

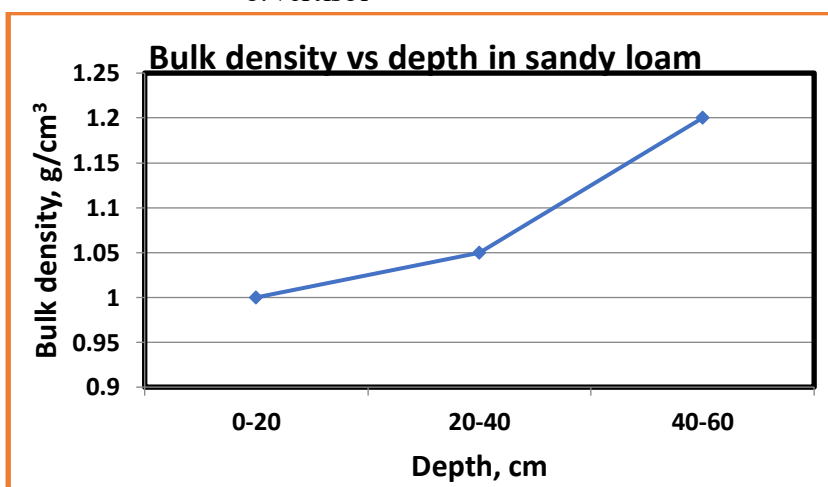
FIGURE 4.1(a,b,c): Effect of soil type and its depth on soil moisture content



a. Heavy clay soil

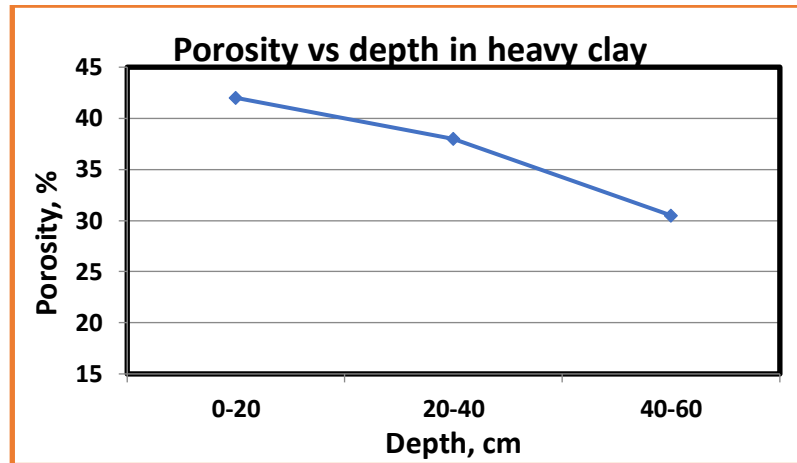


b. Vertisol

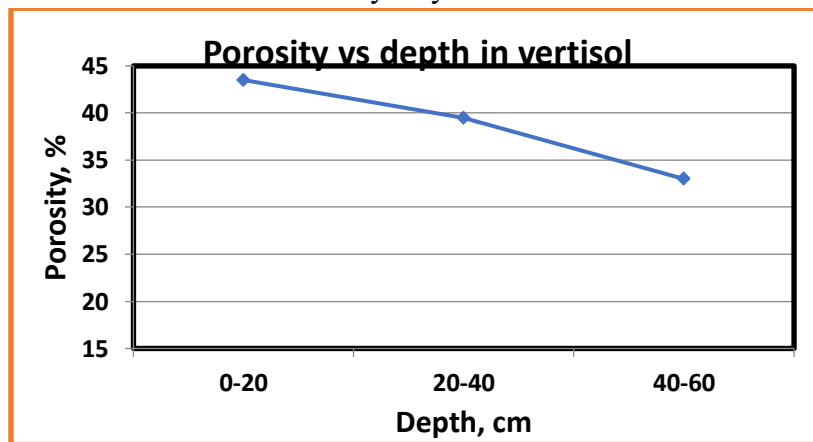


c. Sandy loam

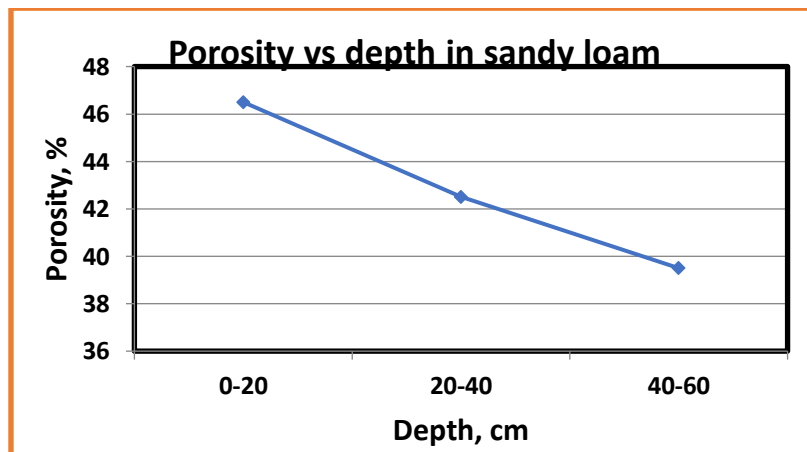
FIGURE 4.2(a,b,c): Effect of soil type and its depth on soil bulk density



a. Heavy clay soil



b. Vertisol



c. Sandy loam

FIGURE 4.3(a,b,c): Effect of soil type and its depth on soil porosity

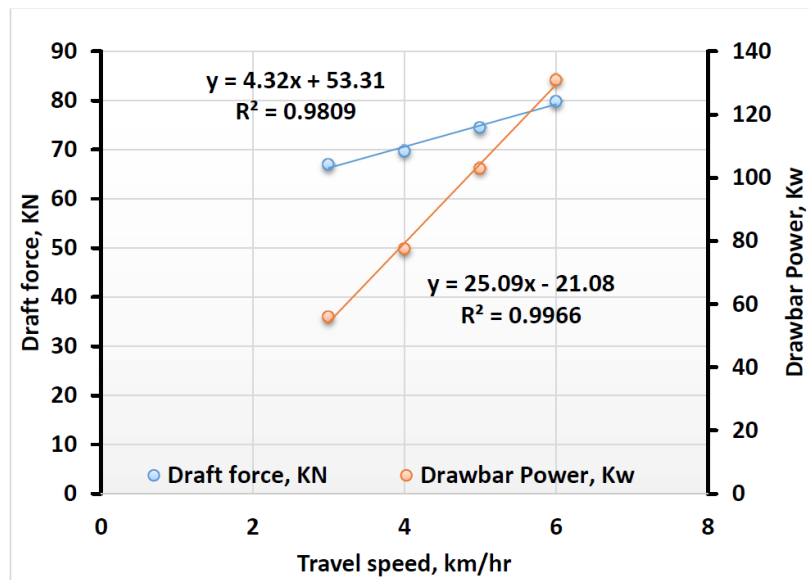
4.2. Evaluation of Farm Tractor Selection

For the study of tractor selection, the influence of travel speed and soil type on draft force and drawbar power for subsoiling, ploughing, harrowing and furrowing activities in the three soil types were depicted in Figures 4.4(a,b,c,d), 4.5(a, bc,d), 4.6 (a,b,c,d) and 4.7(a,b,c,d), respectively and ANOVA tables in Table 4.1, 4.2, 4.3, and 4.4 respectively also.

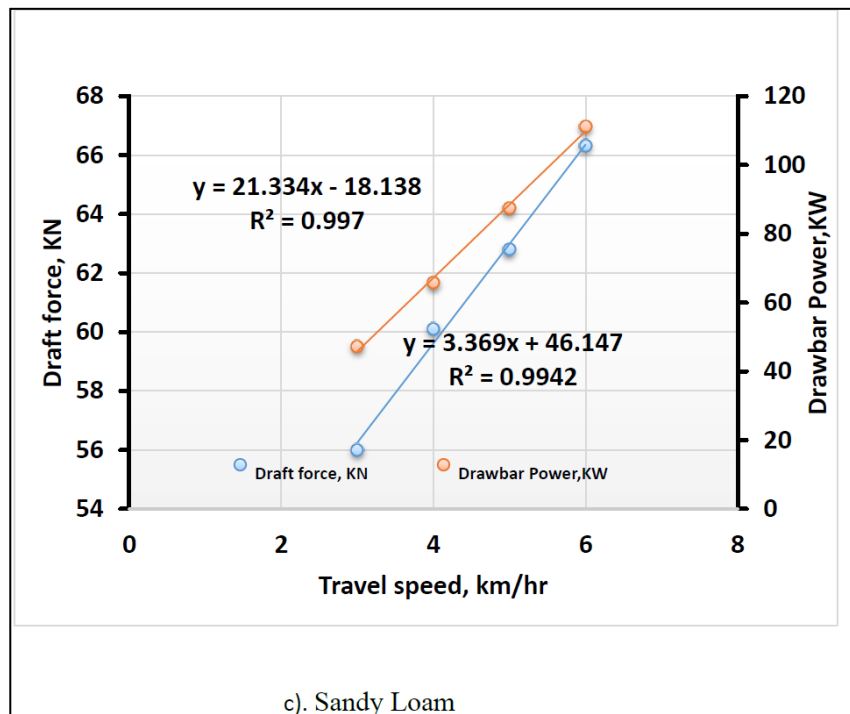
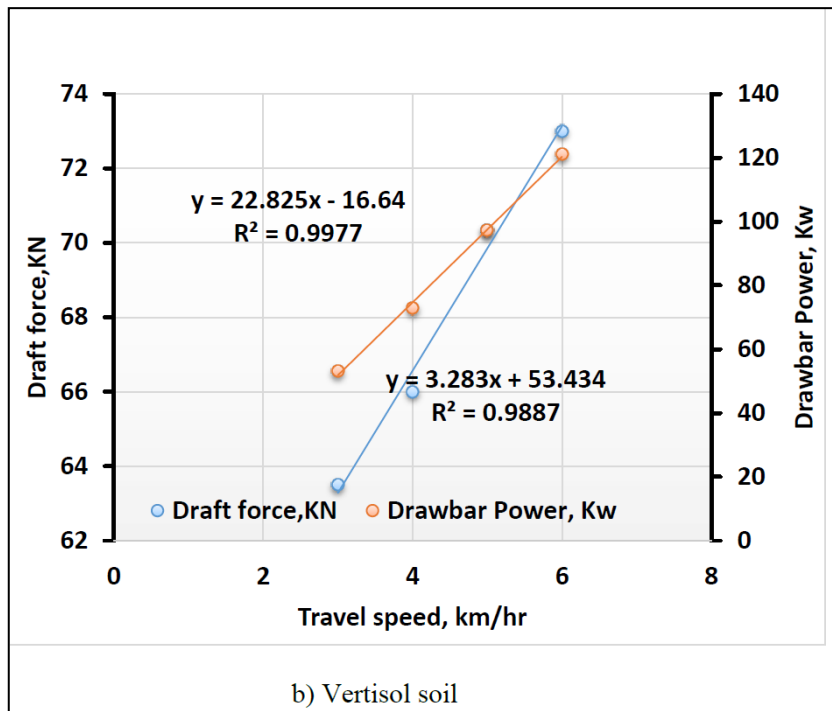
The influence of soil type and travel speed on draft force and drawbar power requirement in three soil types for subsoiling operation was shown in Figures 4.4 (a,b,c,d). From these figures; it is observed that both draft force and drawbar power increase as tractor travel speed increases. High tractor working speeds provide a high shear rate and friction between the soil and tillage tools because tillage involves the movement of the soil from one place to the other. Hence as travel speed increases implement draft also increases (Aruna *et al.*, 2020, Balsari *et al.*, 2021, Zhang *et al.*, 2015)

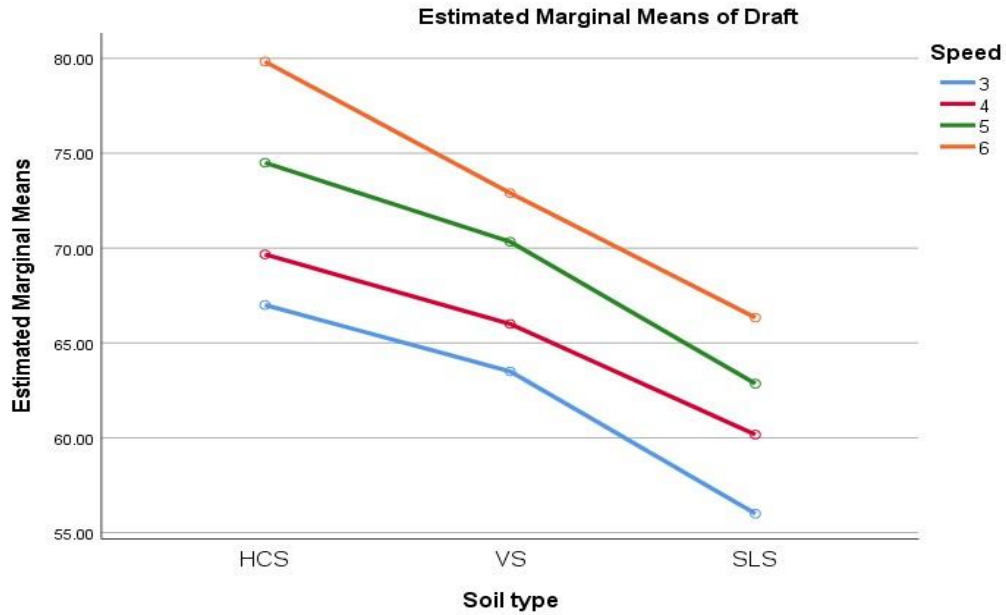
Moreover; the values of these draft force and drawbar power for any equal travel speed in all three soil types are significantly different due to differences in soil failure points which is in line with the findings of Askari and Khalifahamzehghasem (2013). Analysis of variance (ANOVA), Table 4.2 shows the interaction between variables. 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 3 km/hr to 6 km/hr, draft force increased from 63.5 kN to 73 kN and drawbar power increased from 53.16 kW to 121.1 kW. In sandy loam soil, it was 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. The acquired results of this study are consistent with earlier published investigations. Upadhyay and Rahman (2018), for example, evaluated a powered disc harrow and found increases of 43.6%, 31.8%, and 36.6% when the tractor speed was increased from 3.7 km/hr to 6.6 km/hr. Usaborisut and Prasertkan (2018) observed that the average draft of the tested rotary harrow increased from 31.3 to 35.1 kN as the tractor speed climbed from 1.79 to 3.33 km/hr. Ranjbarian et al., (2017) observed similar results after measuring the draft of three distinct implements (mouldboard plough, disc plough, and chisel plough) at four tractor speeds. They demonstrated how the draft increased as

tractor speed increased. Sahu and Rahman (2006) also found that increasing the speed of the tested cultivator with a disk gang increased the draft. A comparison of draft force and drawbar power requirements for subsoiling in three soil types is 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 of the same forward speeds. For example, at 6 km/hr, the drawbar power requirement is 131 kW, 121.1 kW, and 111.1 kW for heavy clay soil, vertisol, and sandy loam soil respectively, in line with the findings of Aday and Ramadhan, (2019) and Jyoti *et al.*, (2019).



a) Heavy clay soil





d) Comparison among soil types at the same travel speed

FIGURE 4.4 (a, b, c d): Effect of travel speed and soil type on draft force and drawbar power for subsoiling

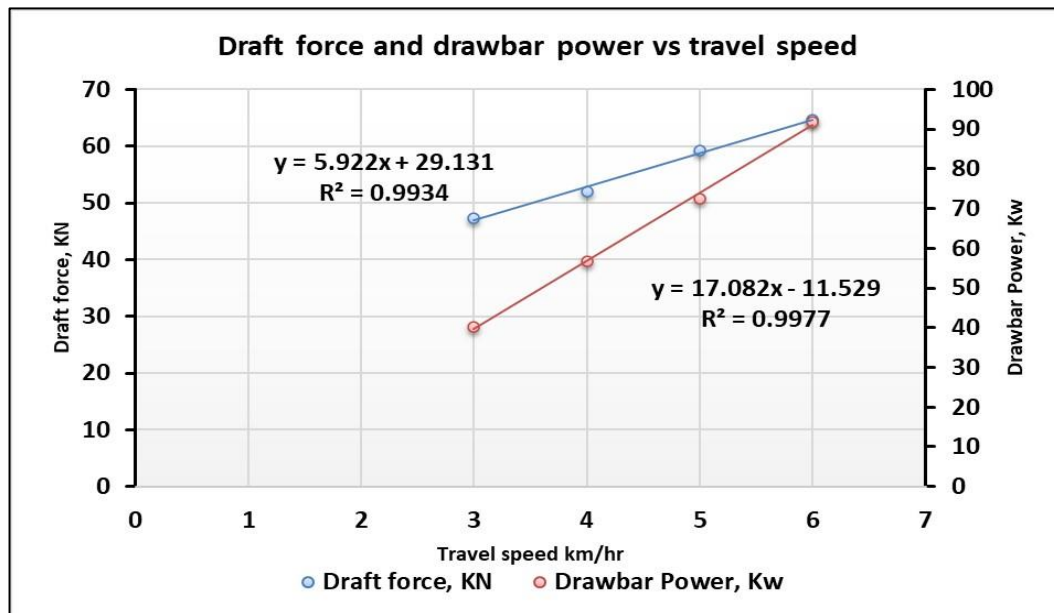
Table 4.1: ANOVA for the effect of travel speed and soil type on the draft force for subsoiling

Tests of Between-Subjects Effects					
Dependent Variable: Draft					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1411.213 ^a	11	128.292	180.880	0.000
Intercept	163655.309	1	163655.309	230738.756	0.000
Soil type	791.738	2	395.869	558.139	0.000
Speed	601.592	3	200.531	282.730	0.000
Soil type * Speed	17.882	6	2.980	4.202	0.005
Error	17.022	24	0.709		
Total	165083.544	36			
Corrected Total	1428.235	35			
a. R Squared = .988 (Adjusted R Squared = .983)					

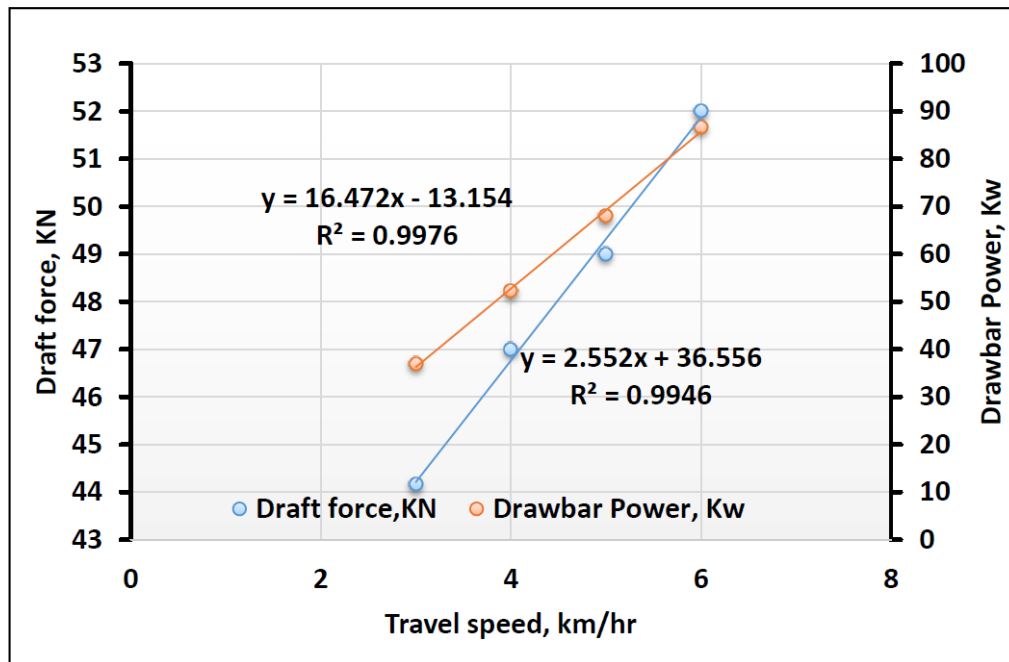
The trend of the effect of tractor forward speed on draft force and drawbar power requirement in three soil types for ploughing operation observed is similar to that of subsoiling, but the values are different. The change in values is mainly due to the differences in tillage depth, type and size of the implements, and the condition of soil during the tillage operations. Hence for the ploughing operation, figure 4.5 (a, b,c,d), 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.

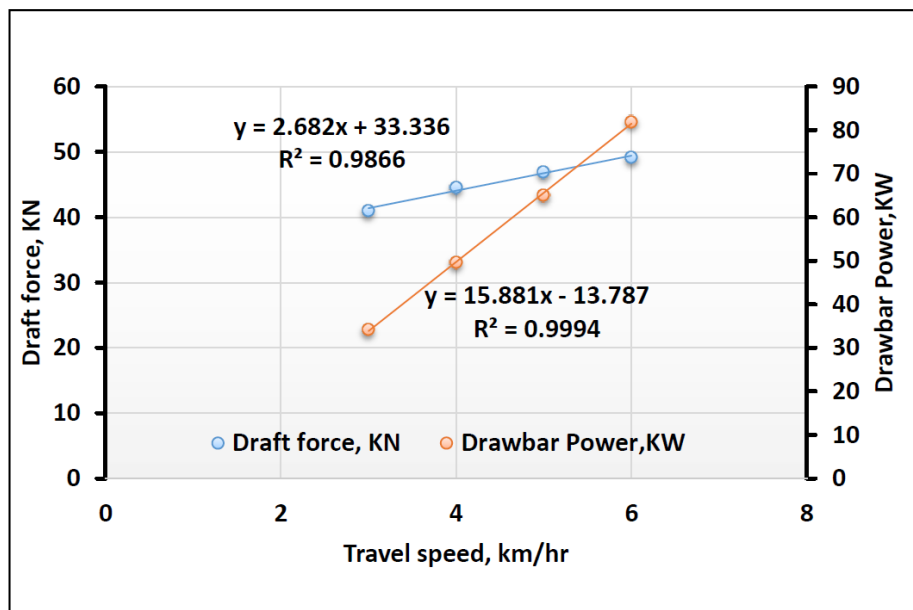
A comparison of draft force and drawbar power requirements for ploughing in three soil types is also presented in Figure 4.5 (d). From this figure, it is also observed that due to the nature of its particles, heavy clay soil requires more draft force and drawbar power and less sandy loam soil at the same travel speed. Table 4.2 also depicts these significant differences



a. Heavy Clay soil



b). Vertisol



c. Sandy loam

FIGURE 4.5(a b, c,): Effect of travel speed and soil type on draft force and drawbar power for ploughing.

Table 4.2: ANOVA for the effect of travel speed and soil type on the draft force for ploughing

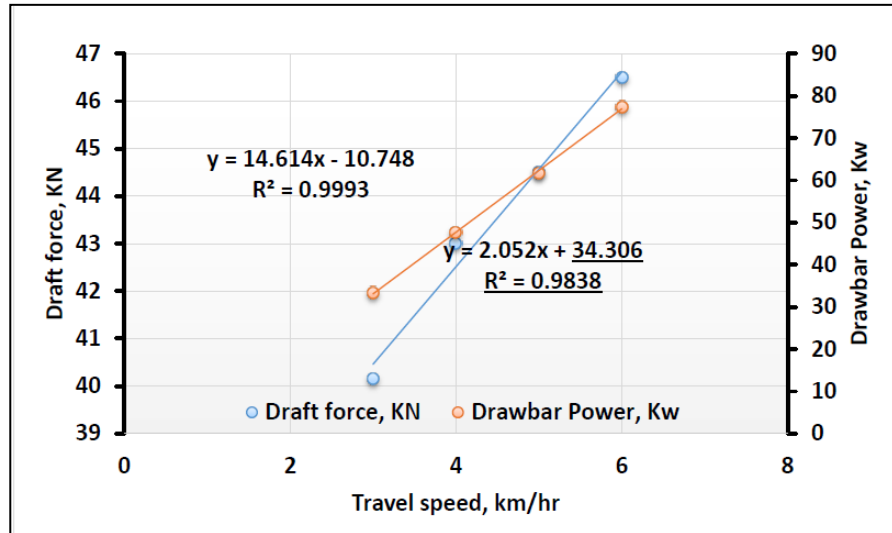
Tests of Between-Subjects Effects					
Dependent Variable: Draft Force					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	508.910a	11	46.265	40.465	0.000
Intercept	84042.010	1	84042.010	73506.131	0.000
Soil type	224.012	2	112.006	97.964	0.000
Speed (km/hr)	281.763	3	93.921	82.147	0.000
Soil type *speed	3.135	6	0.522	0.457	0.833
Error	27.440	24	1.143		
Total	84578.360	36			
Corrected Total	536.350	35			
a. R Squared = .949 (Adjusted R Squared = .925)					

Harrowing is somehow a lighter field operation, when compared with subsoiling and ploughing as the depth of operation is shallower and the soil is well disturbed earlier by ploughing.

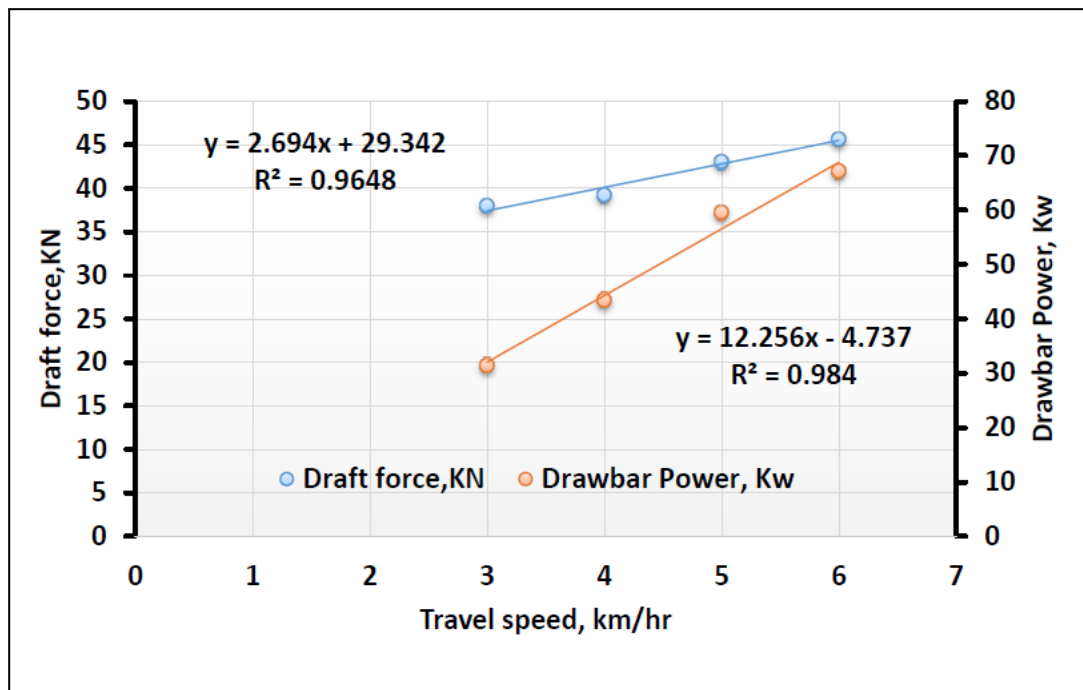
As depicted in figure 4.6 (a,b,c,d) the trend of the effect of tractor forward speed on draft force and drawbar power requirement in three soil types observed is similar to that of subsoiling and ploughing discussed earlier, but with different values. From Figure 4.6(a), it is observed that draft force 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 4.6 (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 4.6 (c) indicates the same trend between travel speed, draft 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, a comparison of draft force and drawbar power requirements for harrowing in three soil types is also presented in Figure 4.6 (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

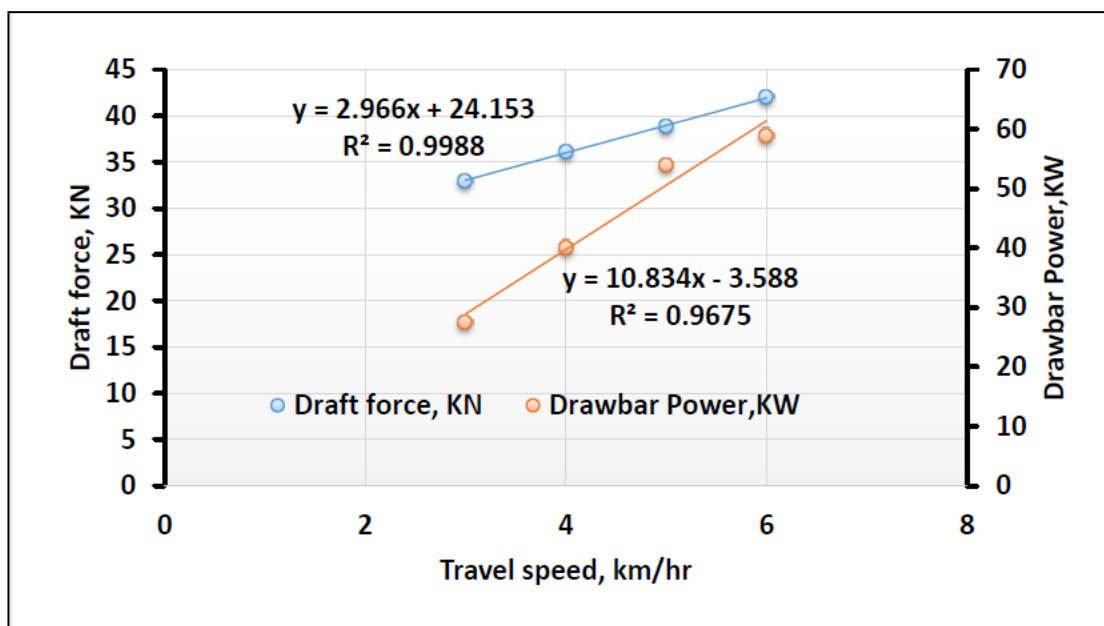
forward travel speed. For instance, at 6 km/hr, the drawbar power requirement is 77.4 kW, 67 kW, and 59 kW in heavy clay soil, vertisol, and sandy loam soil respectively. Table 4.3 also affirms the significant difference between the effect of soil type and travel speed on draft force and drawbar power.



(a). Heavy clay soil



(b). Vertisol soil



(c). Sandy loam

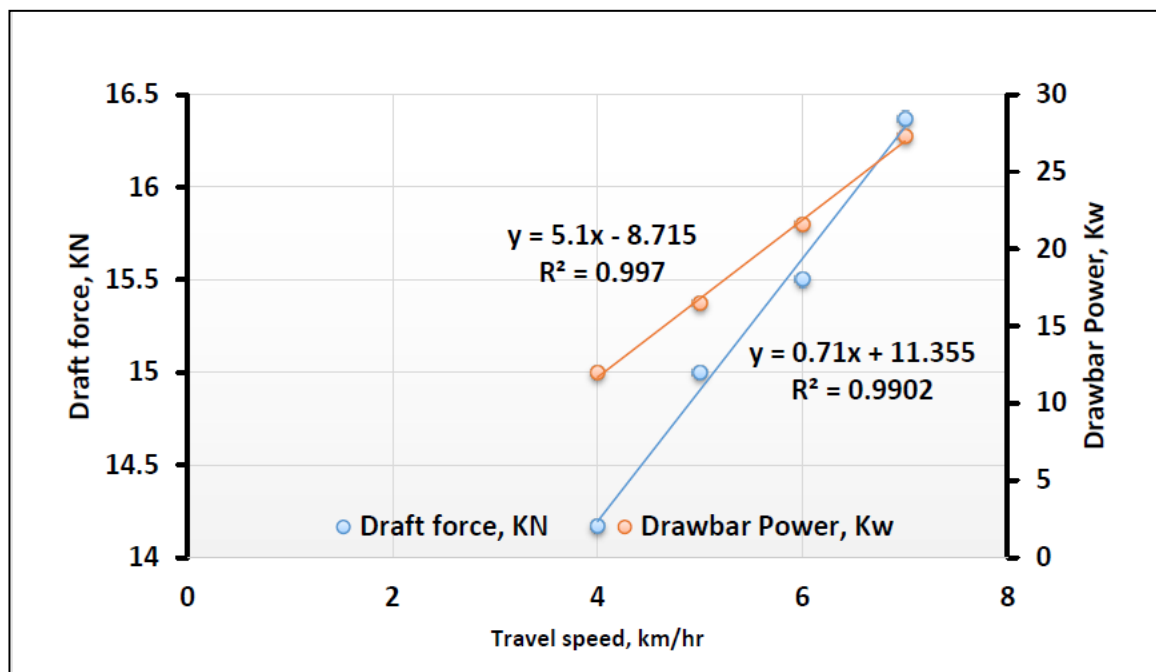
FIGURE 4.6: (a,b,c,) Effect of travel speed and soil type on draft force and drawbar power for harrowing

Table 4.3: ANOVA for the effect of travel speed and soil type on the draft force for harrowing

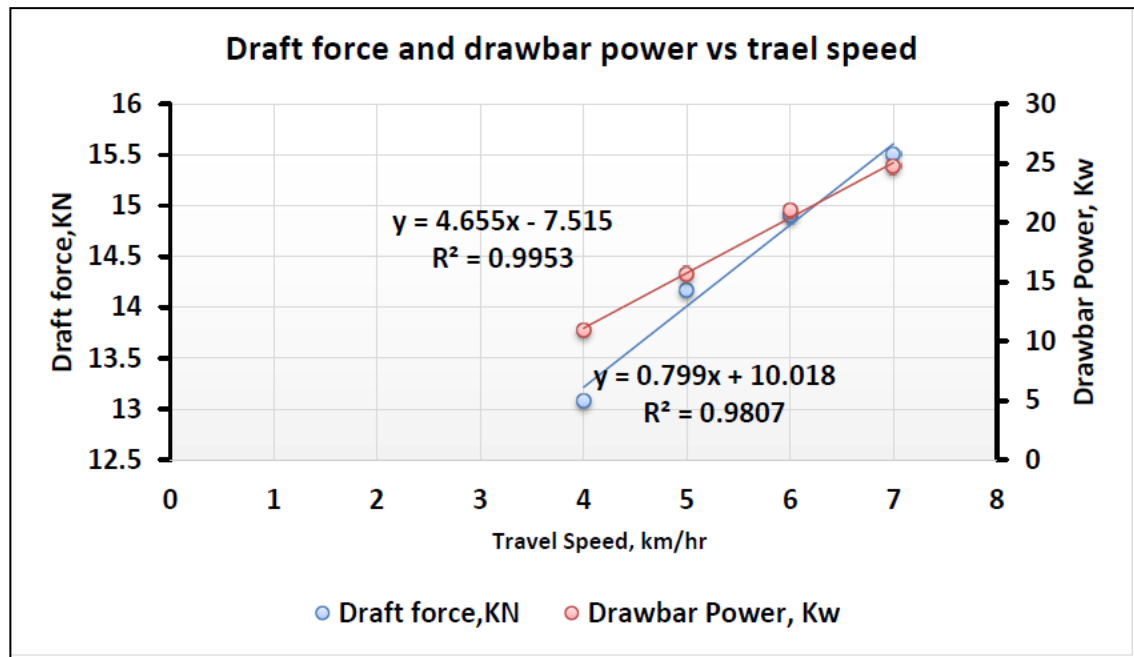
Tests of Between-Subjects Effects					
Dependent Variable: Draft Force					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	528.316 ^a	11	48.029	55.525	0.000
Intercept	59837.314	1	59837.314	69176.085	0.000
Soil type	223.802	2	111.901	129.365	0.000
Speed (km/hr)	294.285	3	98.095	113.405	0.000
Soil type *speed	10.229	6	1.705	1.971	0.110
Error	20.760	24	0.865		
Total	60386.390	36			
Corrected Total	549.076	35			
a. R Squared = .962 (Adjusted R Squared = .945)					

Furrowing is the final and lightest tillage activity which is done immediately after leveling the farm land. Figure 4.7 (a,b, c,d) depicted the influence of travel speed and soil type on draft force

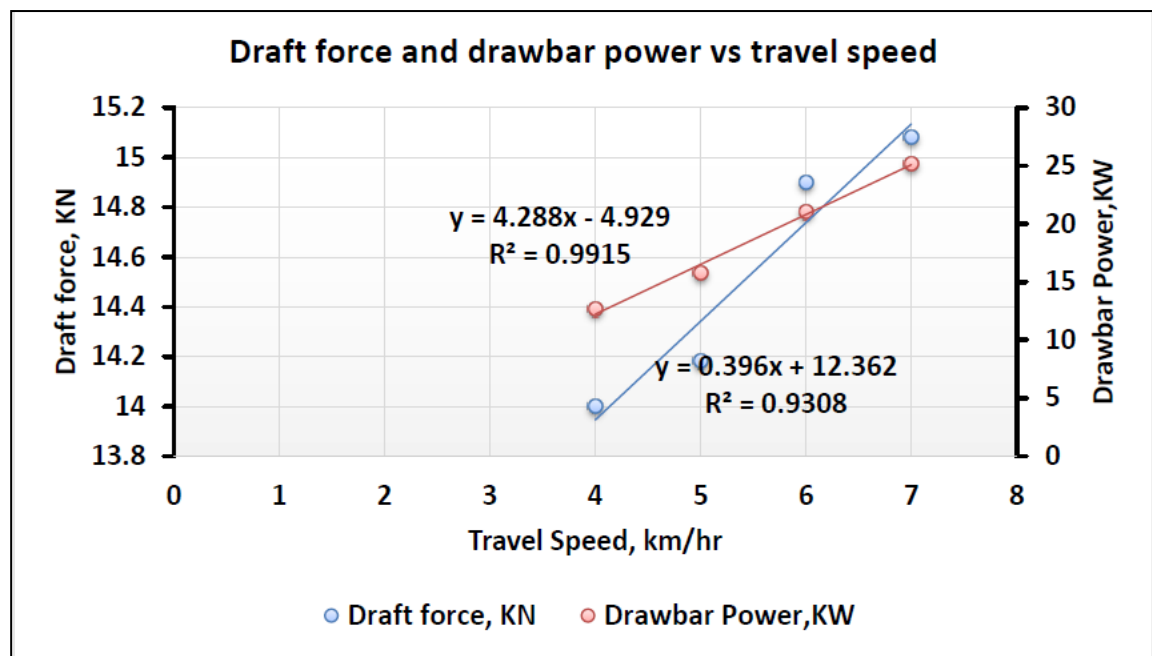
and drawbar power requirements for this task in heavy clay soil, vertisol, and sandy loam soil respectively. For furrowing operation, figure 4.7. (a) indicates that draft force increased from 14.17 kN to 16.5 kN and drawbar power from 12 kW to 27.3 kW when travel speed increased from 4 km/ hr to 7 km/hr in heavy clay soil. Figure 4.7 (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 15.5 kN and drawbar power changed from 11kW to 24.7 kW. Figure 4.7 (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, a comparison of draft force and drawbar power requirements for furrowing in the given three soil types was also presented in Figure 4.7 (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 as for other field activities. If welook 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.



(a). Heavy clay soil



(b). Vertisol



c). sandy loam soil

FIGURE 4.7 (a,b c):Effect of travel speed and soil type on draft force and drawbar power requirements for furrowing

Table 4.4: ANOVA table for Effect of travel speed and soil type on draft force for furrowing

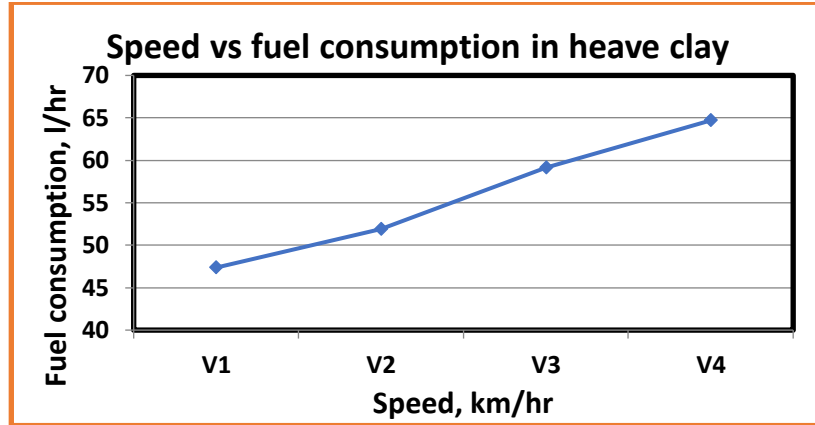
Tests of Between-Subjects Effects					
Dependent Variable: Draft force, KN					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	21.638 ^a	11	1.967	20.118	0.000
Intercept	7726.410	1	7726.410	79020.102	0.000
Soil type	5.161	2	2.581	26.393	0.000
Travel speed (km/hr)	14.273	3	4.758	48.659	0.000
Soil type * speed	2.204	6	0.367	3.756	0.009
Error	2.347	24	0.098		
Total	7750.395	36			
Corrected Total	23.985	35			
a. R Squared = .902 (Adjusted R Squared = .857)					

4.2.1. Effect of soil type and speed on fuel consumption and OEE

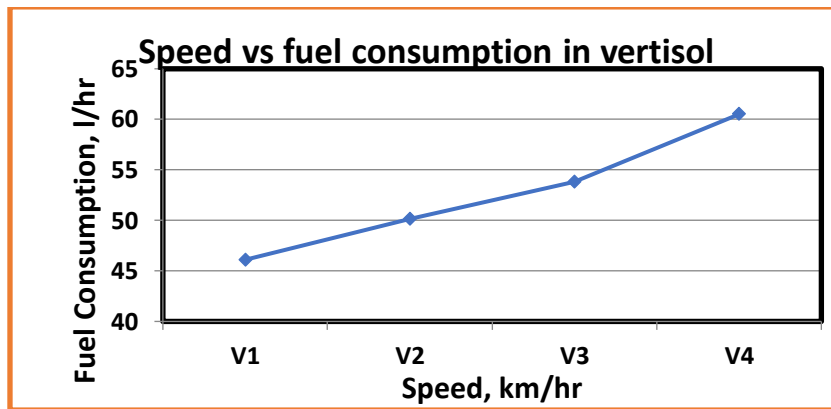
Figures 4.8 – 4.11 show the effect of soil type and travel speed on tractor fuel consumption and overall energy efficiency in three soil types and four tillage activities namely; subsoiling, ploughing, harrowing and furrowing. Figures show that tractor fuel consumption (l/hr) and OEE increase with tractor travel speed and draft force for all soil types and all field activities which was in line with the findings of Serran *et al.*, (2008) and Mehta *et al.*, (2010). The values of v_1 was 3km/hr, $v_2 = 4$ km/hr, $v_3 = 5$ km/hr and $v_4 = 6$ km/hr for all field activities except furrowing. For furrowing the value of v_1 was 4km/hr, $v_2 = 5$ km/hr, $v_3 = 6$ km/hr and the value of v_4 was 7 km/hr

It is indicated that the highest fuel consumption was recorded in heavy clay soil followed by vertisol and sandy loam soil for all tillage activities. Figure 4.8 also indicates that forward velocity, soil type, and interactive effect influenced 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 which means, OEE increased as forward velocity increased and was 10-20% and in line with Ranjbarian *et al.*, (2017) report but most of the OEE values of this study were around the lower ranges. Lopez *et al.*, (2019), also reported the average OEE value for different implements,

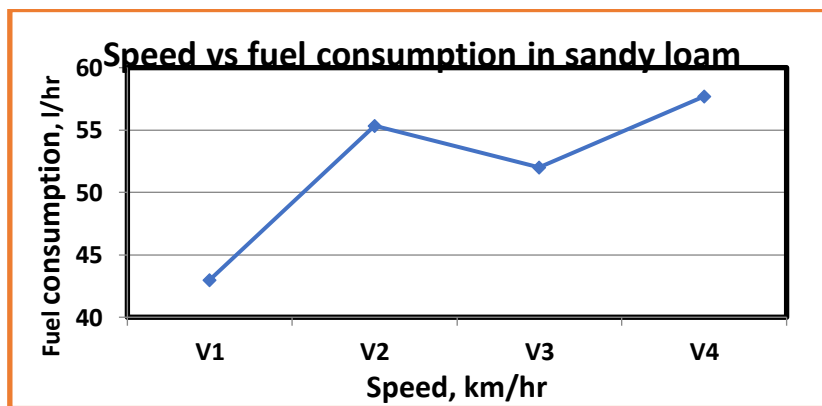
18.23%, for DDP, 6.88 for CHDP, and 4.77% for NT which was lower than most findings. The relationship between OEE and forward velocity in all soil types was linear for all tillage activities in all soil types with the coefficient of linear regression $R > 0.95$



a. Heavy caly

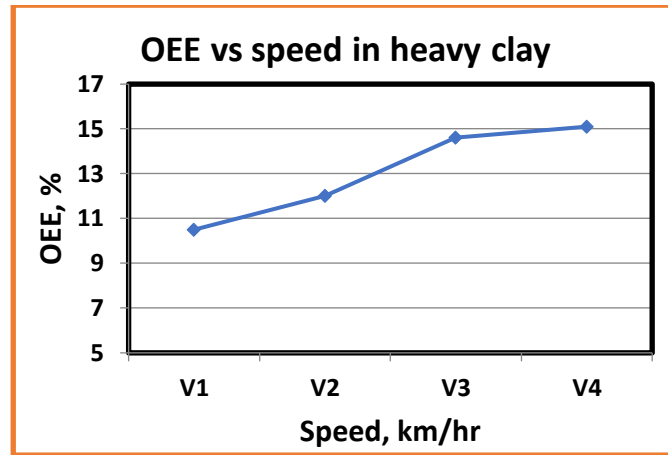


b. Vertisol

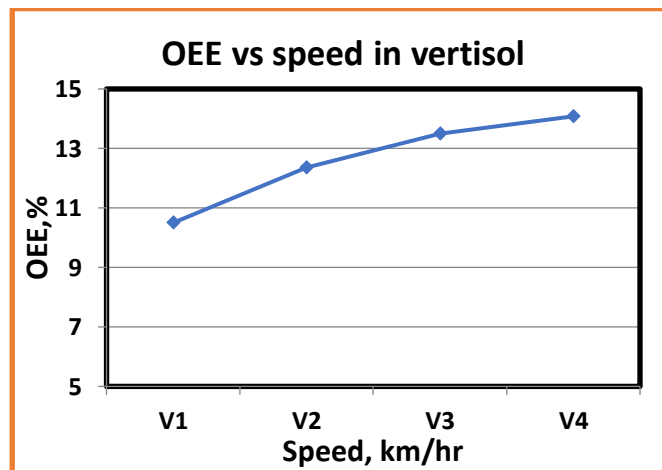


c. Sandy loam

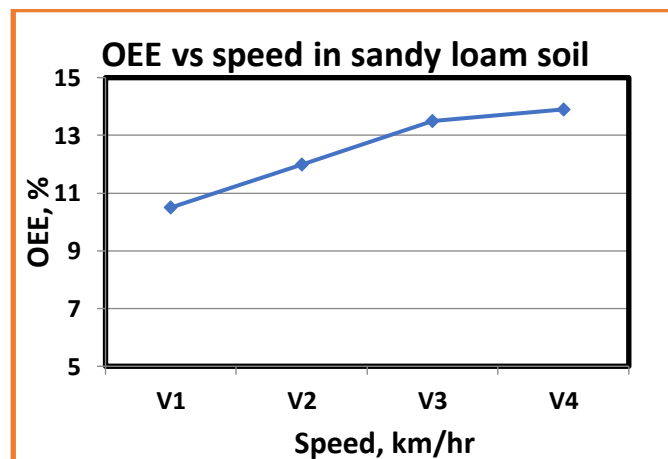
FIGURE 4.8(a,b,c): Effect of soil type and travel speed on fuel consumption for sub-soiling



a. Heavy caly

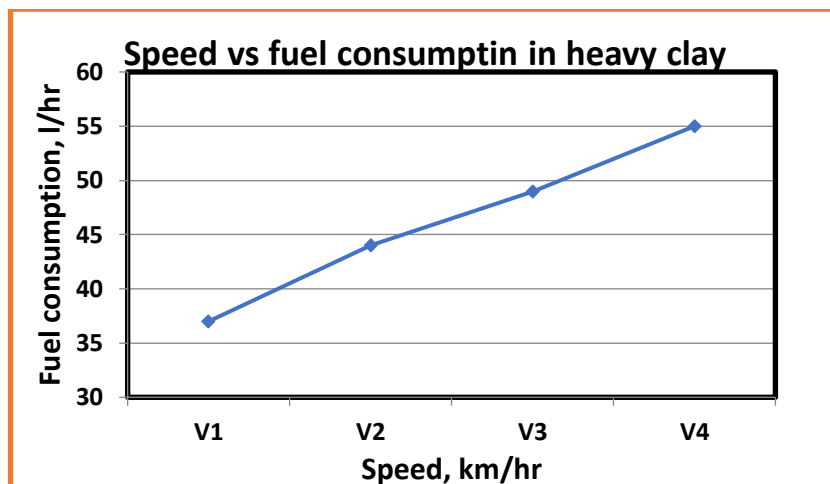


b. Vertisol

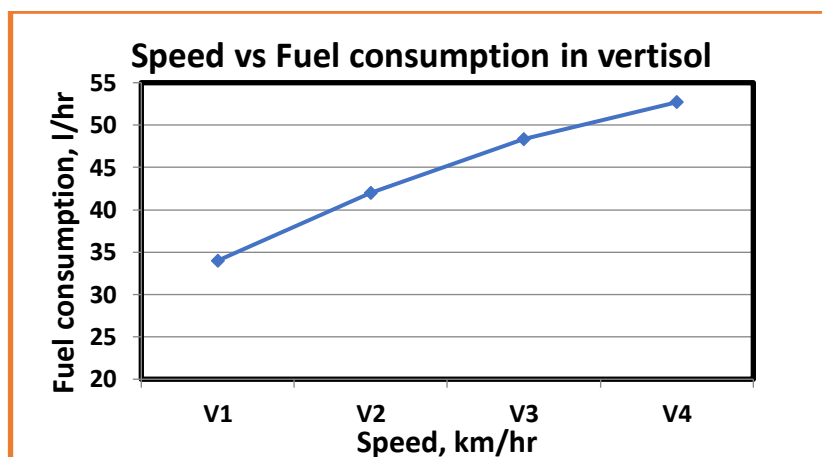


c. Sandy loam

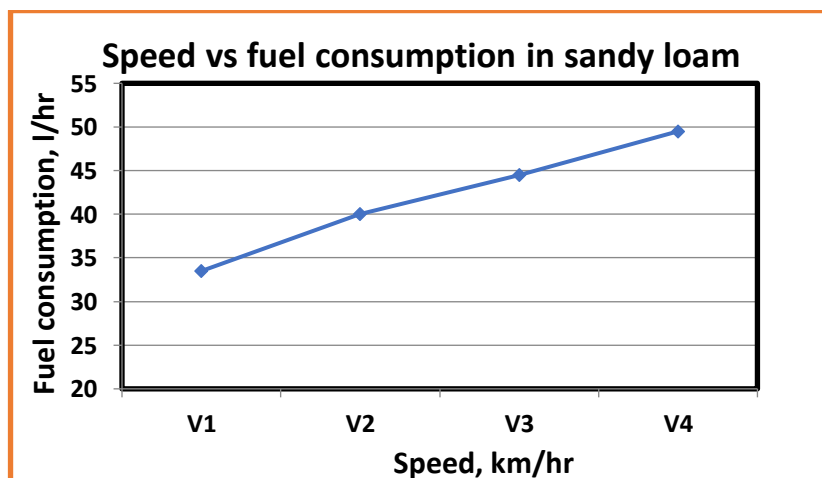
FIGURE 4.9 (a,b,c): Effect of soil type and travel speed on overall energy efficiency for sub soiling.



a. Heavy caly

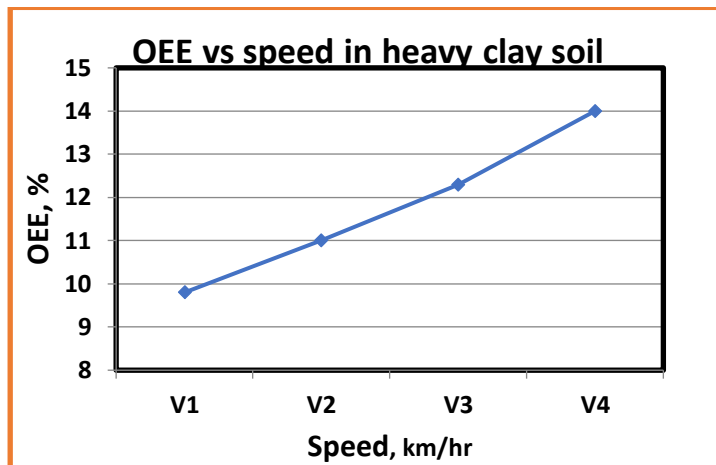


b. Vertisol

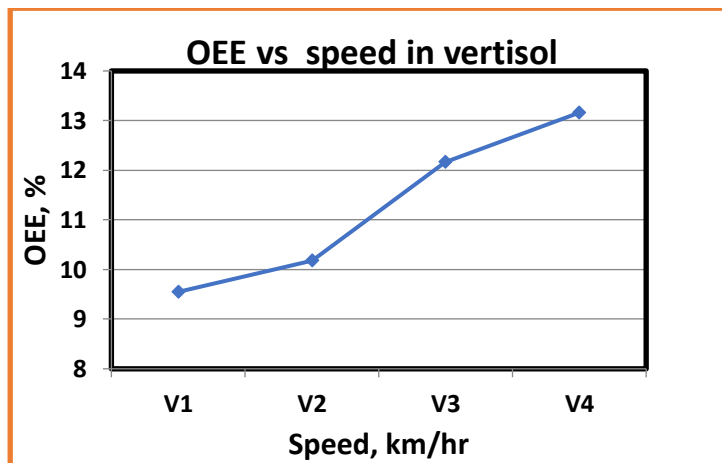


c. Sandy loam

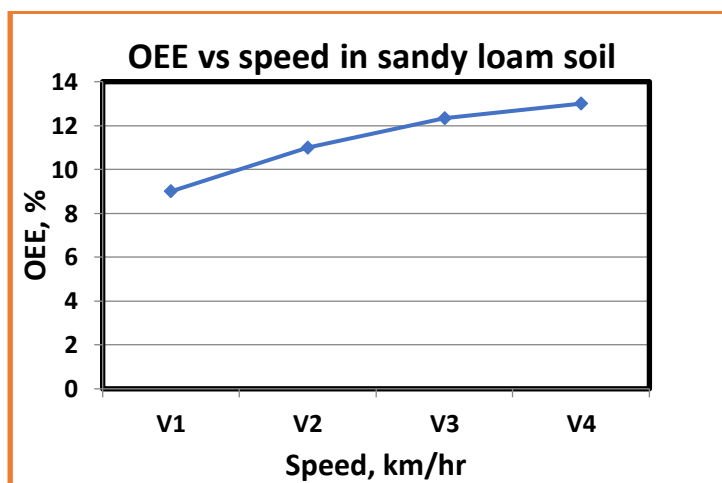
FIGURE 4.10 (a,b,c): Effect of soil type and travel speed on fuel consumption for ploughing



a. Heavy caly

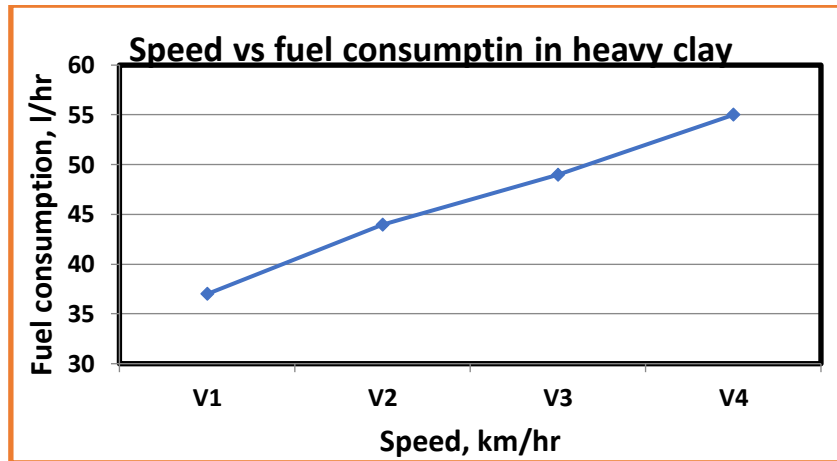


b. Vertisol

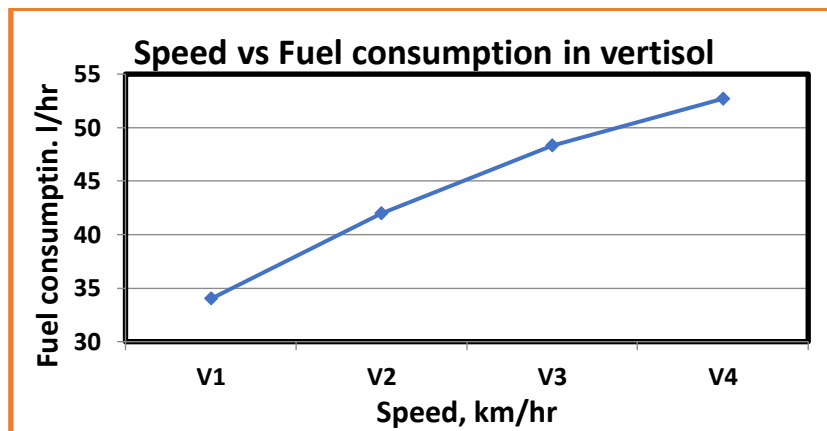


c. Sandy loam

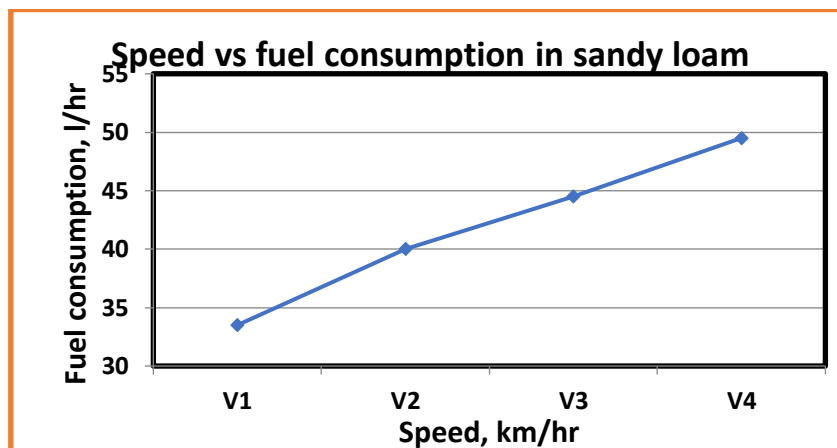
FIGURE 4.11(a,b,c): Effect of soil type and travel speed on overall energy efficiency for ploughing



a. Heavy caly

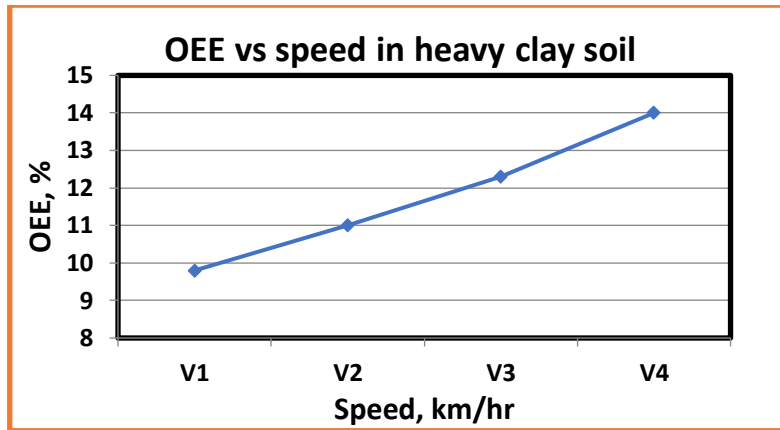


b. Vertisol

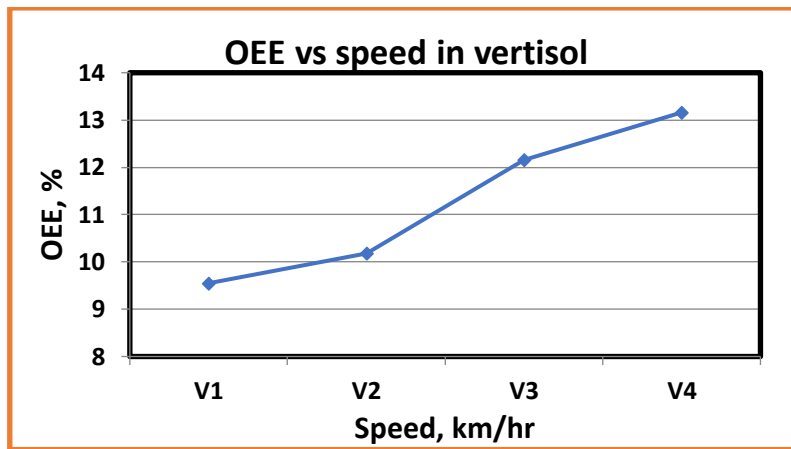


c. Sandy loam

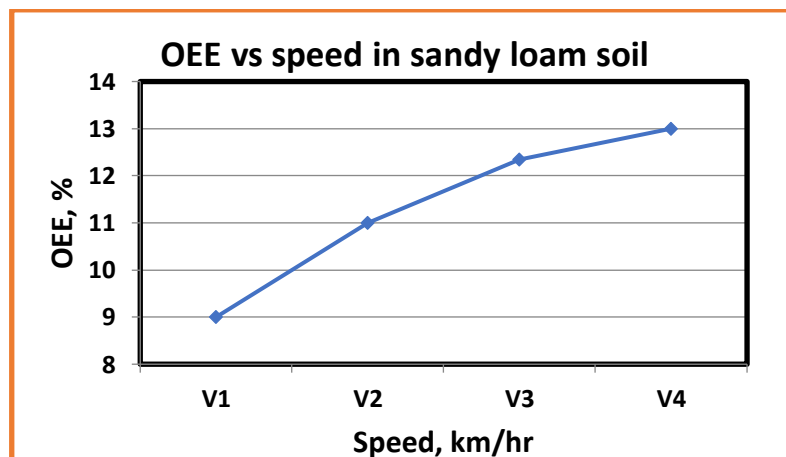
FIGURE 4.12 (a,b,c): Effect of soil type and travel speed on fuel consumption for harrowing



a. Heavy caly

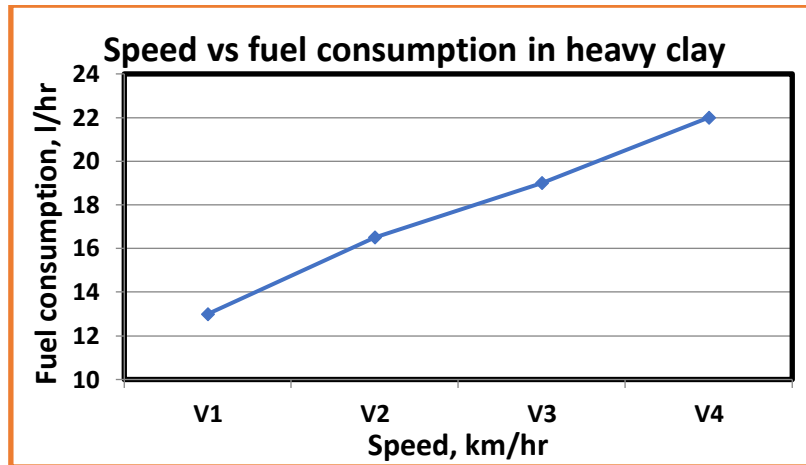


b. Vertisol

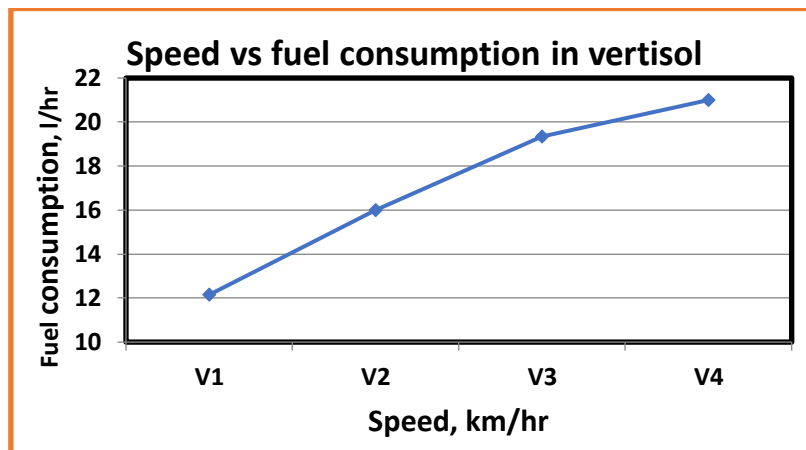


c. Sandy loam

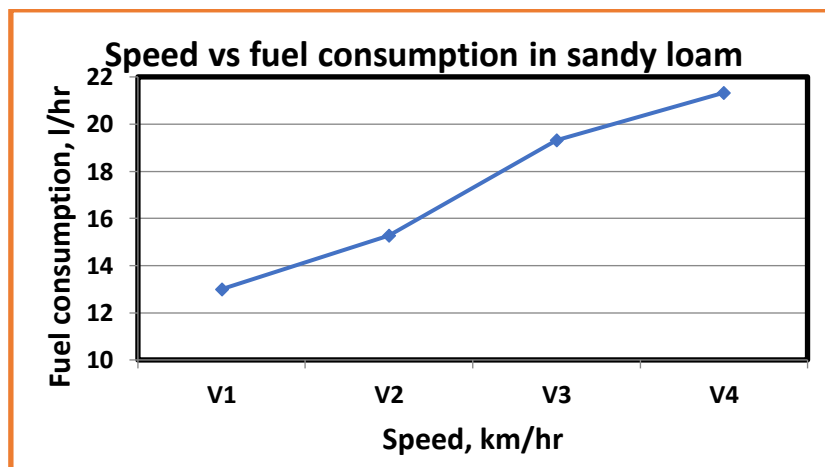
FIGURE 4.13 (a,b,c): Effect of soil type and travel speed on overall energy efficiency for harrowing



a. Heavy caly



b. Vertisol



c. Sandy loam

FIGURE 4.14 (a,b,c): Effect of soil type and travel speed on fuel consumption for furrowing

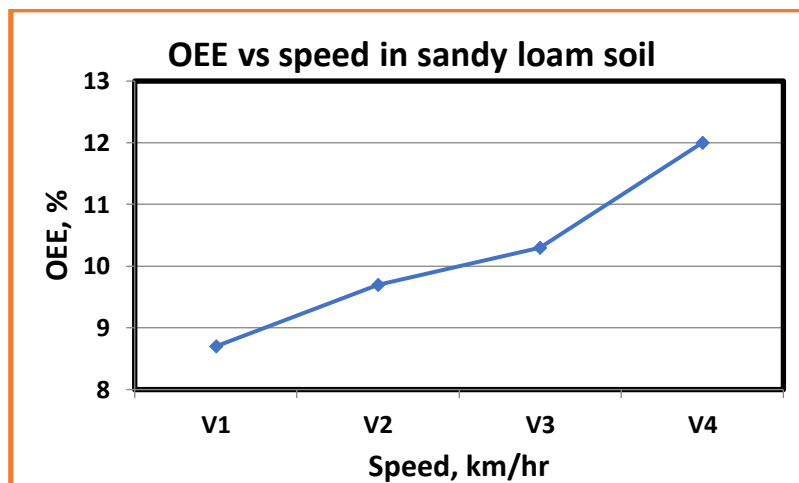
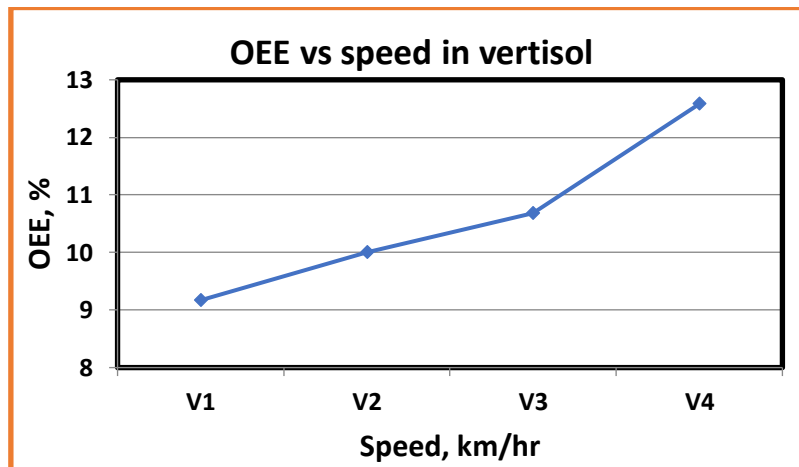
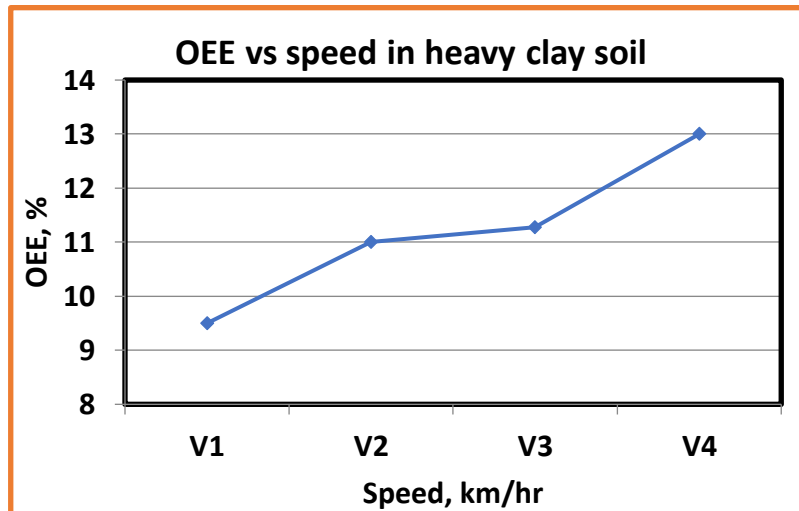


FIGURE 4.15 (a,b,c): Effect of soil type and travel speed on overall energy efficiency for furrowing

4.2.2. Tractors' available and required drawbar power

Figure 4.12 indicates the comparison between the drawbar power available at the tractor drawbar and the one that is required for the specific field operation. From this figure, it is observed that for subsoiling-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 PUR, which is one of the main points to be considered when evaluating tractor-implement compatibility was 0.57, which means only 57 % of the available drawbar power is utilized. The value of PUR is 0-1, which means it is 1(100%) for a perfectly matched tractor implement system. For subsoiling-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 was 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 on the drawbar power requirement, as heavy clay soil requires more compared to sandy loam soil. Figure 4.13 indicates how PUR is affected by soil type and field activity. It is depicted that at the same field activity heavy clay soil has better PUR followed by vertisol and sandy loam soil. Table 4.5 further indicates the analysis of variance for the dependence of PUR on field activity and soil type. In all cases, the PUR is less than the results reported by Gosayeet *al.*, (2015) done at Metahara Sugar Factory.

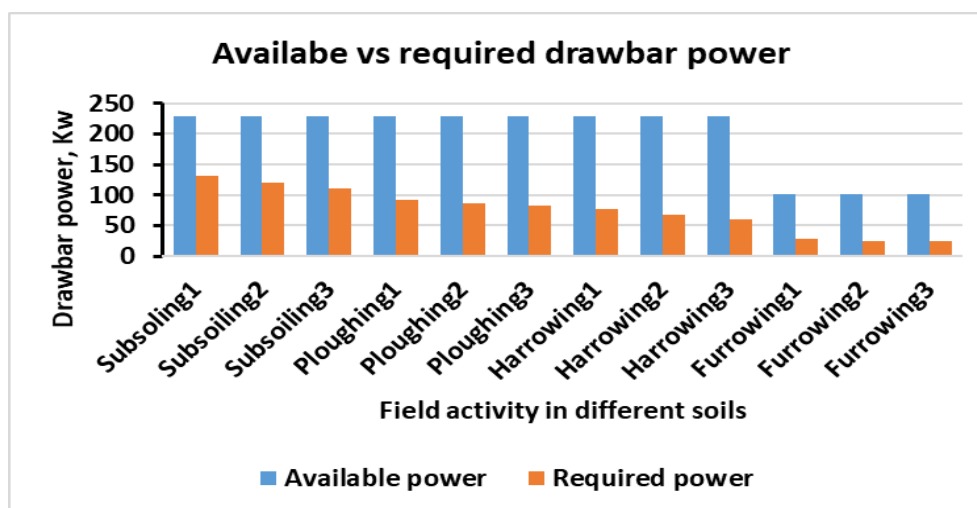


FIGURE 4.16: Comparisons of tractors' available and required DBP

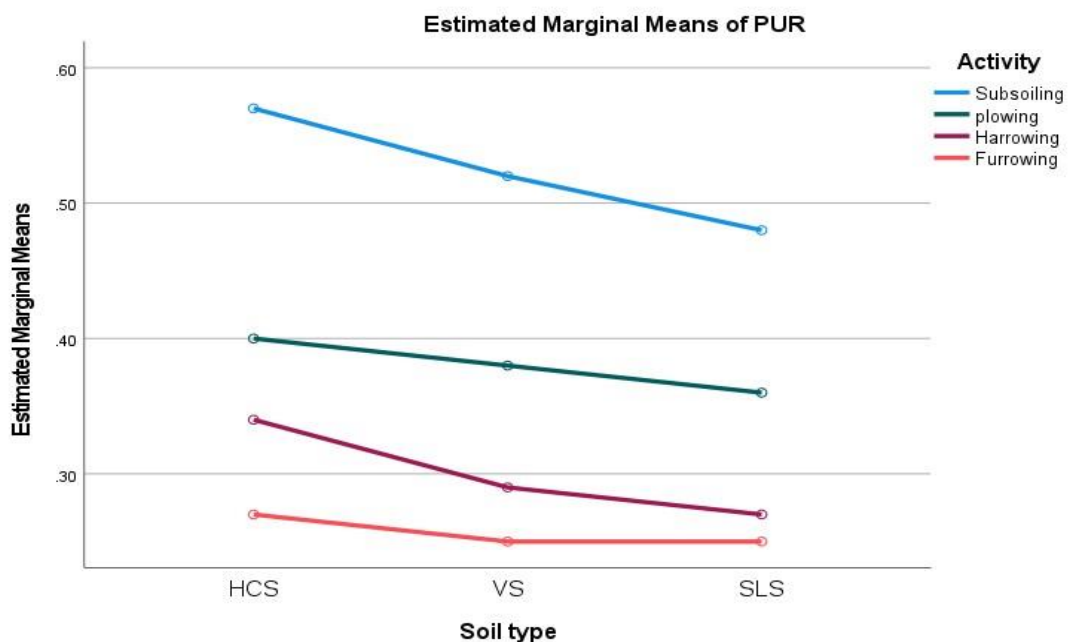


FIGURE 4.17: Effect of soil type and field activity on PUR

Table 4.5: ANOVA for the dependence of PUR on-field activity and soil type

ANOVA ^a						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.116	1	0.116	75.724	.000 ^b
	Residual	0.015	10	0.002		
	Total	0.132	11			
2	Regression	0.122	2	0.061	59.198	.000 ^c
	Residual	0.009	9	0.001		
	Total	0.132	11			
a. Dependent Variable: PUR						
b. Predictors: (Constant), Activity						
c. Predictors: (Constant), Activity, Soil type						

4.3. Evaluation of Farm Machinery Maintenance and Replacement.

4.3.1. Status of the maintenance workshop and tractors

The maintenance workshop of the field equipment maintenance division of WSSF is divided into four sections namely; heavy-duty section, wheel tractor section, estate cars section, tire and battery section, and welding section. The workshop was filled with old, outdated, and partially functioning tools and equipment. Most of the maintenance and repair activities are done without aid tools. Such practices were causing premature failure and breakage of machine parts. The surroundings of the maintenance workshops were dusty and not conducive to performing activities neatly as dust was blowing through the open spaces of the workshop to the workstations. No proper shades for parking tractors and other machinery resulted in early deterioration of these machinery and even easily exposed to theft.

The current status of general tools, machines, diagnosis tools, electrical tools, and measuring tools found in the workshop is presented in Figure 4.14. When we look at the status of general tools there were a total of 26-line items. Out of these items, only 8 (30.7%) of the tools were functional, 5 (19.2%) of the tools were in partially functioning condition and 15 (57.7%) of the tools were non-functional. Regarding machines, there were 13 different machines observed during this study. Out of the 13 machines, 8 (61.5%) were in active condition and 5 (38.46%) of the machines were non-functional. Regarding diagnosis tools, none of the tools were intact. From the total of 8 tools available, only 1 tool (Injection pressure tester) was in fair condition but the rest 7 (87.5%) of the diagnosis tools were faulty. Electrical measuring and maintenance tools were the other categories of tools investigated by this study. There was a total of 7 items observed and only 1 item (portable battery charger) was intact but the rest three 6 tools (85%) of the tools were nonfunctional. Finally, measuring tools available in the workshop were examined. There were 5 measuring tools, 2 (40%) of the tools were in good condition and 3 (60%) of the total tools were nonfunctional.

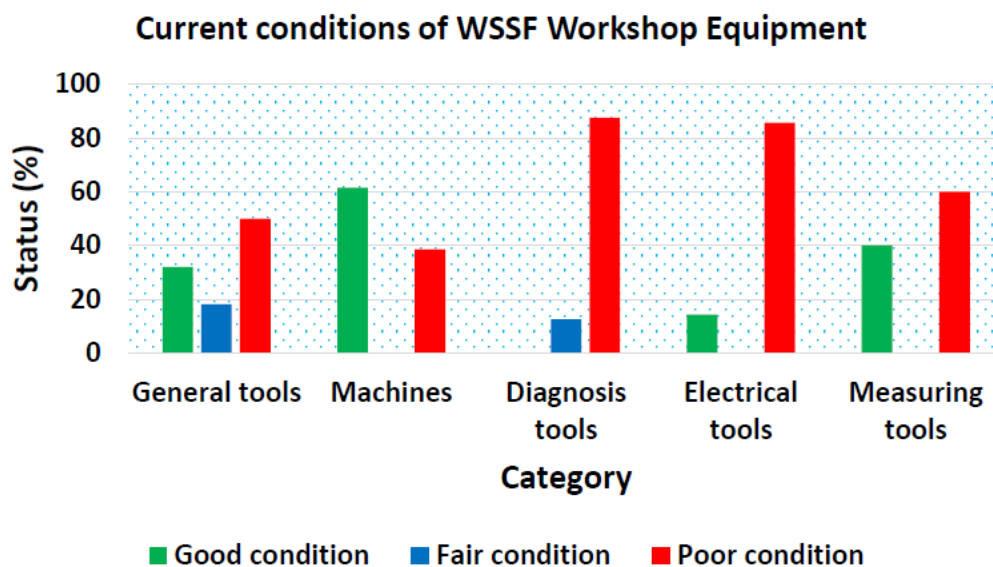


FIGURE 4.18: Status of maintenance materials in WSSF workshop

Regarding the current status of wheel tractors, the study finding indicates that 57.65% of the tractors were intact and in very good condition. The rest 42.35% were nonfunctional either being obsolete or waiting for spare parts as depicted in Table 4.6

Table 4.6: The current status of tractors available at Wonji Shoa Sugar Factory.

Sr. no	Make/Model	Purchase Year	Age (years)	Subtotal	Status	
					Functional	Obsolete/Waiting for spare parts
1	MF/178	1970/71	52	2	0	2
2	STYRE/8100A	1981	42	4	2	2
3	MF/3982	1993/94	30	3	0	3
4	MF/4260	2002/03	21	2	0	2
5	NH/80-66S	2003/04	20	7	0	7
6	MF/5365	2003/04	20	3	0	3
7	MF/660	2006/07	17	2	0	2
8	MF/465	2006/07	17	2	0	2
9	MF/440	2006/07	17	12	0	12

10	BELARUS	2008/09	15	1	0	1
11	JD/375	2011/12	12	3	0	3
12	NH/TD80	2012/13	11	13	13	0
13	SAME 130	2011/12	12	12	8	4
14	MF/5475	2013/04	10	5	0	5
15	BELL/1716AF	2013/14	10	4	4	0
16	KAT/1804	2014/15	9	9	9	0
17	URSUS/20014	2014/15	8	10	10	0
18	URSUS/20014	2016/17	8	10	10	0
19	KAT/1804	2020/21	3	12	13	0
Total				111	64	47
Percent (%)					57.65	42.35

4.3.2. Educational and work experience status of the maintenance workers and operators

Nowadays technology is advancing rapidly to a very sophisticated level in farm machinery technology and other related disciplines. To cope with these dynamic changes, continuous upgrading of the skills of technicians and tractor operators is crucial. One way to do this activity is through regular education and job training programs. The educational background and work experience of the farm machinery maintenance staff of Wonji Shoa Sugar Factory are presented as shown in Figure 4.15 and Figure 4.16 respectively. The result from Figure 4.15 indicates that most of the technicians are certificate and level 4 diploma holders. The problem with lower educational levels is also a problem in other agro-industries as reported by Alemayehu Teshome (2020).

As is indicated in the figure 14% of the maintenance crew have completed only secondary school, 25% percent own a certificate, 36.1 percent have a level IV certificate, 19.5 percent have a B.Sc. degree and only 5.6 percent of the total maintenance crew have MSc. From the above result, it is also observed that the educational level of the maintenance workers and operators is below the satisfactory level. With this level of status, it is impossible to assign the right man to the right job to get the desired quality of maintenance.

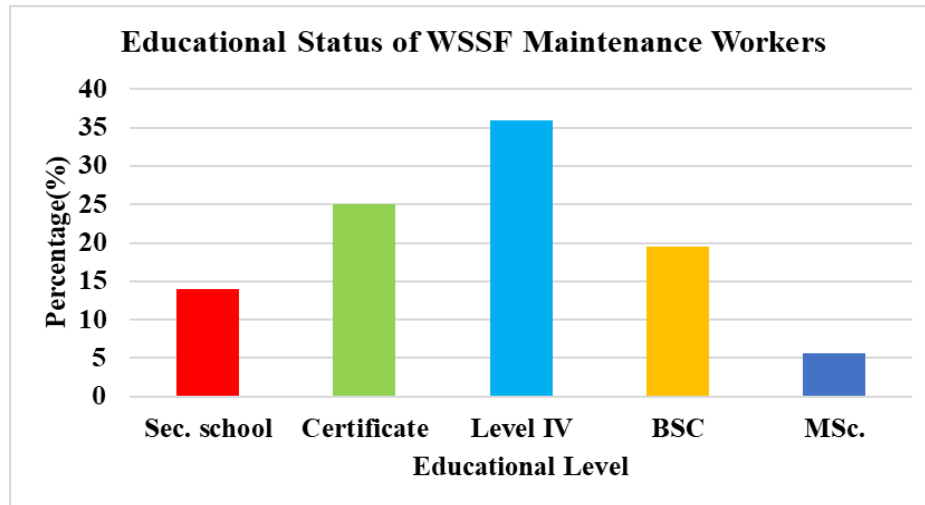


FIGURE 4.19: Educational background of WSSF maintenance workers and machine operators

The work experience of the maintenance crew is indicated in Figure 4.16. From the figure it is observed that about 33% of the total workers have an experience of less than five years and are relatively younger. It is an opportunity to equip these younger maintenance workers with the necessary skills by providing different training.

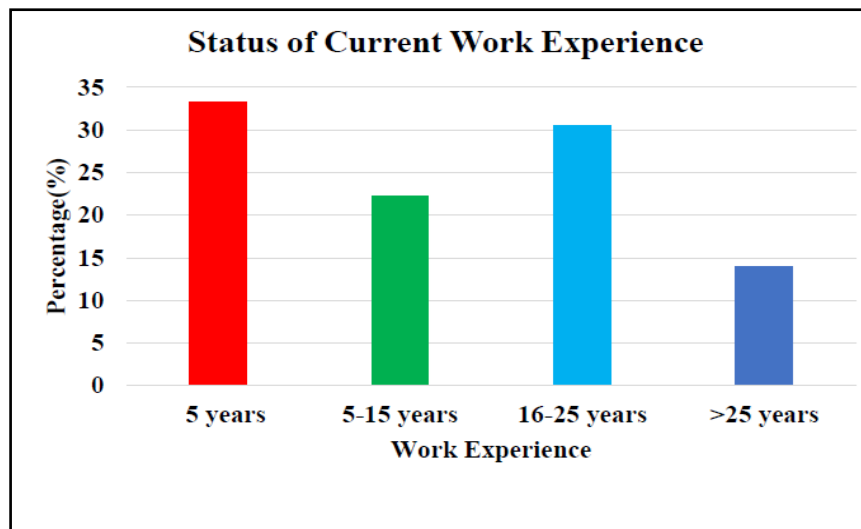


FIGURE 4.20: Work experience of WSSF maintenance workers and machine operators

Therefore, it is better to plan different trainings to bridge the skill gap, especially for younger workers as they are expected to serve the company for many coming years.

4.3.3. Estimated Optimum Replacement Years for Tractors Under the Study

According to the number of years of operation, Table 4.7 shows the total annual cost and annual maintenance cost for various sizes of tractors. As parts deteriorate and maintenance needs increase, it demonstrates an annual pattern of rising R & M (Repair and Maintenance) costs. The average yearly costs were high in the early years, fell to their lowest level in a given year, and then started to grow because of the rising maintenance costs with advancing age as also reported by Pagareet *et al.*, (2019). The total annual cost is determined to be lowest in the **fifth** year (**28773**USD), **seventh** year (**13678** USD), **sixth** year (**7881** USD), and **eighth** year (**8560** USD), for JD 410, SAME, 130, NH 80 and MF 150, tractors respectively. Annual working hours, level of maintenance rendered to tractors and make highly determine the economic life of tractors. Tractors considered in this study were found to have less economic life than the minimum optimum life expected under fair scenarios(10- 30 years) reported by Lips, (2017).

Table 4.7: Annual repair and maintenance costs and estimated average annual total costs

Age (Years)	JD 410		SAME 130		NH 80		MF 150	
	R&M Cost/hr	Total Cost/hr	R&M Cost/hr	Total Cost/hr	R&M Cost/hr	Total Cost/hr	R&M Cost/hr	Total Cost/hr
1	12106	30710	1234	19256	1782	7174	1826	7825
2	13399	32269	1370	18432	2713	7332	2051	7994
3	16187	33960	2592	15985	3111	7421	2332	8242
4	17029	30204	5500	15163	3644	7830	3086	8389
5	17826	28773	7123	14781	3923	7946	3644	8517
6	18186	31863	9675	14157	4574	7881	4194	8675
7	19514	33328	11193	13678	4932	8027	4746	8864
8	22746	33855	12380	16270	5160	8124	4956	8560
9	27886	35676	13044	21005	5337	8320	5254	9104
10	29513	38615	14056	25738	6490	8434	5375	9223

4.3.4. An empirical model to predict the optimum replacement age

The observed values of several factors, including replacement year, annual uses, tractor size (measured in horsepower), and repair and maintenance cost (R & M), are shown in Table 4.8. Based on these findings, a multiple regression analysis was performed to forecast a tractor's ideal life and verify that the relationships between the variables were linear. The approach produces an empirical equation with just two independent variables—annual use and R&M expense. Despite being one of its independent variables, the tractor's size did not have any bearing on the model as also reported by Pagareet *al.*, (2019)

Accordingly, the empirical model shown below by equation 4.1 was taken to estimate the optimum tractors' life under consideration

$$Y = C - ax_1 - bx_2 \text{ -----4.1}$$

Where,

Y: Replacement year (dependent variable)

C: constant,

X₁: annual usage, hours

X₂: R & M cost per hour

and

a, b: coefficients

The proposed equation (Eqn. 4.1) was shown to have the best fit by regression analysis of the observed data, with the coefficient of determination R² being 0.999. We may infer that there is a linear relationship between the variables, which demonstrates that the p-value of this model, which is 0.03, is significant and rejects the null hypothesis. The estimated coefficients found from the analysis are listed in Table 4.9 (source of the regression equation), and the significance level of those coefficients denote the influence of those factors on the forecast value.

Table 4.8: Observed and model predicted economic life of farm tractors

Make	HP	Annual usage(hrs)	R&M Cost/hr	Observed Replacement Year	The predicted model the replacement year	Error (+/-)
John Deer	330	1753	785	5	5.12	-0.12
Massey F.	150	625	322	8	7.82	0.18
SAME	130	667	360	7	7.01	-0.01
New Holland	80	846	450	6	5.88	0.12

Table 4.9: Coefficients of the regression analysis for tractor replacement age

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0 % Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	12.105	.278		43.574	.015	8.575	15.635
	Birr	-.038	.003	-.6.228	-13.566	.047	-.074	-.002
	Hours	.013	.001	5.339	11.629	.045	-.001	.027

4.4. The Decision Support System (DSS)

The first step in the tractor selection process is identifying the most crucial field activity (Mehta *et al.*, 2010). For this study, this process involved all activities in heavy clay soil because for all four field activities heavy clay soil required the highest drawbar power and fuel consumption as well as depicted in Table 4.10. An algorithm leading to computer software in Visual Basic was developed to determine the tractor's optimum size based on the most critical field operation. The flow chart of the program is shown in Fig. 3.10. The decision to select the type of implement was made based on the inputs to the program including, available tractor, kind of activity, working speed, draft of implements, and power conversion factor, etc. The DSS processed these data with the help of two options i.e. pre-defined parameters (default values) and user-defined parameters. A suitable implement having a width nearer to the calculated value was selected among the available implements in the workshop. The software calculated the required drawbar power of the tractor based on, soil type, soil condition, width of the implement, depth of operation, and the travel speed recommended for the activity. Finally, the PTO

power requirement of a tractor using only 80% of maximum engine power was suggested by the DSS

The difference between the experimental results and the corresponding DSS predicted output for the variables; drawbar power (DBP), and power utilization ratio (PUR) was indicated in Table 4.10. The experimental results of drawbar power were calculated by taking experimental draft force and travel speed, but the DSS estimated the drawbar power required by taking additional parameters like soil type and power conversion factor for different soil textural classes. The significant increase in PUR for all field activities in clay soil by selecting and using the DSS proposed tractor was indicated in Table 4.10 (subsoiling 0.57-0.98, ploughing 0.4-0.73, harrowing 0.34-0.61, and Furrowing 0.32-0.68) as presented in this table.

It also indicated the validity of the DSS by using a statistical term called relative deviation (RD) value for experimental and DSS drawbar requirements. The value of the Experimental drawbar power was compared with the one that was estimated by the DSS by relative deviation. The relative deviation of the experimental result from the DSS value was less than 5% as upto 10% is tolerable (Kumar and Pandey, 2009). Such a low error indicates that the developed DSS was of sufficiently high quality to rely on in solving a problem of tractor-implement matching as depicted in Table 4.10. This discrepancy may be due to some instrumental error in recording the field data as well as the degree of accuracy of the various prediction models utilized in the DSS model development. For PUR, the relative deviation (RD) is bigger as the comparison was done between the drawbar power of the tractor actually in the field used for this experiment and the drawbar power of the appropriate tractor recommended by the DSS.

Table 4.10: Experimental results and the corresponding DSS predicted values for drawbar power and power utilization ratio (PUR) in three Soil types

Soil type	Activity	DBP (kW)		RD (%)	PUR
		Experi- mental	DSS		
Heavy Clay soil	Subsoiling	131	132.96	1.49	0.57
	Ploughing	91.94	91.93	0.01	0.4
	Harrowing	77.4	77.46	0.06	0.34
	Furrowing	27.3	29.76	4.5	0.32

Vertisol	Subsoiling	121	118.6	1.98	0.52
	Ploughing	86.65	87.5	0.65	0.38
	Harrowing	67.1	66.5	0.89	0.29
	Furrowing	24.7	25.2	2	0.25
Sandy Loam	Subsoiling	111.1	110.5	0.54	0.48
	Ploughing	81.98	79	3.7	0.36
	Harrowing	61	59.26	2.9	0.27
	Furrowing	25.2	24.8	1.6	0.25

The value of PUR depends on the extent of compatibility of the tractors with their implements. For a perfectly compatible tractor and implement the value of PUR is equal to 1 (Gosayeet *al.*, 2015).

4.5. Economic Analysis of the DSS

For many organizations, selecting the right-sized tractors and implements is a crucial management choice. Correct tractor-implement sizing will result in less time and labor needed while maintaining effective field operations. Large tractors will result in higher than necessary fuel expenses and usage. On the other hand, if the implements are too big for the tractor, overloading will happen, resulting in poor field speeds and, as a result, reduced field capacity and work quality. In this study tractor oversize was observed for all field activities investigated and the result of differences in fuel consumption (l/ha) and lubricant cost (ha/hr) with corresponding reduced costs (Birr) were presented in Table 4.11 and Figure 4.17.

The comparison of the actual and DSS simulated fuel cost per hectare is depicted in Figure 4.18. The result indicated that the fuel consumption cost per hectare can be reduced from 4615 to 2639.79, from 4402 to 1775, from 1491 to 497, and from 497 to 255.6 for subsoiling, ploughing, harrowing and furrowing activities respectively. To evaluate the significance of the differences, a paired t-test at a 95% significant level was done.

The test result indicated that there was a significant difference between the two costs (p-value =0.04). Figure 4.13 indicates the amount of the lubrication cost to be saved by selecting a tractor by the DSS. The lubrication cost saved per hectare was assumed as 10% of the fuel cost saved

(Lazarus, 2024). The result depicted that 197.5, 262.7, 99.4, and 24.1 birr per hectare can be saved by using the system

Table 4.11: Comparison of fuel and lubrication costs

Activity	Fuel consumption (L/ha)			Saved Cost/ha in Birr	
	Actual	DSS	Diff.	Fuel Cost*	Lubrication cost (10% fuel cost)
Subsoiling	65	37.18	27.82	1975	197.5
Plowing	62	25	37	2627	262.7
Harrowing	21	7	14	994	99.4
Furrowing	7	3.6	3.4	241	24.1

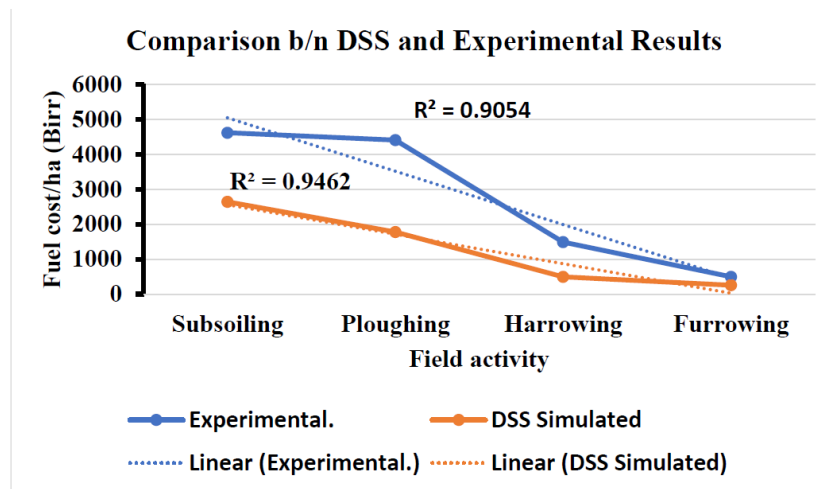


FIGURE 4.21: Comparison of fuel consumption cost between experimental and dss

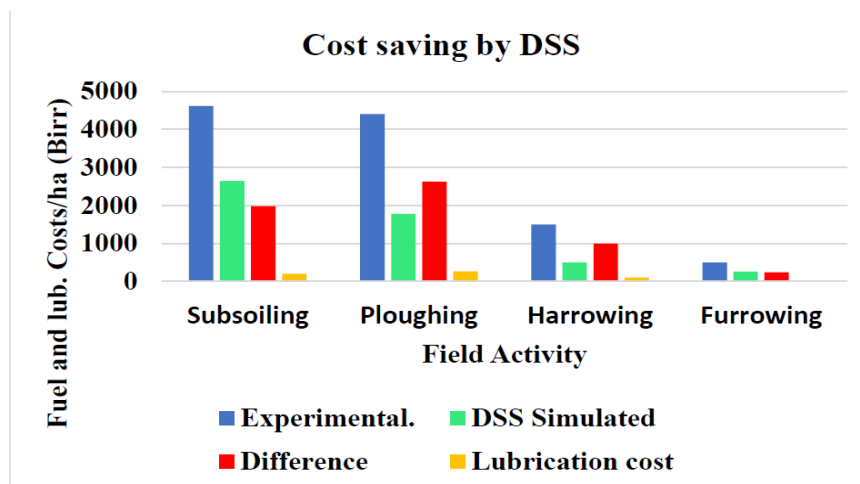


FIGURE 4.22: Cost saving including lubrication oil.

From Table 4.11, it was observed that the fuel consumption rate was significantly reduced by the DSS. To put it in figure it was reduced from 65 l/hr to 37.18 l/hr for heavy clay soil, 62 l/hr to 25 l/hr in vertisol, and 21 l/hr to 7 l/hr in sandy loam soil. The reduction of fuel consumption rate and corresponding lubrication oil cost per hectare indicates the significant economic advantage of the DSS. Hence by using the DSS, it is possible to reduce fuel consumption costs by 2450 Birr/ha, 2240 Birr/ha, 994 Birr/ha, and 241 Birr/ha for subsoiling, ploughing, harrowing, and furrowing respectively. The cost reduction for lubrication was estimated as 10 percent of that of fuel cost.

CONCLUSIONS AND RECOMMENDATIONS

The efficient use of farm machinery is crucial for productivity and cost-effectiveness in agriculture. An experimental investigation of the farm machinery management system was carried out at WSSF focusing on farm machinery selection, maintenance, and replacement strategies. At WSSF, managing machinery is vital for the success of using machinery, efficiently and reducing the machinery downtime costs also. By analyzing different tillage activities in three soil types, tractor-implement matching, maintenance, and replacement strategies, the study offers insights to enhance machinery management of the WSSF. The following conclusions and recommendations are provided through field experiments, regression analysis (modeling), and DDS.

A. Conclusions

1. Among the soil types investigated by this study during field experiments, heavy clay soil was the one that required higher implement draft force (79.8 kN), drawbar power(131.4 kW), and fuel consumption(64.5l/hr) due to its physical structure, followed by vertisol and sandy loam soil. But better overall energy efficiency and power utilization ratio were observed in it, 15% and 0.57 respectively. For all soil types and all field activities, less OEE was observed. Less OEE is the indicator of poor tractor-implement combination and lower fuel consumption efficiency of tractors. PUR, which is one of the main points to be considered when evaluating tractor-implement compatibility was also less especially in vertisol and sandy loam soils. Hence, for all field activities investigated by this study, it was observed that tractors used by WSSF for land preparation were not compatible with the implement attached to them, i.e., in all cases, the tractors were overpowered, and that resulted in high ownership and operation costs and lower productivity.
2. In contrast to what is technically feasible, the current study showed that tractors used at WSSF had a significantly short economic life, 5years, 7years, 6years,and 8 years for JD 410, SAME 130, NH 180, and MF 150 respectively. Many factors may be accountable for this problem but lack of the full implementation of scientific machinery maintenance strategies, shortage of spare parts and poor maintenance facilities are the main problems identified by this study. Moreover, although implementing both planned and unplanned machinery maintenance strategies partially, Wonji Shoa sugar factory has no strategy for machinery replacement. The absence of this replacement strategy was manifested by a

large number of used machinery and scraps piled inside and outside of the factory's compound.

3. It was discovered that annual usage (hrs) and repair maintenance costs per hour play a considerable role in determining a tractor's economic life. Based on that, an empirical model was developed to precisely predict the tractor's ideal lifespan. For the tractors taken into the investigation, the calculated and model predicted optimal replacement years were within tolerable and acceptable bounds in terms of the machines' useful lives. Another sign of the model's reliability was the agreement between the calculated and predicted optimal replacement years. A correlation coefficient of 0.99 shows that the study's observed and predicted outcomes compare favorably in terms of dependability and usability. Additionally, a linear relationship between the variables, demonstrates that the p-value of this model, which is 0.03, was significant and rejects the null hypothesis.
4. The DSS developed to aid decision-makers in the selection of economically optimum machinery was flexible and user-oriented and most of the data was shown through the user interface (computer screen). The very close agreement between results from the field experiment and the decision support system output shows that the system accurately selects the size of the tractor (drawbar power) for the chosen implement and other parameters (width of the implement, travel speed, draft force...etc.). The relative deviation, RD value for field experimental results, and the DSS estimated results were less than 5%.
5. Oversized tractors observed at Wonji Shoa sugar factory fields consume higher than necessary fuel and lubrication and require high maintenance and spare part costs. Therefore; a significant amount of differences in fuel and lubrication consumption per hectare was observed and the expected cost reduction by using the DSS was also presented in this study. The result indicated that the fuel consumption cost per hectare can be reduced from 4615Birr to 2639.79Birr, from 4402Birr to 1775Birr, from 1491Birr to 497Birr, and from 497Birr to 255.6Birr for subsoiling, plowing, harrowing, and furrowing activities respectively. To evaluate the significance of the differences, a paired t-test at a 95% significant level was done. The test result indicated that there was a significant difference between the two costs (p-value =0.04).

B. Recommendations

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. Therefore, either the size of the implement should be increased or the horsepower of the tractor should be reduced i.e., they have to use a smaller tractor of only up to 250 horsepower.
3. Regarding ploughing operation, the disc plough attached to a 410 horsepower John Deere 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 worse 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.
6. Decision makers (farm machinery managers) can use the developed decision support system for the field activities covered by this study (subsoiling, plowing, harrowing, and furrowing), at Wonji Shoa's conditions to easily select a machine for a given soil type

Future research

The current study covered only machinery used for land preparation activities. However, it is known that WSSF comprises different machinery for planting, cultivation, plant protection, harvesting, and cane haulage activities. Therefore, to get a more comprehensive result in reducing the factory's operation costs and making it more profitable, further studies considering the above activities should be done. Next, researchers should develop a more efficient and reliable system.

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APPENDIXES

APPENDIX- I: Draft parameters and an expected range in drafts estimated by the model parameters for tillage and seeding implements

Implement	Width units			Machine		Soil parameters			Range
				Parameters					%
			A	B	C	F1	F2	F3	
Major Tillage Tools Subsoiler/Manure Injector									
narrow point	Tools		226	0.0	1.8	1.0	0.70	0.45	50
30 cm winged point	Tools		294	0.0	2.4	1.0	0.70	0.45	50
Moldboard Plow	m		652	0.0	5.1	1.0	0.70	0.45	40
Chisel plow									
5 cm straight point	Tools		91	5.4	0.0	1.0	0.85	0.65	50
7.5 cm shovel/35 cm sweep	Tools		107	6.3	0.0	1.0	0.85	0.65	50
10 cm twisted shovel	Tools		126	7.3	0.0	1.0	0.85	0.65	50
Sweep plow									
primary tillage	m	390	19.0	0.0	1.0	0.85	0.65	45	
Secondary tillage	m	273	13.3	0.0	1.0	0.85	0.65	35	
Disk Harrow, Tandem									
primary tillage	m	309	16.0	0.0	1.0	0.88	0.78	50	
Secondary tillage	m	216	11.2	0.0	1.0	0.88	0.78	30	
Disk Harrow, Offset									
primary tillage	m	364	18.8	0.0	1.0	0.88	0.78	50	
Secondary tillage	m	254	13.2	0.0	1.0	0.88	0.78	30	
Disk Gang, Single									
primary tillage	m	124	6.4	0.0	1.0	0.88	0.78	25	
Secondary tillage	m	86	4.5	0.0	1.0	0.88	0.78	20	
Field Cultivator									
primary tillage	Tools	46	2.8	0.0	1.0	0.85	0.65	30	
Secondary tillage	Tools	32	1.9	0.0	1.0	0.85	0.65	25	
S-tine	Rows	140	7.0	0.0	1.0	0.85	0.65	15	
C- shank	Rows	260	13.0	0.0	1.0	0.85	0.65	15	

No- till	Rows	435	21.8	0.0	1.0	0.85	.65	15
Minor Tillage Tools								
Rotary Hoe	m	600	0.0	0.0	1.0	1.0	1.0	30
Coil Tine Harrow		250	0.0	0.0	1.0	1.0	1.0	20
Spike Tooth Harrow	m	600	0.0	0.0	1.0	1.0	1.0	30
Spring Tooth Harrow	m	2000	0.0	0.0	1.0	1.0	1.0	35
Roller Harrow	m	2600	0.0	0.0	1.0	1.0	1.0	50
Land Plane	m	8000	0.0	0.0	1.0	1.0	1.0	45
Seeding Implements Row Crop Planter, prepared seedbed								
Seed, fertilizer, herbicides	Rows	900	0.0	0.0	1.0	1.0	1.0	25
Drawn seeding only	Rows	1550	0.0	0.0	1.0	1.0	1.0	25
seed, fertilizer, herbicides	Rows	1820	0.0	0.0	1.0	0.96	0.92	25

Source: ASAE Standards 2003

APPENDIX- II: Field Efficiency, Field Speed, and Repair and Maintenance Factors

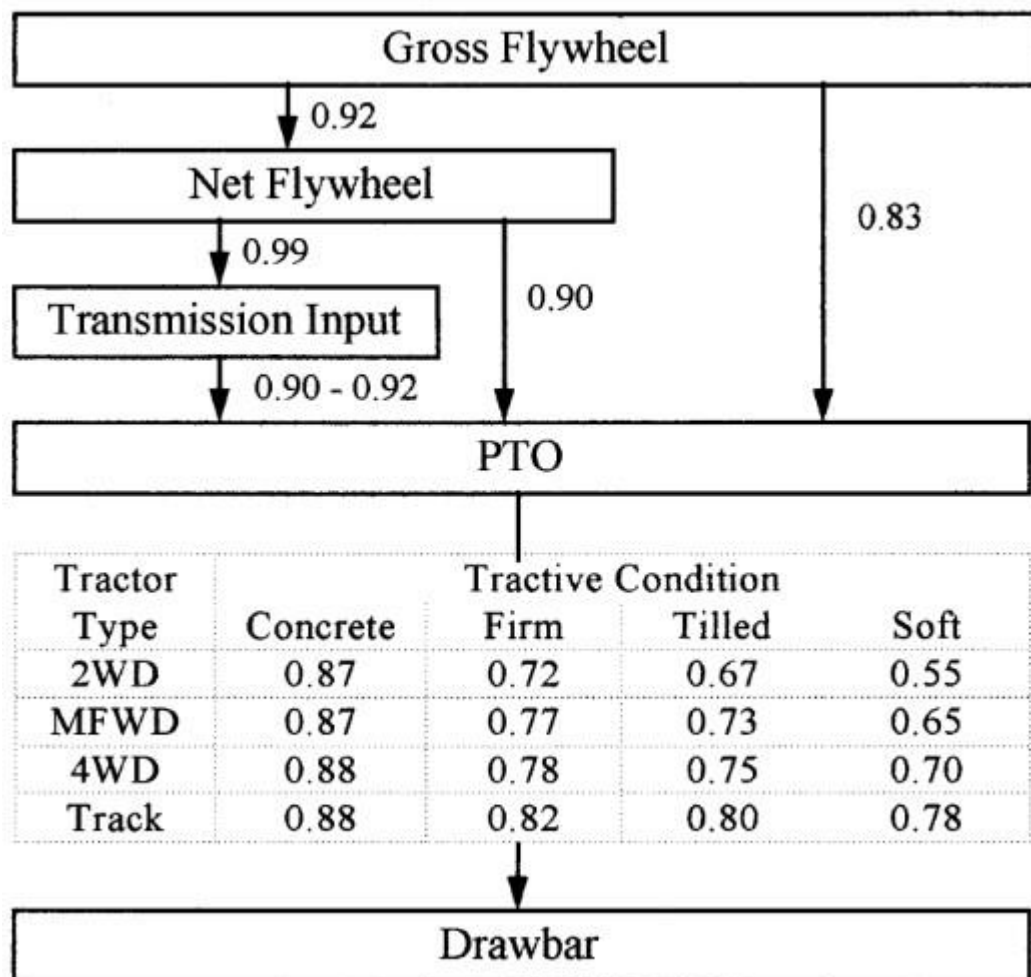
Machine	Field Efficiency		Field Speed		EUL		Repair Factors		
	Range %	Typical %	Range mph	Typical mph	Est. hours	Life	Tot. Life Cost%	RF1	RF2
TRACTORS									
2WD & stationary					12,000		100	0.007	2.0
4WD & crawler					16,000		80	0.003	2.0
TILLAGE & PLANT									
Moldboard plow	70-90	85	3.0-6.0	4.5	2,000		100	0.29	1.8
Heavy-duty disk	70-90	85	3.0-6.0	4.5	2,000		60	0.18	1.7
Tandem disk harrow	70-90	80	4.0-7.0	6.0	2,000		60	0.18	1.7
(Coulter) chisel plow	70-90	85	4.0-6.5	5.0	2,000		75	0.28	1.4
Field Cultivator	70-90	85	5.0-8.0	7.0	2,000		70	0.27	1.4

Spring tooth harrow	70-90	85	5.0-8.0	7.0	2,000	70	0.27	1.4
Roller-packer	70-90	85	4.5-7.5	6.0	2,000	40	0.16	1.3
Mulcher-packer	70-90	80	4.0-7.0	5.0	2,000	40	0.16	1.3
Rotary hoe	70-85	80	8.0-14.0	12.0	2,000	60	0.23	1.4
Row crop cultivator	70-90	80	3.0- 7.0	5.0	2,000	80	0.17	2.2
Rotary tiller	70-90	85	1.0-4.5	3.0	1,500	80	0.36	2.0
Row crop planter	50-75	65	4.0-7.0	5.5	1,500	75	0.32	2.1
Grain drill	55-80	70	4.0-7.0	5.0	1,500	75	0.32	2.1
Harvesting								
Corn picker	60-75	65	2.0-4.0	2.5	2,000	70	0.14	2.3
Sheller								
PT Combine	60-75	65	2.0-5.0	3.0	2,000	60	0.12	2.3
SP Combine	65-80	70	2.0-5.0	3.0	3,000	40	0.04	2.1
Mower	75-85	80	3.0-6.0	5.0	2,000	150	0.46	1.7
Mower (rotary)	75-90	80	5.0-12.0	7.0	2,000	175	0.44	2.0
Mower-conditioner	75-85	80	3.0-6.0	5.0	2,500	80	0.18	1.6
Mow-cond (rotary)	75-90	80	5.0-12.0	7.0	2,500	100	0.16	2.0
SP Windrower	70-85	80	3.0-8.0	5.0	3,000	50	0.06	2.0
Side delivery rake	70-90	80	4.0-8.0	6.0	2,500	60	0.17	1.4
Square baler	60-85	75	2.5-6.0	4.0	2,000	80	0.23	1.8
Large square baler	70-90	80	4.0-8.0	5.0	3,000	75	0.10	1.8
Large round baler	55-75	65	3.0-8.0	5.0	1,500	90	0.43	1.8
Forage harvester	60-85	70	1.5-5.0	3.0	2,500	65	0.15	1.6
SP Forage harvester	60-85	70	1.5-6.0	3.5	4,000	50	0.03	2.0
Sugar beet harvester	50-70	60	4.0-6.0	5.0	1,500	100	0.59	1.3
Potato harvester	55-70	60	1.5-4.0	2.5	2,500	70	0.19	1.4
SP Cotton picker	60-75	70	2.0-4.0	3.0	3,000	80	0.11	1.8
MISCELLANEOUS								

Fertilizer spreader	60-80	70	5.0-10.0	7.0	1,200	80	0.63	1.3
Boom-type sprayer		65	3.0-7.0	6.5	1500	70	0.41	1.3
Bean puller/windrower	50-80							
Beet topper/chopper	70-90	80	4.0-7.0	5.0	2000	60	0.20	1.6
	70-90	80	4.0-7.0	5.0	1200	35	0.28	1.4

Source: ASAE Standards 1993, American Society of Agricultural Engineers, St. Joseph,

APPENDIX- III: Maximum mechanical power performance expected from agricultural tractors



APPENDIX- IV: 2016-2017 Tractors Maintenance cost

Cata-gory	Plat-eNo	VehName	KmOrHr	Drivers	MechaP	Fuel	Lub	TyreandTube	Spare1	GenP	SunP	TotalCost	Unit cost/hr
WT	WT-0111	JOHN DEER	2,311.99	21,658.92	88,163.79	339,426.00	33,058.63	73,793.92	141,214.09	8,872.52	14,602.29	720,790.16	311.7618
WT	WT-0137	JOHN DEER TRACTOR 9410R PL-WT-137	19.50	41,717.11	-	1,270.43	-		-	-	-	42,987.54	2204.489
WT	WT-0183	Johndeer Tractor	15,941.54	211,178.01	133,608.13	2,073,397.84	107,647.67	166,059.11	214,003.39	13,445.90	22,129.09	2,941,469.14	184.516
WT	WT-0185	Johndeer Tractor	10,166.81	119,443.55	131,596.89	611,227.21	234,757.05	131,647.75	210,781.94	13,243.49	21,795.98	1,474,493.86	145.0301
WT	WT-0186	Johndeer Tractor	16,728.47	124,463.67	61,302.58	2,087,098.57	101,502.62	61,263.57	98,189.84	6,169.30	10,153.35	2,550,143.50	152.4433
WT	WT-0187	Johndeer Tractor	1,434.79	53,881.83	42.77	130,461.27	18,304.18	63.03	68.50	4.30	7.08	202,832.96	141.3677
WT	WT-0175	Johndeer Tractor	10,115.06	138,804.24	106,194.65	1,549,466.24	-	159,168.42	170,094.56	10,687.09	17,588.68	2,152,003.88	212.7525
WT	WT-0176	Johndeer Tractor	1,086.14	14,856.72	179,768.82	263,858.94	23,848.93	136,831.33	287,940.10	18,091.36	29,774.54	954,970.74	879.2336
sub total			57,804.30	726,004.05	700,677.63	7,056,206.50	519,119.08	728,827.13	1,122,292.42	70,513.96	116,051.01	11,039,691.78	190.9839
WT	WT-0139	VERSATILE TRAC-TOR WT-0139	2,110.13	122,755.52	62,600.93	904,828.65	59,048.28		100,269.44	6,299.96	10,368.39	1,266,171.17	600.0442
WT	WT-0141	Versatile Tractor	4.15	58,046.95	1,633.31	-	1,255.92		2,616.12	164.37	270.52	63,987.19	15418.6
sub total			2,114.28	180,802.47	64,234.24	904,828.65	60,304.20	-	102,885.56	6,464.33	10,638.91	1,330,158.36	629.1307
WT	WT-0158	Johndeer Tractor	1,636.34	194,631.09	-	128,039.09	7,348.23		-	-	-	330,018.41	201.6808
WT	WT-0159	Johndeer Tractor	2,052.47	48,249.13	20.22	78,028.46	12,208.61	1,000.09	32.38	2.03	3.35	139,544.27	67.98846
WT	WT-0160	Johndeer Tractor	590.53		-	-	4,048.80		-	-	-	4,048.80	6.856214
WT	WT-0161	Johndeer Tractor	602.31	17,994.64	46.82	75,325.44	11,976.39	584.18	75.00	4.71	7.76	106,014.94	176.0139
WT	WT-0162	Johndeer Tractor	1,074.00	147,643.51	608.79	76,960.92	7,704.06		975.11	61.27	100.83	234,054.49	217.9278

WT	WT-0163	Johndeer Tractor	1,460.73	42,260.42	112.95	20,850.57	16,617.74		180.91	11.37	18.71	80,052.67	54.80319
WT	WT-0165	Johndeer Tractor	1,570.25	133,594.57	4,597.59	122,703.11	12,500.66	7,579.68	7,364.07	462.69	761.48	289,563.85	184.4062
WT	WT-0166	Johndeer Tractor	983.30	46,675.10	422.64	3,780.69	-	485.96	676.95	42.53	70.00	52,153.87	53.03963
sub total			9,969.93	631,048.46	5,809.01	505,688.28	72,404.49	9,649.91	9,304.42	584.60	962.13	1,235,451.30	123.9178
WT	WT-0170	WHEEL TRACTOR	190.49	23,682.65	10,317.34	16,123.46	13,080.44		16,525.54	1,038.30	1,708.83	82,476.56	432.9705
WT	WT-0171	WHEEL TRACTOR	2,496.19	49,524.20	4,457.25	213,078.88	10,806.08	41,695.95	7,139.29	448.56	738.24	327,888.45	131.3556
WT	WT-0172	WHEEL TRACTOR	769.30	8,254.03	14,354.58	117,962.34	2,814.39		22,992.08	1,444.60	2,377.50	170,199.52	221.2395
WT	WT-0173	WHEEL TRACTOR	8.75		-	-	56.23		-	-	-	56.23	6.426286
WT	WT-0174	WHEEL TRACTOR	596.65	11,314.57	19,384.43	62,722.61	17,901.25	20,831.10	31,048.52	1,950.79	3,210.58	168,363.85	282.1819
sub total			4,061.38	92,775.45	48,513.60	409,887.29	44,658.39	62,527.05	77,705.43	4,882.25	8,035.15	748,984.61	184.4163
WT	WT-0198	Wheel tractor	3,985.21	176,856.93	21,149.01	62,509.00	21,090.80	29,524.91	33,874.89	2,128.37	3,502.84	350,636.75	87.98451
WT	WT-0199	Wheel tractor	813.20	218,122.23	13,647.39	-	19,424.83	9,143.92	21,859.36	1,373.43	2,260.37	285,831.53	351.4898
WT	WT-0200	Wheel tractor	20.00		65,905.58	-	74,472.76	2,522.16	105,562.57	6,632.53	10,915.73	266,011.33	13300.57
WT	WT-0201	Wheel tractor	2,225.90	179,976.00	52,773.96	122,344.81	29,598.18	29,946.74	84,529.34	5,311.00	8,740.78	513,220.81	230.5678
WT	WT-0202	Wheel tractor	848.62	18,462.66	42,451.94	95,131.97	25,775.40	82,271.27	67,996.31	4,272.23	7,031.18	343,392.96	404.6487
WT	WT-0203	Wheel tractor	775.30	63,223.08	77,577.71	15,670.89	15,773.15		124,258.10	7,807.17	12,848.95	317,159.05	409.0791
sub total			8,668.23	656,640.90	273,505.59	295,656.67	186,135.12	153,409.00	438,080.57	27,524.73	45,299.85	2,076,252.43	239.5244
		summary											

Catagory	PlateNo	VehName	KmOrHr	Drivers	MechaP	Fuel	Lub	TyreandTube	Spare1	GenP	SunP	TotalCost	Unit cost/hr
WT		JOHN DEER 9330/9410 R	57804.3	726004.05	700677.63	7056206.5	519119.08	728827.13	1122292.42	70513.96	116051.01	11039691.78	190.9839
		Versatile	2114.28	180802.47	64234.24	904828.65	60304.2	0	102885.56	6464.33	10638.91	1330158.36	629.1307
WT		Dyna 4 tractor	4061.38	92775.45	48513.6	409887.29	44658.39	62527.05	77705.43	4882.25	8035.15	748984.61	184.4163
WT		YTO -1804	8668.23	656640.9	273505.59	295656.67	186135.12	153409	438080.57	27524.73	45299.85	2076252.43	239.5244
WT		Jonher 5725	9969.93	631048.46	5809.01	505688.28	72404.49	9649.91	9304.42	584.6	962.13	1235451.3	123.9178
WT													

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APPENDIX-V:2017-2018 Tractors Maintenance cost

Catagory	PlateNo	VehName	KmOrHr	Drivers	MechaP	Fuel	Lub	TyreandTube	Spare1	GenP	SunP	TotalCost	Unit cost /hr
WT	WT-0110	JOHN DEER	618.83	35,877.93	65767.63	258769.72	37317.71	9756.21	107488.63	4845.02	6553.21	526,376.06	850.60
WT	WT-0111	JOHN DEER	447.25	91,640.38	27037.95	609603.56	21274.02	52989.56	44190.02	1991.85	2694.11	851,421.45	1,903.68
WT	WT-0137	JOHN DEER TRACTOR 9410R PL-WT-137	14.5		4048.87				6617.35	298.28	403.44	11,367.94	784.00
WT	WT-0137	JOHN DEER TRACTOR 9410R PL-WT-137	14.5		4048.87				6617.35	298.28	403.44	11,367.94	784.00
WT	WT-0183	Johndeer Tractor	2441.44	70,300.97	119906.76	1438062.32	68100.73	187467.2	195972	8833.38	11947.73	2,100,591.09	860.39
WT	WT-0184	Johndeer Tractor	1				103.05					103.05	103.05
WT	WT-0185	Johndeer Tractor	1		6331.38		4753.1	23895.62	10347.82	466.43	630.87	46,425.22	46,425.22
WT	WT-0186	Johndeer Tractor	2494.95	418,553.86	155512.31	1582310.01	85126.42	57425.8	254164.64	11456.4	15495.54	2,580,044.98	1,034.11
WT	WT-0175	WHEEL TRACTOR	2424.17	1002874	62471.38	1431450		50314.39	102101.3	4602.19	6224.76	2660039	1,097.30
WT	WT-0176	WHEEL TRACTOR	2984.41	216699.2	45815.88	1895295	64833.02	31340.65	74880.1	3375.2	4565.18	2336804	783.00
sub total			11442.05	1835946.76	490941.03	7215490.51	281508.05	413189.43	802379.25	36167.03	48918.28	11124540.34	972.25
WT	WT-0159	Johndeer Tractor	1467.5	228,238.46		53347.81	15788.95	6990.37				304,365.59	207.40

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WT	WT-0161	Johndeer Tractor	1830.5	381,197.04	0	21697.66	42265.49	106.04	0	0	0	445,266.23	243.25
WT	WT-0162	Johndeer Tractor	1378.75	251,580.86	2525.43	0	2094.44		4127.48	186.04	251.64	260,765.89	189.13
WT	WT-0163	Johndeer Tractor	1335	483,808.59	1532.3	14752.57	5650.05	6323.05	2504.35	112.88	152.68	514,836.47	385.65
WT	WT-0164	Johndeer Tractor	946	158,680.44	232.51	148935.65	18369.61	485.79	380	17.13	23.17	327,124.30	345.80
WT	WT-0165	Johndeer Tractor	1540	266,044.65	7663.09		7077.16	1375.8	12524.33	564.53	763.56	296,013.12	192.22
WT	WT-0187	Johndeer Tractor	1165.25	80,160.60	279.47	155176.58	10969.41	11.44	456.76	20.59	27.85	247,102.70	212.06
sub total			9663	1849710.64	12232.8	393910.27	102215.11	15292.49	19992.92	901.17	1218.9	2395474.3	247.90
WT	WT-0170	WHEEL TRACTOR	514.5	58005.57	342.11		79123.97		559.13	25.2	34.09	138090.1	268.40
WT	WT-0171	WHEEL TRACTOR	1300.5	110155.5	10155.06	274180.4	3705.7	7568.31	16597.13	748.11	1011.87	424122.1	326.12
WT	WT-0172	WHEEL TRACTOR	46.5	168659.4	5358.67	262721.2	118.23		8758.05	394.77	533.95	446544.3	9,603.10
WT	WT-0173	WHEEL TRACTOR	3.25	250729.1				741.52				251470.6	77,375.58
WT	WT-0174	WHEEL TRACTOR	1504	62399.86	5736.81	302440.5	7653.67	5459.05	9376.07	422.62	571.63	394060.2	262.01
sub total			3368.75	649949.4	21592.65	839342.2	90601.57	13768.88	35290.38	1590.7	2151.54	1654287	491.07
WT	WT-0198	Wheel tractor	3500	175876.2	12749.55	327099.9	15584.73	29154.45	20837.48	939.24	1270.39	583511.9	166.72
WT	WT-0200	Wheel tractor	1958	37794.33	7531.39	170489.7	130459.5	59433.93	12309.07	554.83	750.44	419323.2	214.16
WT	WT-0201	Wheel tractor	121.85		11224.63	25247.09	6498.82	5435.69	18345.2	826.9	1118.44	68696.77	563.78
WT	WT-0202	Wheel tractor	110.5	56330.12	63344.95	17334.71	17283.16	14934.21	103529.1	4666.54	6311.81	283734.6	2,567.73
sub total			5690.35	270000.7	94850.52	540171.4	169826.2	108958.3	155020.8	6987.51	9451.08	1355266	238.17
		Summary											
Catagory	PlateNo	VehName	KmOrHr	Drivers	MechaP	Fuel	Lub	TyreandTube	Spare1	GenP	SunP	TotalCost	Unit cost /hr
		Jonher 9330/9410 R	11442.05	1835947	490941	7215491	281508.1	413189.4	802379.3	36167.03	48918.28	11124540	972.2506317
		Johner 5725	9663	1849711	12232.8	393910.3	102215.1	15292.49	19992.92	901.17	1218.9	2395474	247.9017179
		Dyne for	3368.75	649949.4	21592.65	839342.2	90601.57	13768.88	35290.38	1590.7	2151.54	1654287	491.0685892

		YTO -1804	5690.35	270000.7	94850.52	540171.4	169826.2	108958.3	155020.8	6987.51	9451.08	1355266	238.169262
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APPENDIX-VI: Projected Machinery Hours Based on Average Three Years Performance

Projected Machinery Hours Based on Average the Past Three Years Performance										
S/No	Section	Machinery model	Actual Machinery Hours rate Cost /Hr			Average Machinery Hours cost/ Hr	Consumption Rate Projected For The Next Three Years			Ave.hr
			2016/17 (2009)	2017/18 (2010)	2018/19 (2011)		2019/20 (2012)	2020/21 (2013)	2021/22 (2014)	
1	LPCT	Johner 9410/9330	57,804.30	66474.95	73122.44	65800.56	75670.65	87021.24	100074.43	87588.77
2		Versatile	2,114.28	2,135.42	2348.97	2199.56	2529.49	2908.91	3345.25	2927.88
3		Dyna 4 tractor	4061.38	3368.75	3705.63	3711.92	4268.71	4909.01	5645.36	4941.03
4		YTO -1804	8,668.23	5690.35	6259.39	6872.66	7903.55	9089.09	10452.45	9148.36
5		Jonher 5725	9969.93	9663	10629.30	10087.41	11600.52	13340.60	15341.69	13427.60
6	Harvesting	Grab loader	12,743.20	14820.48	17043.55	14869.08	17099.44	19664.35	22614.01	19792.60
7		BELL TRACTOR 1716AF	49661.72	56309.2	64755.58	56908.83	65445.16	75261.93	86551.22	75752.77
8		KAT tractor	8,792.26	11900.35	13685.40	11459.34	13178.24	15154.97	17428.22	15253.81
9		URSUS	1,165.40	16254.25	18692.39	12037.35	13842.95	15919.39	18307.30	16023.21
		CT	3,872.55	3622.574	4165.96	3887.03	4470.08	5140.59	5911.68	5174.12
		HBT	1,282,586.50	12995.97	14945.37	436842.61	502369.00	577724.35	664383.01	581492.12

APPENDIX-VII: Projected Operators Cost per Hours Based on Average of three Years Performance status

Projected Operators Cost per Hours Based on Average the Past Three Years Performance statusConsumption Rate Projected For The						
Section	Machinery Model	Actual Operators Cost /Hr	Average	Next Three Years		
						Remark
						%

		2016/17 (2009)	2017/18 (2010)	2018/19 (2011)	Operator cost/ Hr	2019/20 (2012)	2020/21 (2013)	2021/22 (2014)	1.15
LPCT	Johner 9410/9330	726004.05	1835946.76	2111338.774	1557763.195	1791427.67	2149713.209	2579655.85	
	Versatile	180802.47	0	0	60267.49	69307.6135	83169.1362	99802.96344	
	Dyna 4 tractor	92775.45	649949.44	747441.856	496722.2487	571230.586	685476.7032	822572.0438	
	YTO -1804	656640.9	270000.67	310500.7705	412380.7802	474237.897	569085.4766	682902.572	
	Jonher 5725	631048.46	1849710.64	2127167.236	1535975.445	1766371.76	2119646.115	2543575.337	

APPENDIX-VIII: Projected Service & maintenance Cost per Hours Based on Average of Three Years Performance

Projected Service&maintenancee Cost per Hours Based on Average the Past Three Years Performance									
Sec- tion	Machinery model	Actual service and maintenance Cost /Hr			Average service & maintenance cost/ Hr	Consumption Rate			Re- mark
		2016/17 (2009)	2017/18 (2010)	2018/19 (2011)		2019/20 (2012)	2020/21 (2013)	2021/22 (2014)	
LPCT	Johner 9410/9330	700677.63	490941.03	685180.7295	625599.7965	719439.8	827355.7	951459.1	
	Versatile	0	0	0	0	0	0	0	
	Dyna 4 tractor	48513.6	21592.65	40311.09375	36805.78125	42326.65	48675.65	55976.99	

YTO -1804	273505.59	94850.52	211804.7633	193386.9578	222395	255754.3	294117.4	
Jonher 5725	5809.01	12232.8	10374.04075	9471.95025	10892.74	12526.65	14405.65	

APPENDIX-IX: Projected Fuel Consumption Cost per Hours Based on Average the Past Three Years Performance

Projected lub& oil Cost per Hours Based on Average the Past Three Years Performance									
Section	Machinery Model	Actual lub& oil Cost /Hr			Average lub & oil cost/Hr	Consumption Rate			Re-mark
		2016/17 (2009)	2017/18 (2010)	2018/19 (2011)		2019/20 (2012)	2020/21 (2013)	2021/22 (2014)	
LPCT	Johner 9410/9330	519119.08	281508.05	456357.5	418994.8647	477654.1	544525.7	620759.3	
	Versatile	0	0	0	0	0	0	0	
	Dyna 4 tractor	44658.39	90601.57	77098.18	70786.04573	80696.09	91993.55	104872.6	
	YTO -1804	186135.12	186135.12	212194	194821.4256	222096.4	253189.9	288636.5	
	Jonher 5725	72404.49	102215.11	99533.17	91384.25733	104178.1	118763	135389.8	

APPENDIX- X: Projected tyre& tube cost per hr Based on Average the Past Three Years Performance

Projected tyre& tube cost per hr Based on Average the Past Three Years Performance

Section	Machinery Model	Actual tyre& tube Cost /Hr			Average Tyre and tube cost/Hr	Projected For The Next Three Years		
		2016/17 (2009)	2017/18 (2010)	2018/19 (2011)		2019/20 (2012)	2020/21 (2013)	2021/22 (2014)
LPCT	Johner 9410/9330	728827.13	413189.43	650949.4392	597655.3331	681327.1	776712.9	885452.7
	Versatile	0	0	0	0	0	0	0
	Dyna 4 tractor	62527.05	13768.88	43488.6801	39928.20337	45518.15	51890.69	59155.39
	YTO -1804	153409	108958.28	149549.3496	137305.5432	156528.3	178442.3	203424.2
	Jonher 5725	9649.91	15292.49	14217.168	13053.18933	14880.64	16963.92	19338.87

APPENDIX- XI: Projected Spare Part Cost per Hours Based on Average the Pas Three Years Performance

Projected Spare Part Cost per Hours Based on Average the Past Three Years Performance									
Section	Machinery Moodel	Actual Spare Part Cost /Hr			Average Spare Part cost/ Hr	Consumption Rate Projected For The Next Three Years			Remark
		2016/17 (2009)	2017/18 (2010)	2018/19 (2011)		2019/20 (2012)	2020/21 (2013)	2021/22 (2014)	
LPCT	Johner 9410/9330	1122292.42	802379.25	1097063	1097062.85	1250651.7	1425742.9	1625346.9	1.01
	Versatile	0	0	0	0	0	0	0	
	Dyna 4 tractor	77705.43	35290.38	64407.61	64407.6117	73424.677	83704.132	95422.711	

YTO -1804	438080.57	155020.83	338067.8	338067.798	385397.29	439352.91	500862.32	
Jonher 5725	9304.42	19992.92	16699.48	16699.4838	19037.412	21702.649	24741.02	

APPENDIX- XII: Projected General Material Cost per Hours Based on Average the Past Three Years Performance

Projected General Material Cost per Hours Based on Average the Past Three Years Performance									
Section	Machinery Model	Actual G. material Cost /Hr			Average Gmetarial cost/ Hr	Consumption Rate			Remark
		2016/17 (2009)	2017/18 (2010)	2018/19 (2011)		2019/20 (2012)	2020/21 (2013)	2021/22 (2014)	
LPCT	Johner 9410/9330	70513.96	36167.03	60808.16	55829.7181	63645.88	72556.3	82714.18	
	Versatile	0	0	0	0	0	0	0	
	Dyna 4 tractor	4882.25	1590.7	3689.582	3387.5105	3861.762	4402.409	5018.746	
	YTO -1804	27524.73	6987.51	19671.98	18061.4056	20590	23472.6	26758.77	
	Jonher 5725	584.6	901.17	846.8889	777.5529667	886.4104	1010.508	1151.979	

APPENDIX- XIII: DSS Code

Private Sub cmdclear_Click(Index As Integer)

Me.txtact1.Text = ""

Me.txtact2.Text = ""

Me.txtact3.Text = ""

Me.txtact4.Text = ""

```
Me.txtsoft = ""  
Me.txttilled = ""  
Me.txtfirm = ""  
Me.txtwi = ""  
Me.txtspeed = ""  
Me.tXtpullH = ""  
Me.txtpullV = ""  
Me.txtpullS = ""  
Me.txtdbpH = ""  
Me.txtdbpV = ""  
Me.txtdbpS = ""  
Me.txtptoh = ""  
Me.txtptov = ""  
Me.txtptos = ""
```

```
End Sub
```

```
Private Sub cmdexit_Click()
```

```
Unload Me
```

```
End Sub
```

```

Private Sub cmdfurrowing_Click()

txtact4 = "Furrowing"

txtsoft = Val(0.55)

txtwi = Val(4.5)

txtspeed = Val(7)

txtsoilp = Val(0.55)

tXtpullH = Val(3.67)

txtpullV = Val(3.45)

txtpullS = Val(3.34)

txtdbpH = Val((tXtpullH * txtwi * txtspeed) / (3.6))

txtdbpV = Val((txtpullV * txtwi * txtspeed) / (3.6))

txtdbpS = Val((txtpullS * txtwi * txtspeed) / (3.6))

txtptoh = Val(txtdbpH / txtsoilp)

txtptov = Val(txtdbpV / txtsoilp)

txtptos = Val(txtdbpS / txtsoilp)

End Sub

```

```

Private Sub cmdharrowing_Click()

txttilled = Val(0.67)

txtact3 = "Harrowing"

txtwi = Val(3.5)

```

```

txtspeed = Val(6)
txtsoilp = Val(0.67)
tXtpullH = Val(13.3)
txtpullV = Val(13)
txtpullS = Val(12)
txtdbpH = Val((tXtpullH * txtwi * txtspeed) / (3.6))
txtdbpV = Val((txtpullV * txtwi * txtspeed) / (3.6))
txtdbpS = Val((txtpullS * txtwi * txtspeed) / (3.6))
txtptoh = Val(txtdbpH / txtsoilp)
txtptov = Val(txtdbpV / txtsoilp)
txtptos = Val(txtdbpS / txtsoilp)
End Sub

```

```

Private Sub cmdploughing_Click()
txttilled = Val(0.67)
txtact2 = "Ploughing"
txtwi = Val(2.8)
txtspeed = Val(6)
txtsoilp = Val(0.67)
tXtpullH = Val(23.1)
txtpullV = Val(18.57)

```

```

txtpullS = Val(17.55)
txtdbpH = Val((tXtpullH * txtwi * txtspeed) / (3.6))
txtdbpV = Val((txtpullV * txtwi * txtspeed) / (3.6))
txtdbpS = Val((txtpullS * txtwi * txtspeed) / (3.6))
txtptoh = Val(txtdbpH / txtsoilp)
txtptov = Val(txtdbpV / txtsoilp)
txtptos = Val(txtdbpS / txtsoilp)
End Sub

Private Sub cmdsubsoiling_Click()
txtfirm = Val(0.72)
txtact1 = "Subsoiling"
txtwi = Val(3.2)
txtspeed = Val(6)
txtsoilp = Val(0.72)
tXtpullH = Val(24.9)
txtpullV = Val(22.8)
txtpullS = Val(20.72)
txtdbpH = Val((tXtpullH * txtwi * txtspeed) / (3.6))
txtdbpV = Val((txtpullV * txtwi * txtspeed) / (3.6))
txtdbpS = Val((txtpullS * txtwi * txtspeed) / (3.6))
txtptoh = Val(txtdbpH / txtsoilp)

```

txtptov = Val(txtdbpv / txtsoilp)

txtptos = Val(txtdbps / txtsoilp)

word_object.Visible = True

End Sub

APPENDIX- XIV: Screen for Tractor selection

Tractor Selection Form

INPUT PARAMETERS		OUTPUT VARIABLES		
Soil Condition and Conv.F		Draft Force (kN/m)	PTO Power(kW)	
Firm		Heavy clay Soil		
Tilled		Vertisol		
Soft		Sandy Loam		
Fied Activity		Drawbar Power(kW)		
Activity 1		Heavy clay Soil		
Activity 2		Vertisol		
Activity 3		Sandy Loam		
Activity 4		PUR		
Other Parameters		Nearest available DBP from tractor database		
Width of Implement(m)		Heavy clay Soil		
Travel Speed(km/hr)		Vertisol		
		Sandy Loam		



APPENDIX- XV: Screen for implement selection

JD 9410R				
JD 830R				
YTO 1804				

Input Variables

Draft Force in Heavy Clay Soil

Draft force S

Draft force P

Draft force H

Draft force F

Working speed

Working speed F

Conversion factors

Conversion factorp

Conversion factorh

Conversion factorf

Subsoiler	
Disc Plough	
Disc Harrow	
Furrower	

IW JD410	IW JD330	IW YTO180
----------	----------	-----------

Clear **EXIT**

APPENDIX-XVI: Workshopequipment checklist

Se.	W/shopEquip	TypeofTool&Equipment	A	B	C
1	MachineShop	LatheMachine	✓		
2	„	MillingMachine	✓		
3	„	PillarDrillingMachine	✓		
4	„	Valveseatandboringmachine			✓
5	„	DrumLathe Machine	✓		
6	„	Cylinderboringandhoningm/c			✓
7	„	ElectricalArcWeldingMachine	✓		
8	„	Powerhacksaw	✓		
9	„	MIGweldingmachine			✓
10	„	Oxyacetyleneandtorchset			✓
11	„	Hand drill	✓		
12	„	Hand grinder	✓		
13	„	CrankShaftGrinder			✓
14	GeneralTool	Lightmechanictoolbox	✓		
15	„	Heavymechanic tool box	✓		
16	„	Lubrication unit	✓		
17	„	Mechanicaljack	✓		
18	„	Floorjack	✓		
19	„	Portablehydraulicjack			✓
20	„	Transmission jack			✓
21	„	Bodymantool	✓		
22	„	Bearing,hub, pulleyextractor		✓	
23	„	Vices			✓
24	„	Chainhoist			✓
25	„	Piston ringextractor			✓
26	„	Piston ringcompressor		✓	
27	„	Valvespringcompressor			✓
28	„	Torchwrenchset		✓	
29	„	Cylinderlinerremoval &installat			✓

30	„	Compressor	✓		
31	„	waterpump forwashingbase			✓
32	„	Axlestand			✓
33	„	Crane		✓	
34	„	Enginestand			✓
35	„	Gearbox stand			✓
36	„	Tireinflation gauge	✓		
37	„	Steam cleaning			✓
38	„	Wheelalignmentgauge			✓
39	„	Hydraulicsystemrepair facilities		✓	
40	Diagnos tool	Petrolenginecompressiontester			✓
41	„	Ignitionsystemtestingset			✓
42	„	Exhaustgasanalyzer			✓
43	„	Injectionpressuretester		✓	
44	„	Dieselenginecompressiontester			✓
45	„	Dynamicignitiontimingadjuster			✓
46	„	Petrolenginecompressiontester			✓
47	„	Leakagetester			✓
48	El'cshoptools	Batterycharger	✓		
49	„	Batterwaterdistillationunit			✓
50	„	Batteryload tester			✓
51	„	Armaturetester			✓
52	„	Headlightalignmentgauge			✓
53	„	Multi-meter			
54	„	Universalelectrictestbench			✓
55	Measur tools	Valiercaliper	✓		
56	„	Innerandoutermicrometer	✓		
57	„	Dialgauge(dialindicator)			✓
58	„	Boregage			✓
59	„	Plasticgage			✓
			19	7	34

APPENDIX- XVII: Questionnaire

Part I. Demographic or personal information

1. **Sex** 1, Male ☐ 2, Female ☐

2. **Age in completed years**

1, less than 25 Years ☐ 2, Between 26 – 35 Years ☐

3, Between 36- 50 Years ☐ 5, above 51 Years ☐

3. **Educational level**

1, Secondary school (9-12gared) ☐ 2, Certificate ☐ 3, TVT/Diploma 4, Frist Degree ☐ 5, Masters and above

☐4.**Work Experience**

1, less than 10 years ☐ 2, Between 10-15 Years

☐ 3, Between 16- 25 Years ☐ 5, above 25 Years ☐**Part**

II. Questions related to Maintenance Status

1. How do you rate the standard and quality of the maintenance workshop?

1, Excellent ☐ 2, Very good ☐

3, Good ☐ 4, Fair ☐ 5, Poor/ bellow standard ☐

2. How is your experience/ practice of keeping records of your daily(routine) maintenance activities jobs?

3. How often do you read machinery manuals (service manuals) during your maintenance activities?

4. Do you know the difference between preventive and corrective maintenance? Which one is better? Why?

5. Are there sufficient spare parts for your daily maintenance activities?

6. How do you evaluate your experience and skills to perform the work you are assigned?

