Optimization of Agricultural Machinery Utilization: A Case of Hetosa Farmers' Cooperative Union, Oromia Region

By: Rediat Getnet Abeyu

A Thesis Submitted to the Department of Mechanical Engineering, College of Mechanical, Chemical, and Materials Engineering

Presented in Partial Fulfillment of the Requirements for the Degree of Master's in

Agricultural Machinery Engineering

Office of Graduate Studies
Adama Science and Technology University

October, 2025
Adama, Ethiopia

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DECLARATION

First, I hereby declare that this master's Thesis entitled "**Optimization of Agricultural Machinery Utilization: A Case of Hetosa Farmers' Cooperative Union, Oromia Region**" is my original work and 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 thesis have been duly acknowledged through citation.

Rediat Getnet Abeyu	____________	____________________
Name of the Candidate	Signature	Date

RECOMMENDATION

We, the advisors of this Thesis, hereby certify that we have read the revised version of the thesis entitled "**Optimization of Agricultural Machinery Utilization: A Case of Hetosa Farmers' Cooperative Union, Oromia Region**" prepared under our guidance by Rediat Getnet Abeyu submitted in partial fulfillment of the requirements for the degree of Master's of Science in Agricultural Machinery Engineering. Therefore, we recommend the submission of the revised version of the thesis to the department following the applicable procedures.

Siraj Kedir Busse (PhD.)	____________	____________________
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Name of the Co-advisor	Signature	Date

APPROVAL PAGE OF M.SC. THESIS

We, the advisors of the thesis entitled "Optimization of Agricultural Machinery Utilization: A Case of Hetosa Farmers' Cooperative Union, Oromia Region" and developed by Rediat Getnet Abeyu, hereby certify that the recommendations and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Siraj Kedir Busse (PhD.)	___________	__________________
Name of the Advisor	Signature	Date
Sintayehu Legesse Zeleke (MSc.)	___________	_________________
Name of the Co-advisor	Signature	Date

We, the undersigned members of the Board of Examiners of the thesis by Rediat Getnet Abeyu have read and evaluated the thesis entitled "Optimization of Agricultural Machinery Utilization in Hetosa Farmers' Cooperative Union, Oromia Region" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirements of the degree of Master of Science in Agricultural Machinery Engineering.

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Finally, approval and acceptance of the thesis are contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and College Graduate Committee (CGC).

Head of the Department	Signature	Date
College Dean	Signature	Date
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LIST OF ACRONYMS

CPM	Critical Path Method
EES	Engineering Equation Solver
EFC	Effective Field Capacity
FE	Field Efficiency
FC	Fuel Consumption
FMI	Field Machine Index
GDP	Gross Domestic Product
GIS	Geographical Information System
GPS	Global Positioning System
ICT	Information and Communication Technologies
INLP	Integer Nonlinear Programming
ISO	International Organization for Standardization
LP	Linear programming
NLP	Nonlinear programming
NPV	Net Present value
PERT	Program Evaluation and Review Techniques
TSA	Tabu Search Algorithm

ABSTRACT

Farm mechanization refers to the integration of various tools, implements, and machinery into agricultural practices to improve production efficiency and effectiveness. A preliminary assessment of the Hetosa Farmers' Cooperative Union reveals several issues with the utilization of agricultural machinery, which hinder its members from delivering timely and effective mechanized services. The research was motivated by significant issues in the union's present machinery management system, including a lack of modern scheduling, outdated equipment, lack of data-based management, and underutilization of the existing machinery. A mixed-methods approach using qualitative and quantitative data collection instruments through interviews, questionnaires, and secondary data sources was employed in the study. Route optimization was done using MATLAB, GIS was used for terrain analysis, CROPWAT and MS Project for precipitation and crop period assessment and task scheduling, respectively. Census and purposive sampling techniques are used to assess the existing machinery, and tabu search algorithm and origin-destination cost matrices have been used in this study to reduce route distances and fuel consumption. The result indicated that the union could minimize the total fuel used by 11.28% throughout the region and up to 23.34% only in the Hetosa woreda. This greatly cuts the operational cost and enhances the working hours. An annual unproductive labor cost of 123,852 birr was identified due to inefficient refueling and machinery downtimes, with a combined financial loss of over 5.48 million birr in tillage and harvesting services. It was found that tractors and combine harvesters were outdated and could not support GPS technologies, thus leading to poor utilization and increasing maintenance costs. The study included Land use analysis of all Hetosa member woredas, which are Zuway Dugda, Dodota, Hetosa, Lude Hetosa, Munisa, Tiyo, and Sire. The study also established that full mechanization would be feasible in sloppy areas like Zuway Dugda and Dodota, while Munisa and Tiyo areas needed semi large scale and small-scale mechanization with targeted intervention supported by strategic scheduling. CROPWAT and MS Project utilized to analysis the growing periods and task scheduling respectively, enabled good machinery allocation and resource management. Based on these findings, the study recommends replacing aging machinery, establishing a fuel storage facility in order to reduce refueling time, promoting cluster farming to reduce fragmentation of farm areas, adopting digital machinery management, and improving coordination with governmental bodies to improve the supply chain. GIS-based landscape analysis is also recommended to enhance sustainable land use and machinery performance in varied landforms for the East Arsi Zone.

Keywords: *Agricultural Machinery Utilization, Farmers' Cooperative, Fuel Efficiency, Operation Cost Optimization, Task Scheduling, Mechanization Strategy, GIS Terrain Analysis.*

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Agriculture is Ethiopia's most important sector, which contributes to overall economic growth and poverty reduction. According to the National Statistics Agency (2021), over 39% of the national GDP and 79% of employment are from agriculture. Approximately 79% of the poor rely entirely or partially on agriculture for survival. Leading the sector to a better product is not only critical for poverty reduction and food security, but it may also help Ethiopia address several other pressing development issues. Many organizations are operating around the world to assist people who need food, shelter, medication, education, and clean water, among other things.

According to the Ethiopian national agriculture mechanization strategy (2014), the economic use of engineering technology to increase the efficiency and productivity of human labor is known as agricultural mechanization. These covers preparing the land for planting, harvesting, on-farm processing, product storage, and marketing. In terms of raising production through timely farm operations, decreasing losses, lowering operating costs through improved management of expensive inputs, and improving the productivity of natural resources, mechanization in agriculture is essential to sustainable development. It also helps decrease drudgery in farm operations.

Bochtis et al., (2019) state that physical optimization has long been the main force behind raising the productivity and efficiency of agricultural machinery. The well-known advantages of economies of scale resulting in increased mechanical functionality have driven this evolution; however, this tendency is currently being stymied by environmental and biological variables that limit the size and weight of the machinery (such as soil compaction). Therefore, it is only theoretically conceivable to slightly increase the efficiency of the modern agricultural gear. Although it is impossible to increase effectiveness further in this regard, new engineering advancements such as advanced sensing and actuating technologies and enhanced information and communication technologies (ICT) have the potential to greatly increase the productivity of complex machinery. However, traditional agricultural machinery management is necessary for the full exploitation of these mechanical advancements. From the study by Shimeket et al., (2019) on cooperative unions for the use of agricultural machinery for more than 40 years, it has been known that producer cooperatives were founded in connection with the deceleration 138/70 to create a socialist economic system, and that these cooperatives provide and utilizes agricultural mechanization services in this process.

Abundant cooperation site employees have started on a large scale at the level of the unions through training, expansion of contemporary agricultural production technologies, creating competent and organized farmer cooperatives, and increasing the area for the farmers. By offering rental services based on the needs and wishes of the farmers, various agricultural mechanization resources can be employed for other activities. The farmer's labor-intensive work has decreased, and it has been able to boost output and productivity, raise member incomes, and improve their standard of living.

Optimization is the act of obtaining the best result under the given circumstances (Singiresu, 2009). Any engineering system's design, development, and maintenance require engineers to make several administrative and technological choices at various points in time. All of these choices aim to maximize the intended benefit or minimize the amount of work needed. Since the desired outcome or the amount of work needed in any real-world scenario can be described as a function of specific choice variables. The process of determining the circumstances that yield a function's greatest or least value is known as optimization.

1.2. Statement of the Problem

The machinery management system of the Hetosa Farmers' Cooperative Union has limitations that hinder its ability to provide timely and efficient mechanized service identified in the Hetosa Farmers' Cooperative Union's machinery management system, which limits and to recommend strategies for improving the system's overall effectiveness. The challenge faced included ineffective task scheduling, inefficient resource utilization, and a limitation of research on cooperative union-specific challenges to mechanization service provision. According to Shimeket et al. (2019), the barrier that faced in the cooperative union included to provide services to its members consistently and timely manner, owing mostly to a lack of machinery and the absence of an advanced equipment management system and lack of mechanization department that lead by knowledge and skill.

Lack of the optimum use of resources contributes to the problem, resulting in inefficiencies in service delivery. Furthermore, the cooperative Unions currently lack an organized task-scheduling system, which would improve service delivery. Without a clear framework for reducing operational expenses, the cooperative's financial limits restrict its ability to expand mechanization services. To solve these issues, this study uses optimization approaches to improve work scheduling and ensure timely service delivery. By reducing operational expenses, identifying the gap to schedule the task, and identifying the resource to be optimized, and recommend the appropriate amount and size of machinery requirements for the cooperative to support future expansion and improve the cooperative's ability to deliver the service to its members efficiently.

1.3. Objectives of the Study

1.3.1. General Objective

The general objective of this study is to optimize the agricultural machinery utilization in Hetosa farmers' cooperative unions.

1.3.2. Specific objectives

- To assess the agricultural machinery utilization in the Hetosa farmers' cooperative union.
- To optimize the operational cost of the agricultural machinery in the Hetosa farmers' cooperative union.
- To determine the machinery and equipment required per hectare for the Hetosa farmers' cooperative union.
- To optimize the task scheduling of agricultural machinery in the Hetosa farmers' cooperative union by using MS Project.

1.4. Significance of the Study

This research will address sustainability issues in farmers' unions by minimizing the operation cost, maximizing working time, and determining appropriate machine sets. the study helps to identify the gap and will provide a scientific agricultural machinery management system. This system helps increase agricultural machinery productivity and efficiency.

1.5. Scope of the Study

The study attempted to assess and optimize the agricultural machinery utilization in Hetosa farmers’ unions. The data from 2018 to 2024 will be collected from the selected farmers’ cooperative union and utilized. The study aims to assess the utilization of agricultural machinery in the Hetosa Farmers' Cooperatives Union and optimize operational costs by identifying the best route and path between Hetosa members’ works using network analysis and the Tabu search algorithm. And the study also conducted an optimum task schedule in daily and seasonal activities, depend on the resources available in the Hetosa farmers' cooperatives unions. Further, the study covers the number of required tractors, combines, planters, and ploughs to give the service to all members.

1.6. Limitations of the Study

- The issue of agricultural machinery management at the Hetosa farmers’ cooperatives unions is complex and includes several sections.
- A primary limitation of this study is its reliance on the crop calendar season, which prolonged the data collection period.
- Limited access to software for operational work, the study utilizes MS Project for scheduling the optimum tasks. MS project design and mostly used for project work.
- The broadness and depth of the study were constrained by the study time.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

Agricultural machinery management is the study of the decision, utilization, and replacement of agricultural machines. Agricultural machinery management is the branch of farm management that specializes in the optimization of agricultural production machinery aspects. The main emphasis is on the efficient choice, use, maintenance, and replacement of machinery. Taking part in a variety of activities, from basic soil cultivation to production expenses in different nations (McNulty, 2009). The importance of this research review is to identify the previous work related to agricultural machinery utilization, to identify the methodology, to identify the gap of the previse research, analysis the best optimization techniques for agricultural machinery utilization in the context of Ethiopian farmers' cooperatives union. The main objective of the literature review is to identify the methodology of the research, the gap of the previse research, and to obtain the theoretical and empirical evidence for this research.

2.1.1. Performance Metrics of Agricultural Machinery

Hunt (2001) indicated that measures of agricultural performance are the rate and quality at which the field operations are accomplished. Hunt and Wilson (2016) emphasize that agricultural machinery performance can be evaluated through two main measures: rate of operation and quality of output. The rate is important for timely operation, and it is influenced by seasonal change and weather conditions. The quality of output is crucial to measuring performance metrics. It refers to a machine's ability to operate without wasting products. The poor quality of the material also caused the machinery to be damaged and its impact on machinery durability.

2.1.2. Key performance indicators (KPIs) for agricultural machinery

Machine capacities: - Machinery performance rates are typically expressed as quantity per unit time. For agricultural field machines, this is often reported as area per hour, while harvesting machines may be measured in bushels or tons per hour. These metrics collectively define machine capacity. Agricultural machinery field capacity includes:

- Theoretical Field Capacity

- Effective field capacity
- Material capacity
- Throughput capacity.

Time Efficiency: - When calculating the capacities or costs of machinery related to the various farm enterprises, the following list outlines the time elements that involve labor and are associated with typical field operations. Time efficiency is a percentage that reports the ratio of the time a machine is effectively operating to the total time the machine is committed to the operation.

- Machinery preparation time at the farmstead.
- Travel time to and from the field.
- Theoretical field time
- Machinery preparation time in the field, both before and after operations.
- Turing time and time crossing grass waterways.
- Time to load or unload the machine's containers if not done on the go.
- Machine adjustment time if not done on the go.
- Maintenance time.
- Repair time.
- Operator's time.

Field efficiency is affected by the theoretical capacity of the machine, machine maneuverability, field pattern, field shape, field size, yield (if harvesting operation), soil and crop condition, and system limitations.

Economic performance: -Hunt and Wilson (2016) indicated that proper farm machinery management covers increasing the economic performance of the overall system to enhance profitability. Modern farming needs a business-oriented approach, using machinery as a tool for profitable production. Efficient machinery management requires the integration and optimization of all machine operations to enhance total farm profit. According to Hunt and Wilson (2016), Economic performance is measured in dollars per unit of output, with lower costs per unit indicating better performance. They identify three key components:

- Machine performance,
- Power performance, and
- Operator performance.

Machine performance is defined as the output per unit of time. Power is defined as the rate of work done. Work in a technical sense is the application of a force through a distance. The efficiency with which power is used to achieve the production goals of the farm. Effective equipment management requires a deep comprehension of the nature of power and how to use it most effectively.

2.3. Cost Analysis of Agricultural Machinery

2.3.1. Machinery Cost

Agricultural machinery management decisions entail an accurate knowledge of costs. The cost of field machinery operating is determined by so many elements that each farm's machinery system must be handled as a unique case. Significant differences in machine use, price levels, energy required, fuel prices, and labor expenses indicate that he will need to build his standard costs, using the average costs determined by others simply for comparison purposes (Hunt, 2001). Machinery ownership costs account for a significant share of crop and livestock producers' output costs. Row crops, fruits and vegetables, and forages are all grown with increasingly specialized technology and equipment. Machinery costs are difficult to determine, especially for small businesses or activities (Cross, 1995). From the study by Srivasava et al. (2006), machinery expenses include ownership and operation costs, as well as penalties for late delivery.

Machine costs are classified as time-related and use-related. Only when a machine is used do use-related costs arise. Interest, insurance, personal property taxes, and housing are examples of overhead costs (Lazarus, 2009). The entire cost of doing a field activity comprises charges for the implement or machine, the power used, and labor (Keneper et. al.,1982). Types of machine costs:

A. Fixed costs: Machine costs are classified as time-related and use-related. Only when a machine is used do use-related costs arise. Interest, insurance, personal property taxes, and housing are examples of overhead costs (Lazarus, 2009).

i. Depreciation

Makkar, R. (2020) defines depreciation as a machine's declining value over time as a result of use. It is frequently the most expensive expense. Due to a variety of factors, including age, wear and tear, and obsolescence, machines lose value over time.

Depreciation can be computed in several ways. These consist of the following: -

a. Straight-line method

For every year the machine is owned, the value is depreciated by the same amount according to the straight-line depreciation technique. If the appropriate salvage value is used for the machine's age, this method can always be used to estimate expenditures over a certain period. The following can be used to get the annual depreciation value:

Expression: -

$$D = \frac{C-S}{L*H} \ldots\ldots (2.1)$$

Where D is average annual depreciation, Rs/h; P is purchasing price, Rs.; S = salvage value, taken as 10% of the purchase price; L is life of machine, years, and H is annual use of machines, hours.

b. Declining-balance depreciation method

Instead of using the value determined by the straight-line approach or the sum of the digits method, it displays the true value of a machine at any age. A machine depreciates differently each year when using the decreasing balance approach, but the annual percentage of depreciation remains constant.

$$\text{Periodic Depreciation} = \text{Expense Beginning book value x Rate of depreciation} \ldots (2.2)$$

c. Sum-of-the-years digits method

Because the machine's annual depreciation rate drops with age, it is a far more accurate way to determine a machine's true value at any age.

$$\text{Depreciation Expense} = \left(\frac{\text{Remaining life}}{\text{Sum of the years digits}}\right) \text{x(Cost} - \text{Salvage value)} \ldots\ldots (2.3)$$

d. Units of production depreciation method

During the asset's useful life, the units-of-production depreciation technique depreciates assets based on the total number of hours consumed or the total number of units that can be produced using the asset. The units-of-production method's formula is:

$$\text{Depreciation Expense} = \text{units x (Cost Salvage value)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.4)$$

ii. Interest in investment

The interest is a sizable, costly expense for agricultural machinery after depreciation. It is a direct cost associated with borrowed funds. Money that may be used elsewhere in the company is locked up when machinery is purchased, even if cash is paid for it. Although they can vary greatly, interest rates typically range from 12 to 16 percent.

iii. Insurance, housing, and tax

Together, insurance and housing costs amount to 3% of the purchase price annually.

B. **Operating costs (Variable cost):** Expenses for items such as repair, maintenance, lubrication, fuel, oil, and labor are increased because of actual machine working hours. They are known as operating costs.

Fuel cost: According to Lazarus (2009), fuel cost is determined by multiplying fuel consumption by fuel price. For each type of implement, fuel consumption is assumed to be 0.044 gallons of diesel fuel per PTO horsepower-hour on average. Within a certain implement type, fuel consumption per acre is averaged across sizes. Diesel fuel is used in all power units, vehicles, tractors, combines, etc.

Lubrication cost: According to Nebraska Tractor Test data, a general rule of thumb is applied for estimating the cost of lubrication. For example, the rule of thumb that is applied for power machinery is 15% of fuel costs. For non-power equipment, 5% of the purchase price.

Labor cost is calculated using the cost of labor per hour. The complete cost of labor, including typical wage rates, benefits, taxes, and payroll overhead costs paid to the machine operator, should be included in calculations of equipment costs. The number of labor hours per acre is determined by the machinery's field capacity. The total number of labor hours required to operate machinery, including time spent finding, connecting, adjusting, and moving the machine, is determined by a labor adjustment factor.

Repair and Maintenance Cost: repairs are fixed costs in some respects and operating costs in other respects. Srivasava et al. (2006) indicated that repair and maintenance expenses vary greatly depending on the care supplied by the machine's manager. Some expenses will always be required to replace old or failed parts and/or repair damage caused by accidents. Repair and maintenance expenses tend to rise in tandem with machine size and complexity, and therefore with machine purchase price. The repair and maintenance cost formula estimates total accumulated repair costs based on lifetime use hours.

2.4. Field working days

According to Alphonse. H (2008), the availability of workable days for field operations varies seasonally, impacting operation schedules and timeliness costs. It affects the number and size of the machine. And also it influence on the machinery variable cost. Larger machinery can reduce the variability cost by timely operating tillage, planting, and harvesting activities, and it covers all activities for fewer good working days. However, large machinery required high investment cost, and it needs proper machinery task scheduling. The study indicated that there are two rain season approaches to estimate the suitable agricultural working days. One approach is to use an annual series of actual field working days, as Shaw (1965) did when they utilized 20 years of historical data series from the state of Iowa, U.S.A. This method avoids bias and errors of methodology, but these data are rarely available, and changes in farming techniques can make them inappropriate. The two primary methods estimate suitable working days included : (1) using historical data, like Shaw (1965), who relied on 20 years of field data from Iowa. While accurate, such data are rare and may be outdated due to evolving farming practices. (2) Soil workability models, reviewed by Rounsevell (1993), typically assess soil water content, as it affects particle forces in the soil. These models, especially those incorporating water budgets and soil-specific thresholds, show good accuracy for monthly predictions but struggle with daily forecasts.

2.5. Soil Suitability for Agricultural Activities

Soil type and suitability affect the agricultural machinery utilization. It determines the type and size of machinery. And also, it influenced the time to do agricultural activities. Which included ploughing, planting, cultivating, and harvesting. The Food and Agriculture

Organization (FAO, 2006) states key factors affecting soil suitability include fertility, texture, structure, moisture retention, and depth. The soils are classified as highly suitable for agriculture, based on their physical and chemical characteristics. This includes high nutrient content and favorable moisture retention. Shoji et al. (1993) indicated that Mollic Andosols are fertile and have high water retention due to their high organic matter content and low bulk density. IUSS Working Group WRB (2015) stated that Luvic Phaeozems are considered for their productivity in cereal and legume cultivation due to high base saturation and humus content. Humic Nitosols' deep, well-structured profiles and high drainage capacities are especially beneficial for both commercial and subsistence agriculture, according to Eswaran et al. (2000). Because of their moderately leached soils with stable structures and moderate to high base saturation, chromic, haplic, and luvisols which are typically found in temperate and tropical climates are widely employed for agricultural production (FAO, 1998). Moreover, Vitric Andosols, another subtype of volcanic soil, are rich, light, and appropriate for intensive farming practices (Shoji et al., 1993). Lastly, while being younger and less established, Eutric Cambisols provide moderate fertility and ease of maintenance under conventional tillage systems (FAO, 2006). The fertility and high clay content of Eutric Vertisols are described by FAO (2006); however, their shrink-swell behaviour makes tillage and planting more challenging. While they are less likely to break than Vertisols, Vertic Cambisols can nonetheless provide problems with mechanical workability and moisture control. IUSS Working Group WRB (2015) studied Eutric Fluvisols usually found in floodplain regions, which exhibit a variety of profiles and textures. Despite being usually fertile, seasonal flooding and inadequate drainage can reduce their productivity. On the other hand, Eutric Leptosols need to be carefully managed through conservation techniques for long-term agricultural use because of their shallow, frequently stony profiles, which limit their root depth and water-holding capacity (FAO, 2006).

IUSS Working Group WRB (2015), described Lithic Leptosols are shallow and rocky, often underlain by bedrock, which restricts moisture storage and rooting depth, greatly limiting their agricultural viability.

2.6. Optimization Techniques for Agricultural Machinery

2.6.1. Introduction to optimization and its relevance to agricultural machinery.

Optimization techniques are categorized into two. The first one is traditional optimization techniques, and the second one is modern optimization techniques. Calculus methods, calculus variations, nonlinear programming, geometric programming, quadratic programming, linear programming, dynamic programming, integer programming, stochastic programming, separable programming, multi-objective programming, program evaluation and review techniques (PERT), and the Critical Path Method (CPM) are examples of traditional optimization techniques. Game theory is also included. The following are examples of modern optimization methods: fuzzy optimization, neural networks, ant colony optimization, particle swarm optimization, genetic algorithms, and simulated annealing. As previously mentioned, the study's optimization types and categories used the tabu search method. Task scheduling and path optimization are done using the Tabu search method.

Optimization techniques are essential in a variety of sectors and businesses. They are utilized to enhance productivity, cut down expenses, increase earnings, and address intricate issues. These methods entail choosing numerical parameters or functions that can produce the intended result with restricted resources (Bhattarai, 2018). These optimization techniques are implemented according to the organization's nature and utilized in the sectoral natural economy, managing an industrial corporation, simplifying the transportation system, and making engineering design.

Optimization techniques are an important tool for maximizing or minimizing a function to address specific constraints. These methods create a systematic solution for the agricultural sector. By implementing optimization techniques, farmers can minimize farm machinery operation costs, develop a proper task scheduling system, deliver efficient service, and utilize their resources, and ultimately it leads to increased productivity and production.

2.6.2. Review of various optimization techniques

According to Toilc et al.(2018), Optimization techniques can be categorized based on various factors. It included the number of functions involved(single or multi-objective), the type of variables(discrete or continuous), and the nature of variables (linear and non-linear programming). Figure 2.1 describes a detailed classification of optimization techniques based on the chronological order of emergence.

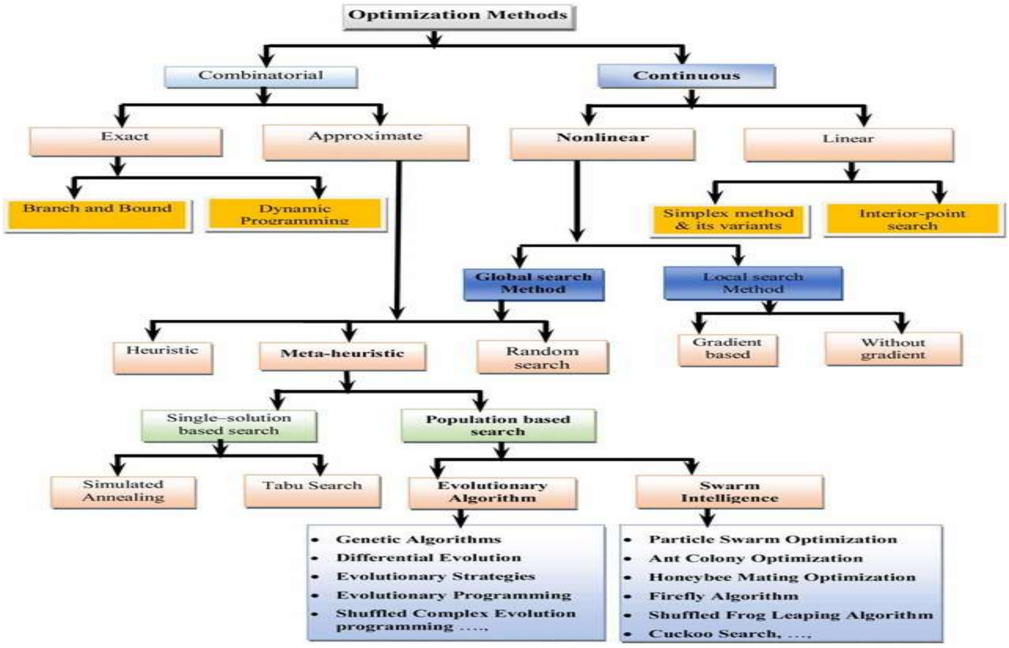


Figure1. Classification of optimization Techniques (Janga and Nagesh, 2020)

Classical Optimization Techniques: - Included as dynamic programming, linear programming, and nonlinear programming, and it provided the fundamental basis for the field. The simplex techniques, presented by George Dantzig in his findings, have transformed the solution of liner programing (Dantzig et al., 1998). Liner programing used for different areas, including resource allocation, production planning, task scheduling, salesperson, and transport routing. Dimitri P. Bertsekas. et al. (2016) expand the functionality of linear programming by a nonlinear objective function and constraints. Dynamic programming was founded by Richard Bellman, and it is optimal for overlapping sub-optimization problems. Including the shortest path and knapsack problems, this technique is an ideal solution in this area.

Modern Optimization Techniques: - It is an integration of computational capabilities and algorithmic design to solve the complex optimization challenges. It included integer programming, mixed integer programming, and quadratic programming. Wolsey's publication "Integer Programming" explores integer programming methods and their real-world uses in extensive detail (Wolsey et al., 1998). Braun et al.(2008) described mixed integer programming, a technique that uses both continuous and discrete decision variables, and mixed integer nonlinear programming. Michael J. Best stated in the title of "Quadratic Programming with Computer Programs." Quadratic programming is used for problems with a quadratic objective function and linear constraints (Best et al., 2003).

Metaheuristic Optimization Techniques: -The techniques are solutions to complex optimization problems that may fix the challenges for traditional and modern methods. It covers genetic algorithms, particle swarm optimization, simulated annealing, and ant colony optimization. John Holland explained the genetic algorithm in the publication "Adaptation in Natural and Artificial Systems." And the study established the groundwork for this domain (Holland et al., 1992). Kennedy and Eberhart (1995) presented Swarm Optimization. And it gives straightforwardness and efficiency in optimization findings. Kirkpatrick et al. (1983) introduced Simulated annealing, which works by copying the annealing process in metallurgy to pinpoint a global optimum. Dorigo and Stutzle (2004) explored the ant colony optimization techniques which create insoiration from the foraging behavior of ants and has been effectively utilized in a diverse array of combinatorial optimization challenges.

Tabu Search: - Is one of the popular metaheuristic optimization techniques that efficiently navigate the solution space, mostly applied in combinatorial optimization problems. It uses a "tabu list" to remember past solutions and moves, preventing revisits. Through a balance of exploration and exploitation, tabu search can effectively discover top-notch solutions for complicated optimization challenges (Xinmeng *et al*., 2017). TSA relies heavily on the initial solution provided. A high-quality initial solution can greatly assist TSA in locating an optimal solution within the solution space, whereas a subpar initial solution may hinder the convergence rate of TSA (Liu, 2002). The basic steps of the Tabu Search algorithm are shown in Figure 2.2.

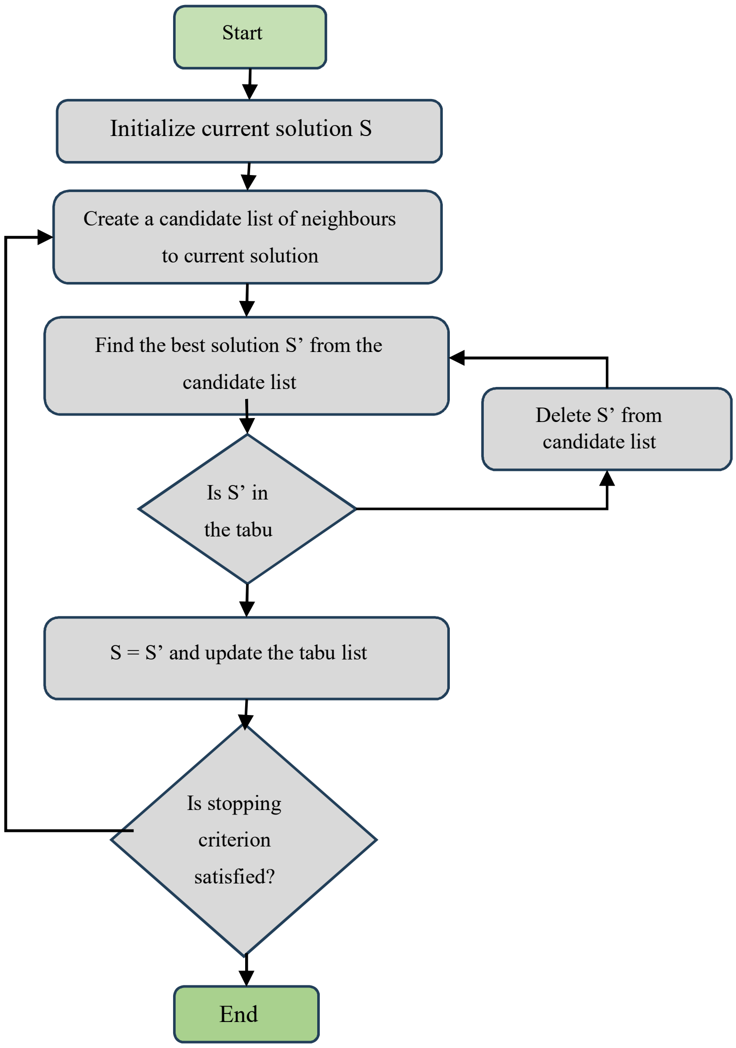


Figure 2. Search algorithm (Adapted from Peng et al., 2017)

Tabu search has proven to be a successful approach in tackling optimization problems. These include, but are not limited to, the traveling salesman problem, machinery scheduling, and vehicle routing. The key to its effectiveness lies in its capability to evade local optima and venture into different areas within the solution space. Integer nonlinear programming (INLP) is used in practical optimization challenges that entail discrete decision-making, like agricultural equipment, devising production plans, and managing machinery such as tractors and combines.

In this research, the study employed a hybrid algorithm of the tabu search technique to optimize the schedule and path of the agricultural machinery. And the study employed an integer nonlinear programming model to optimize the total (fixed and operational) cost of the cooperatives union.

2.6.3. Comparative analysis of optimization techniques used in Agricultural practices

Liang (2022) studied the optimization of an agricultural machinery task scheduling algorithm based on multi-objective optimization. To improve the effectiveness of machinery task scheduling, the researcher starts from the perspective of multi-objective optimization to achieve task scheduling based on a multi-objective particle swarm optimization algorithm. The position of each particle is a combination of resource options for each construction activity, and the displacement range and speed range are determined. The adaptive grid method and the roulette selection method are used to choose the global optimal solution of the particles, and an external storage library is introduced to store the existing non-inferior solutions. Furthermore, based on the real requirements of current agricultural machinery work scheduling, the researcher suggests a task scheduling algorithm appropriate for contemporary agricultural machinery. The researcher comes to the conclusion that the multi-objective optimization-based machinery task scheduling algorithm presented in this study achieves the fundamental goal of algorithm optimization and has a good machinery task scheduling effect. However, this study only addresses the machine's work scheduling; it is unable to address the cost of operation.

Indraningsih, et al. (2021) studied the optimization of agricultural machinery utilization in modern agriculture. The researcher states that the provision of agricultural machinery in the Modern Agriculture Program is to overcome labor shortages. The method used was descriptive, explanatory, and financial analysis. The results showed that the utilization of agricultural machinery in the Modern Agricultural Program was still not optimal. It was still underutilized. There were several obstacles, both from economic and social aspects.

The utilization of 4-wheel tractors and rice trans-planters has not been economically managed. As a result, they cannot generate funds for equipment maintenance and the development and UPJA's sustainability. Not all types of agricultural machinery are socially suitable for farmers' needs. There is competition between agricultural machinery users and workers. Moreover, not all local governments fully support agricultural machinery. The researcher concludes that to optimize and succeed in the modern agriculture program implementation, agricultural extension workers with certification as UPJA Facilitators are required. This study makes the research gap quite evident; however, they are unable to solve the issue using engineering methods.

According to the study done by Najafi and Torabi (2015) "Optimization of Machinery Use on Farms with Emphasis on Timeliness Costs," the study analyzed how machinery timeliness costs affect farmers' profit in Marvdasht, Iran. Using mixed integer and linear programming, they compared ideal cropping patterns to current practices based on data from 80 farm managers. The finding revealed that 81% of farmers rented tractors, resulting in high costs for tractor owners. According to the study, tractor buying and renting a combine harvester is recommended when the farm is more than 10 hectares. In practice, there is a huge gap to manage over five-hectare plots between farmers' current practices who have a five-hectare plot. A joint ownership of machinery is recommended for neighboring farms to reduce costs, but the study did not address operational costs, thereby limiting its scope.

Mihov (2022) states in the title "mechanization in agriculture and conservation of resources." The life cycle of a tractor and agricultural machinery encompasses several stages from development to disposal. This concept includes all machinery involved in complex production processes. According to ISO 9004-1, the life cycle is defined as a series of processes initiated by the identification of needs and concluding with the fulfillment of those needs and subsequent disposal of the product.

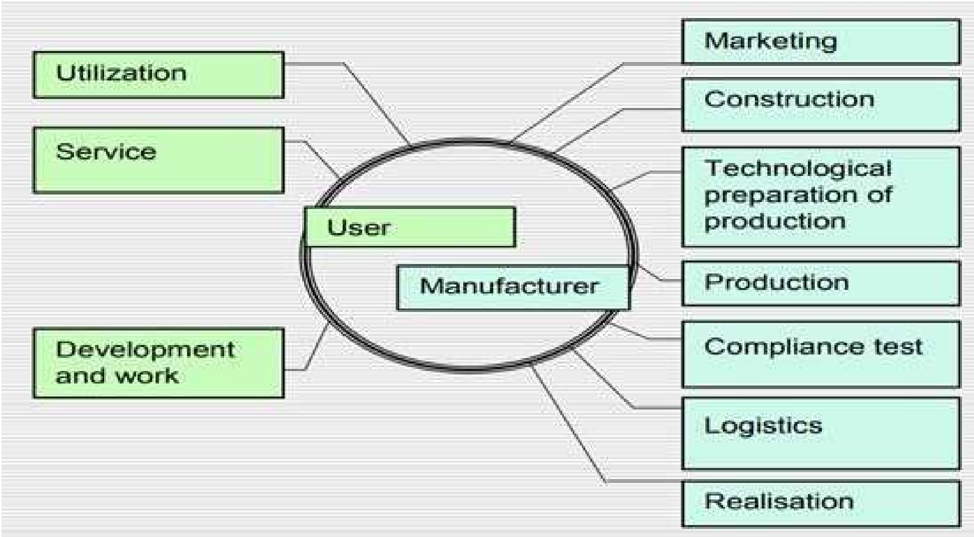


Figure 3. Life cycle of a technical product related to the manufacturer and its user.

Due to technological advancements, increasing maintenance costs, or new regulations, agricultural machinery can become obsolete. The disposal methods can be categorized into three. It included complete utilization, often the least economical when the machinery is severely worn. And the second is element-by-element utilization, where machines are disassembled and components sorted by material for reuse in other equipment. And the last method considers that the durability of machinery depends on staff skills, working conditions, and maintenance frequency. To determine the machine's liquidation value, it is essential to evaluate the wear and residual life of the individual parts.

Zefeng(2020) stated that the optimization of agricultural machinery is important to enhancing agricultural mechanization. Linear programming and workload models were utilized to assess the most efficient distribution of agricultural machinery within the Xinjiang Production and Construction Corps. The study also analyzes optimized agricultural machinery and equipment compared to the current models. The result shows that the new model significantly improves efficiency and reduces operation costs. The Xinjiang production and construction crops are facing an efficiency issue in the power machine. The rate of 81.18% for the large tractor and 90.34% for the medium tractor shows an inefficient distribution. Further, the matching ratio of the machinery improved from 1:1.6 to 1:2.7, achieving a 27.9% reduction in total operational cost for the machinery year.

Daniel et al. (2021) studied the complex integer linear optimization techniques. The method used to address the farm production planning and machinery scheduling for both perennial and non-perennial crops. The study also aims to increase farmers' net value (NPV) by enabling multi-crop planning, farm machinery scheduling, and crop rotation with coverage of low-water-use crops to address water scarcity in arid regions. The model determined the optimal scheduling routes and analyzed irrigation requirements by using Geographic information systems.

According to Jian et al. (2023), develop a comprehensive mixed-integer nonlinear programming model. The finding is a solution for inaccuracies in calculating the objective function and the incompleteness of constraints. By incorporating the timeliness loss cost for key operations across different crops into the objective function, this model optimizes the agricultural machinery management system. The study examines the effectiveness of the model; it conducted a test on corn and soybeans as examples, and timeliness loss functions for sowing and harvesting operations were derived. By using the MINP model using Lingo (V.14.0), the result indicated that the optimized machinery system resulted in improvements in total power, workload per unit power, and total operational costs compared to the current systems.

Optimization model to maximize the net income of agricultural machinery households through a 0-1 mapping relationship for operation assignment and path planning, Li et al. (2021). By using a particle swarm algorithm, they effectively allocate machinery paths for soybean harvesting within a specified timeframe. This method achieves a rapid convergence speed of 617, reaching a target stable value of 205 and determining optimal path plans. The results show a total income increase of 60,000 yuan after unified allocation, with the average income per agricultural machine rising by 8,600 yuan, thereby improving the overall income levels of agricultural machinery households.

2.7. Research Gap

There is a significant gap regarding the optimization of agricultural machinery utilization. However, the problem is scientific, the methods vary, and it depends on the complexity of the objective function and parameters to use. These optimization techniques need a location-based solution. Also, the African agricultural industry faces unproductive utilization of agricultural machinery. The constraints vary from the Agricultural mechanization industry to industry. The 'optimization of agricultural machinery utilization’ needs modern and best algorithms. Especially for task scheduling optimization. This research aims to address the gap in the farmers’ cooperative union issue of agricultural machinery usage by optimizing unplanned machinery allocation, optimizing operation cost, and determining machinery sets for the Hetosa farmers’ cooperative union. The outcome of the study was to increase the efficiency of the machinery management system by minimizing the time and operation cost of the machine.

These findings do not provide a solution to all Hetosa farmers' cooperatives union gaps. It needs more investigation regarding the machinery management system. Moreover, to identify the gap in the policy, strategy, and structure to implement the proper machinery management system. Further, the study recommended studying each Kebele of Hetosa members and working on path optimization techniques to get an optimized operational cost. In addition to that, for scheduling, it is better to identify a better optimization technique for a specific area.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Study Area Descriptions

The study was carried out in Hetosa Farmers Cooperatives Union, located in Hetosa Woreda Arsi zone of the Oromia region. The altitude of this woreda ranges from 1,500 to 4,170 meters, with Mount Chilalo as the highest point. A land survey shows that 52.8% is arable, including 46.5% for cereals, while 16.3% is pasture, 28.1% is forest, and 2.8% is unusable land. Anole is a local landmark, and important cash crops include onions, potatoes, and sugar cane. The Hetosa Cooperatives Union serves seven Farmers' Unions across the woredas: Hetosa, Dodota, Sire, Lume Hetosa, Zeway Dugda, Tiyo, and Munisa.

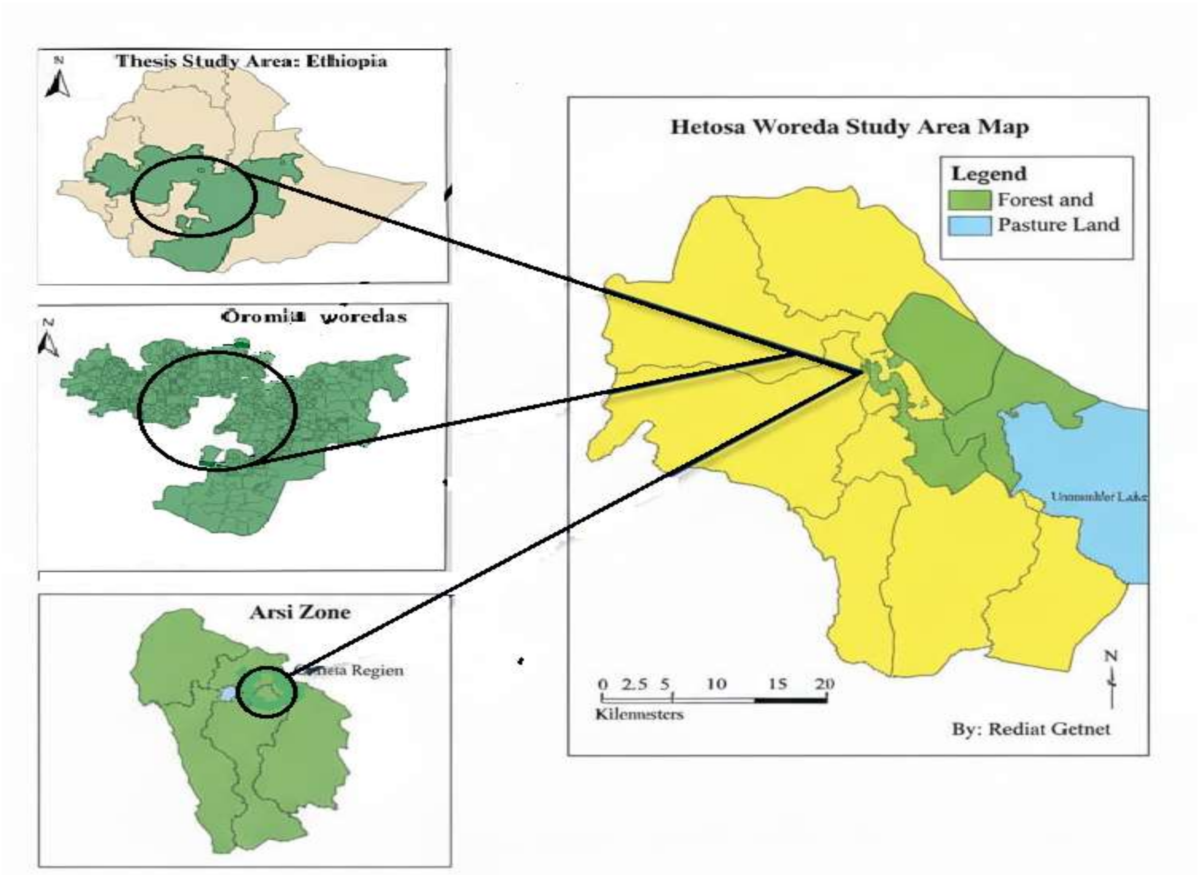


Figure 4 .Maps of Hetosa Woreda, Oromiya Region

3.2. Materials

For the study of the farm machinery management system, all operational equipment was employed, including implements, tractors, and harvesting equipment like combine harvesters. To measure the travel distance of the machine and to measure the working farm plots, the study utilized GPS technology by connecting to the phone. To identify the working woredas, Kebele rode, Woredas, and kebeles land holding land usage Areas the study used ArcGIS technology. To measure the field capacity of the machine the study utilized tape and stopwatch.

3.2.1. Farm machinery in the Hetosa Cooperative Union

The following machinery has been identified in the Hetosa cooperative union:

Table1.List of farm machinery identified in the Hetosa Cooperative Union

Machinery	Brand	Model	Total working hours
Tractor	John Deer	6130j	7624
	John Deer	6130j	6300
	New Holland	T5060	New
	New Holland	T5060	New
	New Holland	T6080	5400
Combine harvester	Class	Class wb	5833.6
	Class	Class wb	7004.7
	Class	Class wb	5946.8
	New Holland	T5-80	New
	New Holland	T5-80	New
	New Holland	T5-80	New
	Class	Class wb	6280
Moldboard plough	Lemken	Saphir 7	
Disk plough	Nardi	SOD70/E	
	Nardi	SOD70/E	
Row seeder	Lemken		
	SOLA	TRICOMBI-294-ESP	
Stubble Melcher	Lemken		
Trailer			

For the study of the farm machinery management system, all operational equipment was employed, including implements, tractors, and combine harvesters. To measure the travel distance of the machine and to measure the working farm plots, the study utilized GPS technology by connecting to the phone. To identify the working woredas, Kebeles rode, Woredas, and kebeles land holding land usage Areas, the study used ArcGIS technology. To measure the field capacity of the machine, the study utilized tape and a stopwatch.

3.3. Methods

3.3.1. Methods of Data Collection

Both quantitative and qualitative data were collected, including machinery specifications and age, fixed and variable machinery costs, meteorological variables such as rainfall, temperature, humidity, and crop season, as well as crop type and season, road access, soil characteristics, slope, and elevation. The data included financial status, human resources, organization structure, and farm machinery management practices of the farmers' cooperatives union. The data were collected through survey questionnaires, field observation, interviews, document reviews, and literature review.

A. Questionnaire: - The questionnaire included information on the machinery management system, task scheduling, agronomical data, and financial data.

B. On-Site Observation:- farm machinery fuel consumption per hectare, traveling time, field capacity, and machinery downtime were recorded by using GIS and GPS measurements and visual documentation.

C. Interview: - farm machinery manager, operators, and agronomists were purposively interviewed.

C.

D. Literature Review: - Relevant studies, policy documents, and technical publications were reviewed to provide background for the analysis of machinery management systems.

E.

E. Document Review:- Financial records, procurement files, operational reports, and field notebooks from the Farmers' Cooperatives Union were examined, in addition to the Federal Cooperative Proclamation.

3.3.2. Sampling Techniques

Census sampling methods were used for the entire machinery available in the union, while purposive sampling methods were used for interviewing the mechanization department, finance, and agronomist.

3.3.3. Types of data sources

A. Primary data sources

The Primary sources of data included available machinery, machinery operators' data, machinery operation data, and machinery technical manager data.

B. Secondary data sources

The secondary data were gathered from documented data concerning agricultural machinery utilization. This data was collected from client files, follow-up reports, internal audit reports, financial data, literature review, and other periodic reports in Hetosa farmers' cooperative union.

Climatic data for this study were collected from reputable online databases, regional meteorological centers, and FAO resources, including the New LocClim V10.1 database. Additional datasets, such as those from CFSR, were incorporated. Meteorological data were obtained from the Asela, Degaga, Huruta, Kulumsa, Ogolocho, and Melkasa stations, which were selected due to their agro-climatic similarity to the study area and their representation of the nearest lowland agroecology. Temperature, humidity, wind speed, and sunshine hours, were compiled and prepared for analyzing climate variability by using CROPWAT 8.0.

3.4. Optimization and Cost of Farm Machinery

3.4.1. Optimization of Agricultural Machinery Utilization

Utilizing agricultural machinery needs a complex optimization model and it required to consider the dynamic nature of agricultural activities, variability of the weather and soil conditions. By considering this variable optimization of agricultural machinery modeling gives a direction for machinery behavior, utilization of energy, and performance.

On the other hand, optimization makes equipment run as efficiently as possible while using less fuel, having fewer adverse effects on the environment, and increasing overall profitability.

3.4.2. Capacity and Cost of Farm machinery

The mathematical modeling of the tractor includes the theoretical capacity and effective field capacity as given in Equations 3.1 and 3.2.

A. Theoretical capacity (Ct):-

$$C_t = \frac{S*W}{10} \qquad 3.1$$

Where S is the average speed of the machine, km/h, and W is the rated width of the machine in meters.

B. Effective field capacity (Ce):-

$$C_e = \frac{S*W*EF}{10} \qquad 3.2$$

Where, E_f field efficiency of the machine, in fractions. Considering the fixed and variable costs, the total cost of operation of the tractor is given by (Hunt, 2001):

$$A_c = F_cP_t + A_t(RM + L + 0 + F + T_c) \qquad (3.3)$$

Where, A_c is Annual costs of operating the tractor (Birr/yr); F_c is Annual fixed costs, fraction of purchase price; P_t is Purchase price of tractor, R_s; A_t Annual use of tractor (h/yr); RM is Repair and maintenance costs of tractor, Birr/h; Laboure costs, R_s/h; O is Oil costs, Birr/h; F is Fuel costs, Birr/h; T_c is Timeliness costs (Birr/h); yr is Year. Since RM, O, F = f (A) where A is the cropped area, therefore, RM, O, F = f (E) where E is the energy spent to cover the area. This implies:

$$A_c = F_cP_t + \text{(Field hours)}(L + \text{timeliness cost}) + \text{(transport hours)}(Lt) \qquad (3.4)$$

Where L is the Tractor operator's wages for field work (Birr/h) and Lt is labor cost for transport work, there should be a timeliness charge for transport work, but for simplicity, it may be assumed that this does not limit field operation. The optimum size of the tractor is one that will perform all the desired operations at a minimum cost. The annual hours of work required for each class of tractor operation are given by (Hunt, 2001):

$$\text{Field Time} = \frac{C_1 * E_o}{r * R_p} \qquad (3.5)$$

Where C_1 is the ratio of A and r. A is Area; r is Ratio of drawbar power to rated engine power for drawbar loads and ratio of PTO power to rated engine power for PTO loads; Eo is Energy required per unit area; Rp is Rated power. Which is given by:

$$\frac{\partial^2(Ac)}{\partial {R_p}^2} = \frac{2\ \mathrm{C1\ Eo\ (L + Tc)}}{(R_p)^3} + \frac{2\ \mathrm{C2\ \ Et\ \ Lt}}{(R_p)^3} \qquad (3.6)$$

Where, Et is energy required by the tractor for transportation (0.53 (hp/km)), C_2 is the constant of transportation time. Which is a positive quantity, indicating that the calculated $(R_P)_{opt}$ would have a minimum operation cost. The timeliness of a field operation must be considered in the optimum power required of a tractor. The total timeliness cost for an operation depends on the scheduling of operations (delayed, premature, and balanced). So, the total timeliness cost (T_c) can be estimated as:

$$T_c = \frac{\mathrm{K*Y*V*}A^2}{\mathrm{X*U*Z}} \qquad (3.7)$$

Where, K is Timeliness loss factor; Y is Crop yield, V is Value of crop in Rs/t; A is Total area under crop, ha, U is Ratio of total working days to total days, fraction; Z is Effective machine capacity, ha/day; X is 2 for premature or delayed scheduling and for balanced scheduling

Table2. Timeliness loss factor for different operations and crops

Crop	Wheat		Barley		Paddy		Maize	Soybean		Moong		Oil seeds	
Operation	Tillage & sowing	Harvesting & threshing	Tillage & sowing	Harvesting & threshing	Tillage & sowing	Harvesting & threshing	Tillage & sowing	Tillage & sowing	Harvesting & threshing	Tillage & sowing	Harvesting & threshing	Tillage & sowing	Harvesting & threshing
K value	0.00456	0.0065	0.0067	0.00437	0.00625	0.0066	0.0047	0.0179	0.0189	0.0052	0.066	0.0138	0.0351

This implies:

$$(\mathrm{R_P})\mathrm{opt} = [\left(\frac{A_C E_i}{F_c r_i P_u}\right)\left(\mathrm{L} + \frac{\mathrm{K*Y*V*}A^2}{\mathrm{X*U*Z}}\right) + \frac{0.53*Lt*W_t}{F_c r_i P_u}]^{\frac{1}{2}} \qquad (3.8)$$

Where, F_c is fixed cost percentage of a tractor; P_u is price per unit power of tractor, Rs/hp; A_c is area under crop, ha. E_i is Energy required for operating an implement for a particular crop; K_{ic} is Timeliness loss factor of an implement for a particular crop; Y_c is Yield of crop, q/ha; V_c is Value of crop, Rs./q; X is Constant equal to 2 for premature or delayed schedule and 4 for Balanced schedules; U is Fractional utilization of time; L_t is Labor rate for transportation, Rs./h; D is Distance to be traveled, km. W_t is the weight to be transported, t; r_i is Ratio of drawbar power to rated engine power for drawbar load and ratio of PTO power to rated engine power for PTO loads for a particular crop.

3.4.3. Cost of Farm Machinery

There are two types of machinery costs, viz. fixed and variable costs. Fixed costs depend on how long a machine is owned rather than how much it is use. It includes depreciation, interest, taxes, shelter and insurance. Variable costs, also called operational costs, vary in proportion to the amount of machine used. It includes repair and maintenance, fuel, oil or lubrication, and labor costs.

Fixed costs

A. **Depreciation: -** Depreciation costs reflect the decline in value of an asset, such as a machine, due to age and use. The straight-line method assigns an equal depreciation amount each year over the asset's useful life. It requires a determining salvage value and can be calculated using the formula:

$$D = \frac{C-S}{L*H} \qquad (3.9)$$

Where D is Depreciation per hour, P is Capital investment; S is salvage value, taken as 10% the capital investment; L is life of machine, years; and H is Number of working hours per year.

B. Interest on Investment: - Annual interest is calculated on an average investment by using the prevailing interest rate by the following formula:

$$I = \frac{C+S}{2} * \frac{i}{H} \qquad (3.10)$$

Where, I is annual interest charge, Birr/year; C is Capital investment in Birr; S is salvage value, Birr; and i is interest rate in percent.

C. **Insurance and Shelter**: - Insurance and shelter expenses constitute 2% of the annual purchase price.

D. Tax: - Hunt (2001), stated that VAT and sales taxes are included in the purchase price of farm machinery. Taxes resemble property taxes, typically costing one to two percent (1-2%) of the purchase price annually (Bowers, 1994). This tax can be calculated using equation 3.13.

$$T=\left[\frac{C}{2}\right]\times 0.55\times TR \quad (3.11)$$

Where: T & TR- tax (Birr) and tax rate respectively, C- capital investment (Birr).

Variable costs

A. Repair and Maintenance Costs: - The study utilized the recorded farm machinery repair and maintenance document. The study formally requested the Hetosa Farmers' cooperatives Union detailed documentation of the cost related to repair and maintenance cost. The study accessed all necessary information and analyzed the annual machinery expenses, sum-up the total figures for each machinery from 2018/19 to 2024/25. The machine included tractor, combine harvester, and implements of the cooperative union. This method helps to increase the accuracy of the cost related to repair and maintenance.

B. Fuel and Oil Cost: - The same presider with repair and maintenance cost the study assesse all machinery fuel and oil cost from 2018/19 to 2024/25. The study analysed the cost separately for each machine. To insured the recorded data, the study measured the distance between starting point and the ending point of the machine by using GPS technology. The starting point was Hetosa farmer's cooperatives union and ending point was farm plots. And study also recorded machinery speed and horse power (HP). The ploughing width and length was measured by GPS based technology.

The factor that affect fuel consumtion is depending on the travlining speed, the distance cover , and the operation type of the task. On this research to chack the actiual fuel consumtion for each activity. First fully filled the fuel tank, and then for land preparetion operation the study utilized mould bord plough, and disc plough. And measured fuel for travling from station to farm plots. After that the study finout the fuel consumtion tractor for travle purpose. then the study filled ageien the fuel tank and measure land prepartion operation different plough separetlly and identify the fuel requiered for this purpose.

For seedbed preparation the study followed similar procedure with land preparation. First tractor fully filled. After that recorded the fuel consumption for travel purpose. The refill the fuel and start record on fuel consumption on seeding activity. The study recorded every activity including, operational time and downtime. And we measured seeder width, tractor HP, speed to travel and to done seeding activity, distance, and time taken to cover the seed bed activity of a the area by using GPS technology. Finally the study measured the actual fuel consumption rate per hector.

The study identified fuel consumption rate of combine harvester by recording separately the down time and the operational time of the combiner. The down time included the traveling time from station to farm plots, and returning time. The operation time considered quintal per hour. For traveling, the study measured from station to farm plots. For harvesting the study conducted operation hour per quintal. All combine harvester speed, width, and areas of the plots recorded by GPS technology.

C. **Labor Charge: -** To conduct the research, the study utilized a document associated with machinery operation for labor cost. the payroll recorded document were included from 2018/19 to 2024/25. To utilize the research, the study identified the labor type, and salary for each machine. This included per-dime of the labor. The study added all salary and per-dime and convert into monthly after that to sum up the monthly salary and per-dime into annually. The per-dime data were collected from finance office. In some case one operator working for two machine including tractor and combiner. So the study identified the number of machinery operated by one operator. And salary of the operator divided and distributed for each machine. The per-dime was recorded separately for tractor and combine harvester. The salary of accountant and machinery manager also divided and distributed for each machine.

Finally the study aggregated their annual salaries and distributed this total across all labor costs for the tractor and combine harvester.

D. Lubricant's cost: - The study show that the total lubrication cost on most farm machinery average percent is around 15% of the fuel costs. According to Norm (2008), the lubrication cost is estimated as 15% of the total amount of fuel costs. The amount of many expressed in terms of birr/hour. Norm (2008), stated lubrication costs for all machinery are estimated to be 15 percent of fuel expenditures, the annual fuel costs should be multiplied by 0.15 to determine the combined lubrication and fuel costs

$$\text{Lubrication cost per hour} = \text{fuel cost per hour} * 0.15 \ldots\ldots\ldots\ldots \quad (3.12)$$

3.4.3 Modeling and Optimization of Agricultural Machinery

Agricultural mechanization management needs a comprehensive system to allocate tasks and to utilize maximum machinery economic productivity, and minimize operation costs. In modern farm machinery management practice, the farm machinery manager should consider agroecology, farming systems, economical and technological advancement of the machine. The optimization technique should depend on this principle. These principles include the utilization of existing mathematical modeling, economic sustainability, and appropriate machinery selection for agronomy and agricultural machinery(Zefeng, 2020; Jian et al., 2023). These research used mathematical modeling to investigate analyze the issues related to machinery utilization, machinery replacement condition and time, and best task allocation, cost minimization. To conduct the objective function the study utilized tabu search and non integers nonlinear programing algorism(INLP) to opimiz the farm machinery utilization in the Hetosa Farmers Cooperative Union, Oromia Region.

Machinery Path Optimization

Hetosa Farmers Cooperatives Union Farm Machinery task allocation are Varies types of machinery in different farm plots that are spread out. In this scenario "heterogeneous" refers to each machine achieved different task, and each farm plots required different tasks. Xinmeng et al. (2017), answer that the issues of heterogeneous problems by reducing the overall distance traveled by all machinery while also minimizing the variation in distance traveled by each machine. The study considered scheduling model for bellow description.

- Each field ought to be served until the end, and each machine should be utilized
- The service capability of each machine is directly related to the service time of each field.
- Given that the inter-field travelling speed of every machine is constant, the distance traveled is directly related to the time taken by each machine.
- The objective function is measured in terms of time.
- All machines executing the same operation are of the same type and identical.

The service sequence for every machine commences at the agricultural machine depot, traverses through various fields, and ultimately loops back to the depot.

The objective function for the scheduling problem is formulated as follows (Gareth et al., 2015; Xinmeng et al., 2017):

$Objectivefunction: f = \min(w * \sum_{m=1}^{M} \sum_{i=0}^{H} \sum_{j \neq i, j=0}^{H} (d_{ij}x_{ijm}/v) + \text{r} *$ ${}_{m=1}^{M}\beta \sum_{i=0}^{H} \sum_{j \neq i, j=0}^{H} (d_{ij}x_{ijm}/v))$ …………………………………………….……. (3.13)

The primary goal is to reduce the weighted sum of the total distance covered by all agricultural machinery and minimize the variability in the distance traveled by each machine. And the time required by each machinery from one field to another is the distance traveled by the machine at a constant speed as given in equation (3.14):

$t_{ij} = d_{ij}/v, \forall i, j \in \{0,1,\cdots,H\}, i \neq j$…………………..………….....…...…… (3.14)

The total distance traveled by the machine equals the sum of the distances traveled by the machine from one field to another, as given in equation (3.15).

$D_m = \sum_{i=0}^{N} \sum_{j=0, j\neq i}^{N} x_{ijm}d_{ij}, \forall m \in \{1,2,\cdots,M\}$ ………………….……………….…… (3.15)

The starting and ending location of each machinery is the same, the depot. As given in equation (3.16).

So = SH+1 …………………………….………………………...…………...(3.16)

From equations (3.15) to (3.16), the variables are given in the table below:

Table 3.Variables for the Machinery Scheduling Formula

Variable	Description
M	Total number of available machines
H	Total number of fields to be served
Si, (i=1,2...H)	Each field is labelled 1 to H, with the depot labelled as 0 and H+1
Ho	Agricultural machine depot
dij	Distance between the two fields i and j
v	Constant speed of machines
tij	Travel time of the machine between the two fields i and j
Dm	Total distances that machine m travels
W	The weight of the total travel distances of all machines
Xijm	1 if machine m travels from field i to field j , otherwise 0

ymi	if machine m serves field i , otherwise 0

Tabu Search

Chapter 2 illustrates the concept of Tabu search, a metaheuristic optimization method designed to effectively explore the solution space and avoid becoming trapped within a local area of optimality (Gareth et al., 2015). Tabu search algorithm (TSA) explores the nearby solutions of an initial solution before transitioning to a new solution and repeating the process. As the algorithm advances, certain moves are either forbidden or temporarily restricted, known as tabu, limiting their usage for a specific duration(reference). This approach leads to a search method that makes decisions based on past encounters, enabling efficient navigation through the search space (Xinmeng et al., 2017). The three-neighbor solution is navigated in this Tabu search analysis called movements.

Movement 1: To create a new sequence for the fields to be visited, the order of two adjacent fields in the sequence is switched, mathematically as given in Equation 3.17:

$S_0, \ldots, S_k, S_{k+1} \ldots, S_{H+1} \rightarrow S_0, \ldots, S_{k+1}, S_k \ldots, S_{H+1}$ ………………………………… (3.17)

Where k =1…., H-1

Movement 2: To add one machine to a field operation, unless it surpasses the maximum number of machines available for that operation, mathematically as given in Equation 3.18:

$U_{ih} \rightarrow U_{ih} + 1$ ……………………………………………………………..……… (3.18)

where, i =1 . . . n; h = 1, . . ., H; and $U_{ih} + 1 \leq m_i$

Table4.The general tabu search algorithm

Mathematical Modeling for the Operational Cost of Machinery

Step 1	Generate an initial solution: Set the initial solution as both the current solution and the optimal global solution
Step 2	For a new local solution iteration using Eq. (4.1). Generate and store the neighboring solution using Eq. (4.5 to 4.7)
Step 3	Check for the best local solution and set it as the current solution.
Step 4	If (best local solution > global solution) Set the local solution as the global solution and check for convergence
Step 4	Update the diversification factor to move to another initial position.
Step5	Repeat the process from step 2 to step 4 and check for convergence

Step 6	If the New Global solution has no improvement, and take it as the output of the result.

The agricultural machinery system optimization model is generally designed to reduce operational expenses. The objective of minimizing the cost comprises three elements: the yearly fixed machinery costs, the yearly variable costs for each machinery unit, and the annual time loss cost.

Therefore, the objective function comprising the fixed and variable costs is given as:

$$\text{Min}(\text{Total}_{\text{cost}}) = Min(Fixed_{cost} + Variable_{cost}) \qquad (3.19)$$

Modeling of Annual Fixed Cost of Machinery

The machinery's yearly fixed cost consisted of the annual depreciation and management fees. Given the substantial investment in machinery and its extended lifespan, it is important to consider the value of the invested capital. Therefore, the dynamic depreciation method was implemented to determine the annual depreciation cost for each machine (Jian et al., 2023). The models for tractors and implements are shown in equations (3.20 and 3.21).

$$C_{ft} = \sum_{j=j_1}^{j_m} \left\{ \left[\left[P_{tj}(1+I)^{L_{tj}} - P_{tj}S_{rt} \right] \times \frac{I}{(1+I)^{L_{tj}-1}} + \alpha P_{tj} \right] X_j \right\} \qquad (3.20)$$

$$C_{fm} = \sum_{k=k_1}^{k_m} \left\{ \left[[P_{mk}(1+I)^{L_{mk}} - P_{mk}S_{rm}] \times \frac{I}{(1+I)^{L_{mk}-1}} + \alpha P_{mk} \right] X_k \right\} \qquad (3.21)$$

In equation (3.20) to (3.21), The annual fixed cost of the tractor is C_{ft}; the 1st type of tractor is j_1; the type of tractor within the machinery systems is j_m; the purchasing price of the j_{th} type of tractor is P_{tj}; the discount rate is I (%); the depreciation period of the j_{th} tractor is L_{tj} (years); the salvage value rate of the tractor is R_{st} (%); the quantity of the j_{th} tractor required to complete operations throughout the year is represented by X_j; the annual fixed cost of the implement is C_{fm}; the 1st type of implement is k_1; the type of implement within the machinery systems is represented by k_m; the purchasing price of the kth implement is P_{mk}; the depreciation period of the k_{th} implement is represented by L_{mk} (years); the salvage value rate of the implement is R_{sm} (%); and the quantity of the kth implement required to complete operations throughout the year is X_k.

Model for Annual Variable Cost of Operation Machinery Units:-The variable costs of operating machinery units in agricultural machinery systems are calculated by adding up the variable costs of all machinery units involved. These costs are determined by factors such as operation time, quantity of machinery units, and daily variable cost of each unit. Since the variable cost can change for the same machinery unit depending on the operation being carried out, and different types and quantities of machinery units may be used at different agricultural stages, it is important to clearly distinguish the variable costs for each operation and stage. The variable cost model for operating machinery units is given in Equation (3.22).

$$C_v = \sum_{j=j_1}^{j_m} \sum_{k=k_1}^{k_m} C_{vjk} = \sum_{i=q_s}^{q_e} \sum_{j=j_1}^{j_m} \sum_{k=k_1}^{k_m} \sum_{l=l_1}^{l_m} D_i X_{ijkl} C_{ijkl} A_{ijkl} \quad (3.22)$$

Within this formula, C_{vjk} denotes the yearly fluctuating cost of the machinery unit consisting of the j_{th} category of tractor and the k_{th} category of operation machinery; q_s signifies the initial agricultural phase of the q^{th} task; q_e signifies the final agricultural phase of the q^{th} task; l_1 denotes the first type of crop; l_m denoted the first type of crop; the duration of the i^{th} agricultural stage is D_i (in days). C_{ijkl} represents the variable cost per unit area of the machinery unit, which includes the j^{th} type of tractor and the k^{th} type of operation machinery, performing operations for the lth crop during the i^{th} agricultural stage. A_{ijkl} represents the operating efficiency (hectare m^2/day) of the machinery unit, consisting of the j^{th} type of tractor and the k^{th} type of operation machinery, for the l^{th} crop during the agricultural stage.

Constraints of the objective function

i. **Tractor Allocation Constraint:-** The restriction on tractor allocation specifies that the amount of each type of tractor must be lower than the highest number of that particular model assigned to any agricultural stage. The tractor allocation constraint is represented by Equation (3.23).

$$X_j - \forall_i \left\{ \sum_{k=k_1}^{k_m} \sum_{l=l_1}^{l_m} X_{ijkl} \right\} \geq 0 \quad (3.23)$$

ii. **Implement the allocation Constraint:-** The restriction on implement allocation specifies that the amount of each type of implement must be lower than the highest number of that model assigned to any agricultural stage. The implementation allocation constraint is represented by Equation (3.24).

$$X_k - \forall_i \left\{ \sum_{j=j_1}^{j_m} \sum_{l=l_1}^{l_m} X_{ijkl} \right\} \geq 0 \quad (3.24)$$

iii. **Boundary Constraint for Start and End Dates of Key Operations and Optimization Flow Chart:-** A regulatory connection was present between the commencement and conclusion dates of essential crop activities and the number of machinery units needed for said activities. In this analysis, the operation time for each operation is constant if the operation for a single crop is considered.

The optimization flow chart is given in Figure 3.1 below.

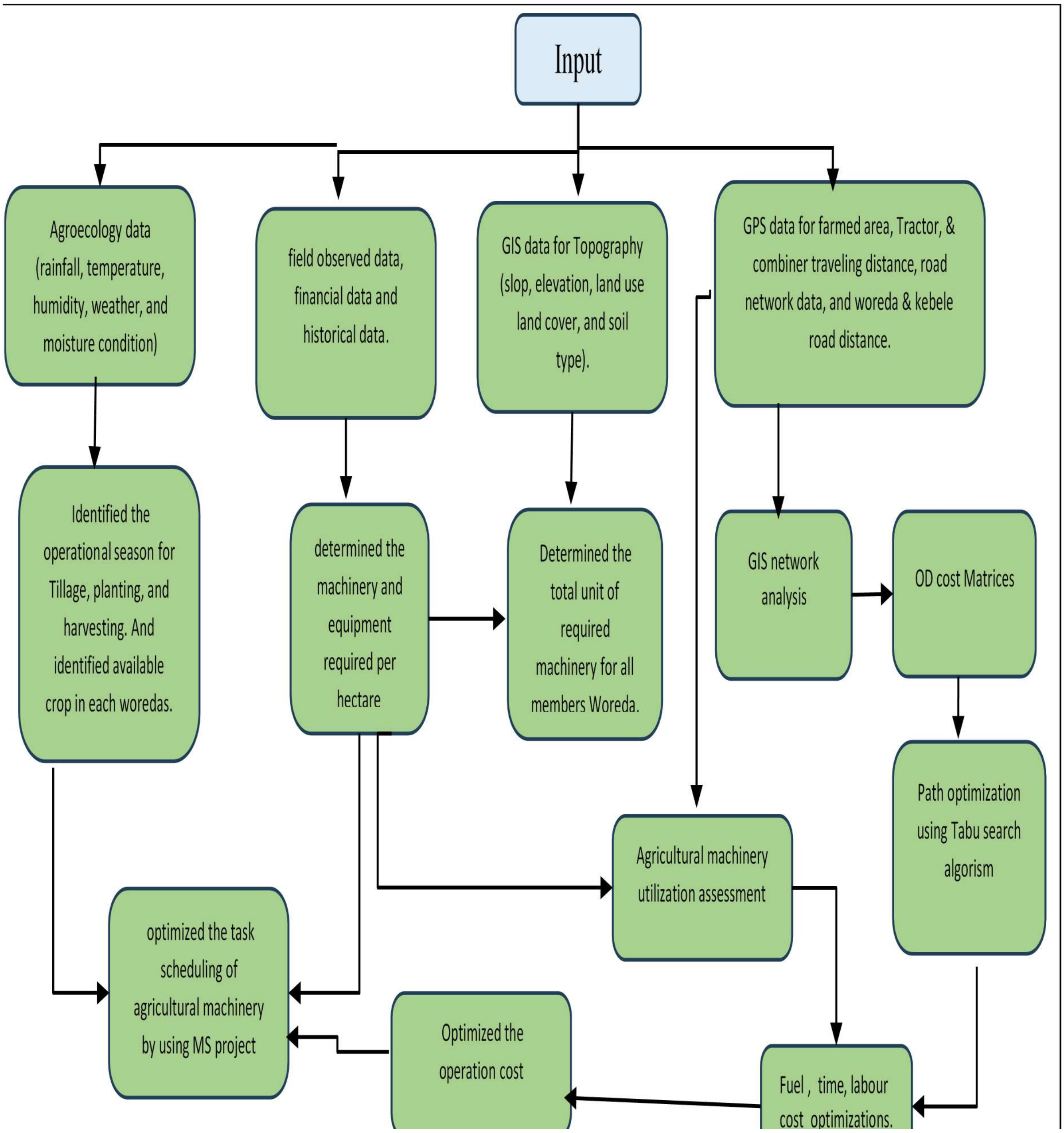


Figure5 for optimization of agricultural machinery utilization

Task scheduling

Estimating the reference crop evapotranspiration

The crop Evapotranspiration is formulated mathematically as:

$$ET_C = ET_O \times K_C \quad \text{......} \quad (3.25)$$

Where: ET_C = Crop Evapotranspiration

ET_O = Reference Crop Evapotranspiration

K_C = Crop coefficient

Calculation procedures of ET0 using the Penman-Monteith Equation

According to MOA National Guidelines for Small Scale Irrigation Development in Ethiopia (2018), For areas with available data on temperature, humidity, wind, sunshine hours, or radiation, the Penman-Monteith method is recommended. This equation includes two components: the energy (radiation) term and the aerodynamic (wind and humidity) term, formulated as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad \text{......} \quad (3.26)$$

Where	ETo	reference evapotranspiration [mm day-1],
Rn		net radiation at the crop surface [MJ m-2 day-1],
G		soil heat flux density [MJ m-2 day-1],
T		mean daily air temperature at 2 m height [°C],
u2		wind speed at 2 m height [m s-1],
es		saturation vapor pressure [kPa],
ea		actual vapor pressure [kPa],
es - ea		saturation vapor pressure deficit [kPa],
D		slope vapor pressure curve [kPa °C-1],
g		psychrometric constant [kPa °C-1].

The study employed CROPWAT 8 software to estimate evapotranspiration (ETo), which is essential for assessing crop water requirements.

Input data required for ETo computation

- The climate data needed for computing reference evapotranspiration using the FAO Penman-Monteith method includes:
- Long-term average maximum and minimum temperatures (°C)

- Long-term average relative humidity (%) or vapor pressure (kPa)
- Wind speed (km/h or m/s)
- Sunshine duration (hours, or optionally as a percentage or fraction of day length)
- Radiation (calculated by the software in $MJ/m^2/day$)
- The software allows seamless unit conversions during data entry as needed.

Length of growing period determination

Agro-climatic characteristics, rather than just precipitation distribution, primarily determine the growing season. Once precipitation meets or exceeds 50% of evapotranspiration (ET), early rains become more effective. After the rainy season, crops rely on soil moisture reserves for maturation, thus extending the growing season. Therefore, assessing the growing season's duration requires consideration of the soil's moisture retention capacity.The length of the growing period can be determined using the following methods:

LGP determination based on climate data

The growing period is determined using a simple water balance model that compares water availability (precipitation) with crop water demand (Potential Evapotranspiration or PET) using monthly values. A typical growing period consists of a long dry phase, a moist period, and a wet period.

Option 1: Using the Excel spreadsheet

1. Calculate monthly potential evapotranspiration for the area using the Penman-Monteith method or obtain it from a Class I Meteorology station or New-LocClim V1-10 software, preferably using site-specific climate data.
2. Calculate 50% of the ETo monthly values.
3. Input the mean monthly rainfall data into the tables.
4. Subtract the 50% ETo values (crop water demand) from the monthly rainfall (water availability) to identify months with deficits.
5. Count the number of days in months with surplus water balance to determine the length of the suitable growing period for rainfed crop production.

3.5. Data Analysis

MATLAB was used for cost optimization, while schedule optimization was performed with MATLAB and ARCGIS software.

3.6. Ethical Consideration

The study followed all guidelines prepared by ASTU’s. A research introduction letter prepared and signed by ASTU's School of Mechanical, Chemical, and Materials Engineering, granting approval for the study and contact with informants. All participant were informed about the study's aims and garneted that data would be used only for academic purposes. Interviews and surveys were conducted only with the respondents' permission, with careful attention to respecting their rights and attitudes.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. Agroecology Assessment of the Hetosa Members Woredas

4.1.1. Climate and Weather Patterns Analysis of the Hetosa Members Woredas

Rainfall: -The study conducted different woreda with different rainfall patterns were collected and examined at several stations using historical metrological data. The result shows that on the study area, there are different rainfall seasonal pattern and distribution on the seven woreda's.

a) Dry Season (November–January)

During this season, all seven woreda's are relatively dry. However relative to the six woredas Assela stations had relatively a little-bet higher amount of rainfall throughout this period. In this season harvesting planting operation are more preferable depending on the crop type, and seed variety.

b) Little Rainfall Season (February and October)

In this season little rainfall were recorded. Compered to other four region Assela, Kulumsa, and Ogolocho a little bit more rainfall recorded during these season. Depend on the crop type and the seed variety, planting and harvesting recommended the same with the dry season. The rainfall patter is similar to dry season but, in these scenario little rainfall were existed.

c) Moderate Season (March–June)

March, April, May, and June are all considered to be the medium rainfall season. Compared to earlier months, the precipitation is comparatively higher during this period. Asela and Kulumsa were the weather stations that recorded the highest amounts of precipitation. Depending on the crop variety, soil type, and soil moisture content, tillage and planting activities are more appropriate during this season.

d) High Season (July–September)

The peak rainy season, which lasts from July to September, has the greatest recorded rainfall totals. Asela, Melkasa, and Huruta had significantly more precipitation than the other stations. It is crucial for agricultural operations because this is the time when the area has the most accessible moisture.

Depending on the crop type, seed variety, soil type, and soil moisture level, most of the time after planting operations, it is the plant growing period during this season.

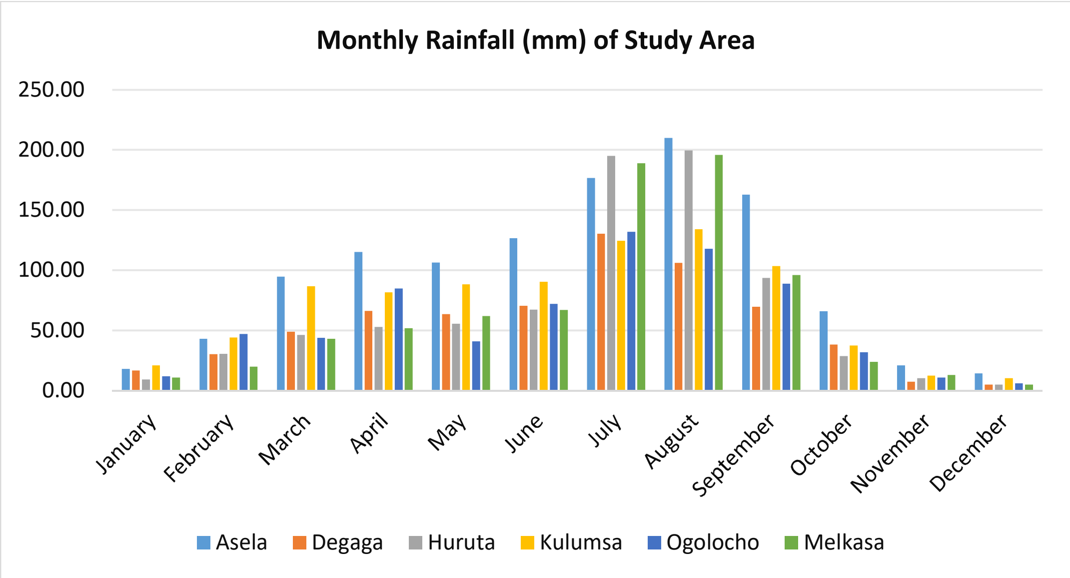


Figure 6. Rainfall data of the study area

The figure indicated that, there is variation rainfall pattern and distribution within different meteorological stations. Which is important for task scheduling and allocation. Depending on the season optimizing machinery utilization is also important.

Monthly temperature, humidity, weather, and precipitation analysis:- The following figure 6 describes the information from six meteorological stations, which are Melkasa, Huruta, Kulumsa, Assela, Ogolocho, and Degaga. The study utilized the climate condition in seven woredas. And the results indicated that climate condition is varies to woreda's to woreda's. The Melkasa station represent, the Dodota and Sire woredas' climate conditions. And the Huruta station meteorological data, were represented Lode Hetosa woreda, and the Kulumsa station, which matched the climate of Hetosa woreda.

Ogolocho station provided climate data for Zuway Dugda woreda, while the Assela station was associated with Tiyo woreda. Furthermore, Munisa woreda was represented by Degaga station. These findings demonstrate the value of meteorological data in comprehending regional climate dynamics, which is essential for Ethiopian resource management and agricultural planning.

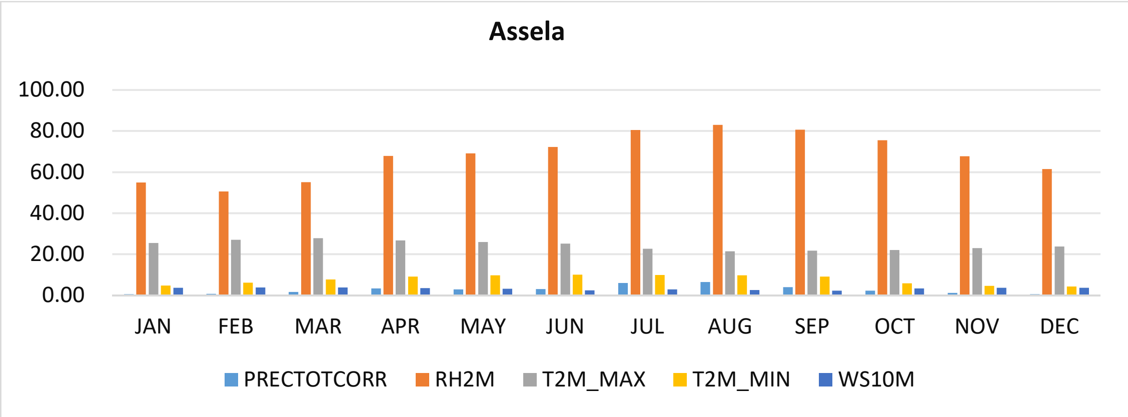


Figure 7. Monthly Assela temperature, humidity, weather, and precipitation analysis

According to the FAO Irrigation & Drainage (2016) the area with < 40% RH can be designated as Low humid; areas within the range of 40% to 70% are moderately humid, and when RH is > 70%, the area is grouped as high humid. The result table showed that Assela station RH Nov, Dec, Jan, Feb, Mar, Apr, and May are moderately humid. The months of Jun, Jul, and August are grouped as highly humid. According to the result, the maximum temperature of the Assela station is 27.13C^0, and the minimum temperature is 4.35C^0. and maximum precipitation 6.52 in August, and minimum precipitation 0.66 in January. The maximum weather condition is 3.91 in February, and the minimum weather condition is 2.27 in September.

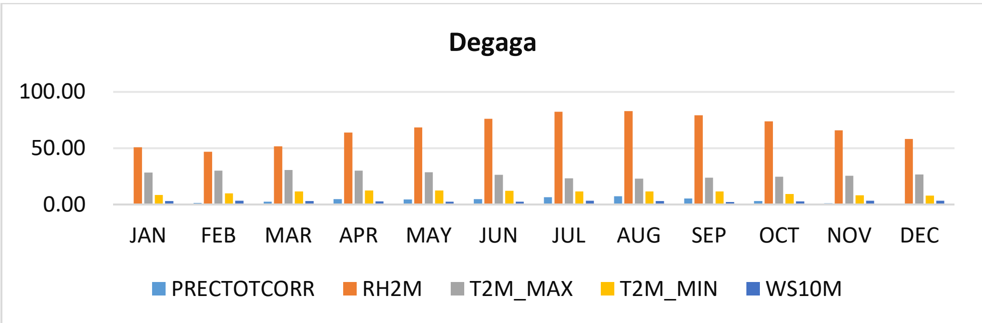


Figure 8. Monthly Degaga temperature, humidity, weather, and precipitation analysis

According to the FAO Irrigation & Drainage (2016), the area with < 40% RH can be designated as Low humid; areas within the range of 40% to 70% are moderately humid, and when RH is > 70% the area is grouped as high humid. The result table showed that Dagaga station RH Nov, Dec, Jan, Feb, Mar, Apr, and May are moderately humid. The months June, Jul, Aug, Sep, and Oct are grouped as highly humid. According to the result, the maximum temperature of the Degaga station is 30.76 °C in the month of march, and the minimum temperature is 7.89C^0 in the month of December and maximum precipitation 7.43 in the month of August, and minimum precipitation 0.68 in the month of December. The maximum weather 3.34 in the month of February and the minimum weather 2.18 in the month of September.

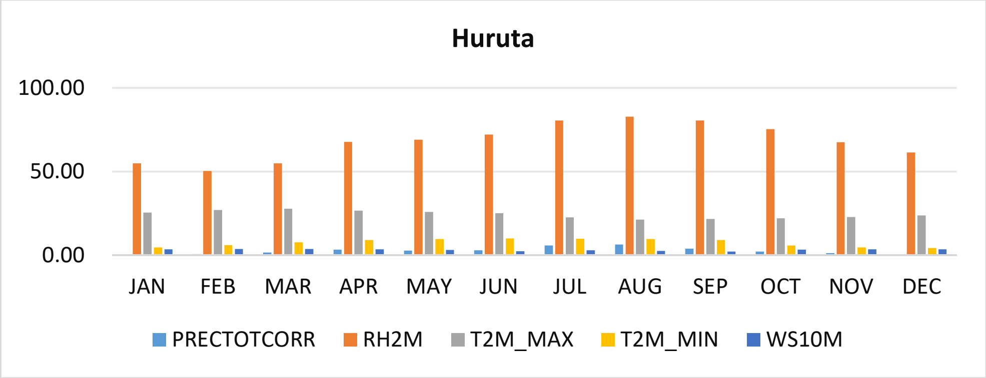


Figure 9. Monthly Huruta temperature, humidity, weather, and precipitation analysis

According to the FAO Irrigation & Drainage (2016), the area with < 40% RH can be designated as Low humid; areas within the range of 40% to 70% are moderately humid, and when RH is > 70%, the area is grouped as high humid. The result table showed that Huruta station RH Nov, Dec, Jan, Feb, Mar, Apr, and May are moderately humid. And the months Jun, Jul, Aug, Sep, and Oct are grouped as highly humid. According to the result, the maximum temperature of the Huruta station is 27.93C^0 on March and the minimum temperature is 4.35C^0 on December. And maximum precipitation 6.52 on August, and minimum precipitation 0.66 on January. the maximum weather condition is 3.91 on February, and the minimum weather condition is 2.27 in September.

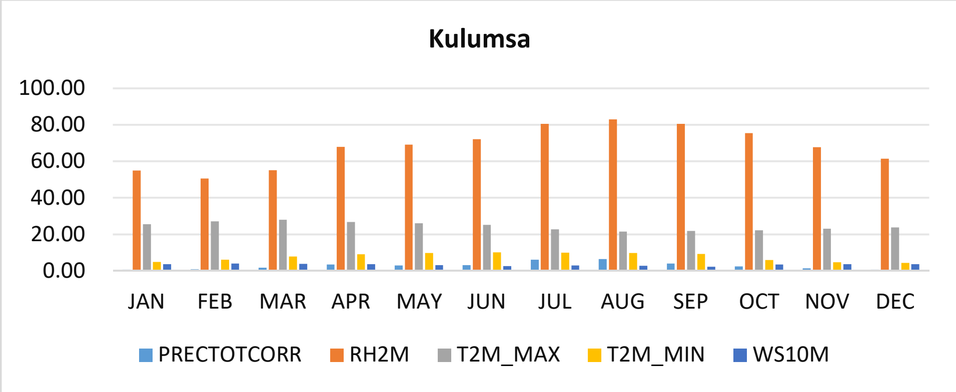


Figure 10. Monthly Kulumsa temperature, humidity, weather, and precipitation analysis

According to FAO Irrigation & Drainage (2016), the area with < 40% RH can be designated as Low humid; areas within the range of 40% to 70% are moderately humid, and when RH is > 70%, the area is grouped as high humid. The result table showed that Assela station RH Nov, Dec, Jan, Feb, Mar, Apr, and May are moderately humid. And the months Jun, Jul, Aug, Sep, and Oct are grouped as high humidity. According to the result, the maximum temperature of the Kulumsa station is 3.91C^0 on February, and the minimum temperature is 4.35C^0 on December. and maximum precipitation is 6.52 in August, and the minimum precipitation is 0.66 in January. The maximum weather condition is 6.52 in August and the minimum weather condition is 0.66 on January.

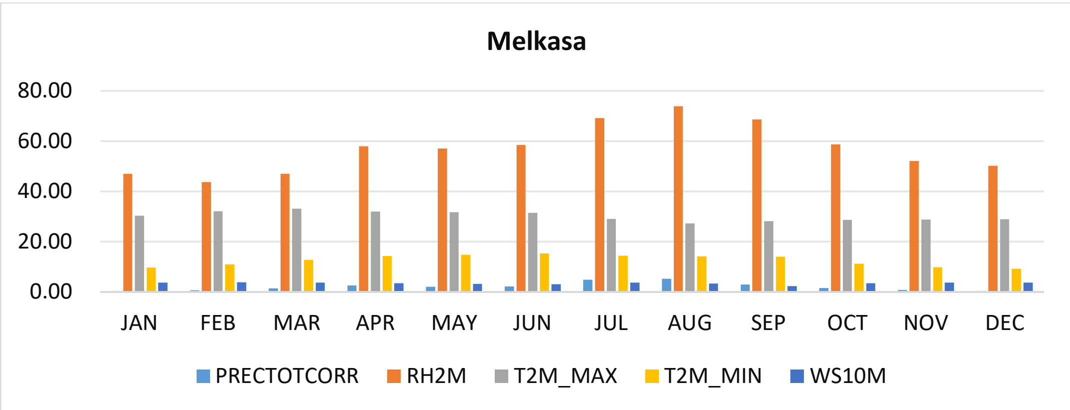


Figure 11. Monthly Melkasa temperature, humidity, weather, and precipitation analysis

According to the FAO Irrigation & Drainage (2016), the area with < 40% RH can be designated as Low humid; areas within the range of 40% to 70% are moderately humid, and when RH is > 70%, the area is grouped as high humid. The result table showed that the Melkasa station RH Age is highly humid. The remaining months are moderately humid. According to the diagram, the maximum temperature of the Kulumsa station is 33.1C^0 on

March and the minimum temperature is 4.35C^0 on December. and maximum precipitation is 6.52 in August, and the minimum precipitation is 0.66 in January. The maximum weather condition is 3.88 on February, and the minimum weather condition is 2.35 on September.

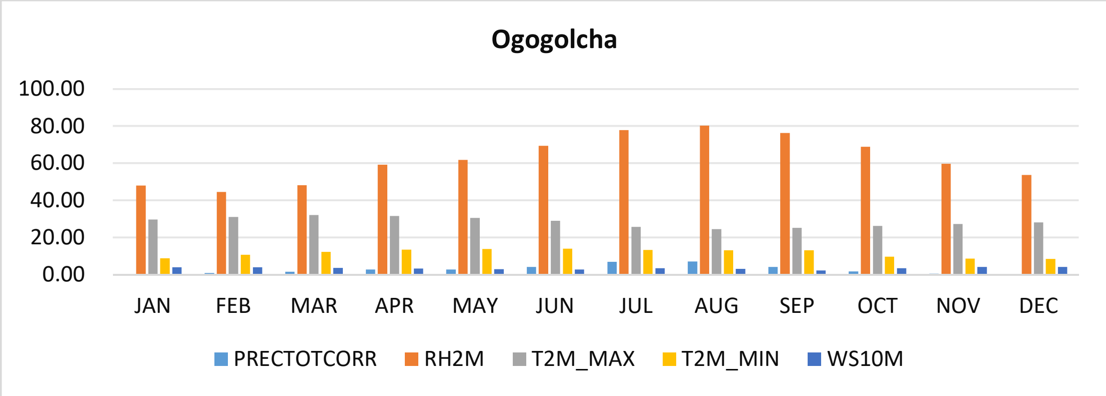


Figure12.Monthly Ogololcha temperature, humidity, weather, and precipitation analysis

According to the FAO Irrigation & Drainage (2016), the area with < 40% RH can be designated as Low humid; areas within the range of 40% to 70% are moderately humid, and when RH is > 70%, the area is grouped as high humid. The result table showed that Ogogolcha station RH Nov, Dec, Jan, Feb, Mar, Apr, May, Jun, and Oct are moderately humid. And the months, Jul, Aug, and Sep grouped as high humidity. According to the result, the maximum temperature of the Ogogolcha station is 32.15C^0 on March and the minimum temperature is 8.45C^0 on December. and maximum precipitation is 7.05 in August, and the minimum precipitation is 0.35 in December. The maximum weather condition is 4.09 in November, and the minimum weather condition is 2.19 in September.

Soil Moisture Content: -The result of the diagram shows how the soil moisture content varies seasonally in several woredas, including Zuway Dugda, Dodota, Sire, Tiyo, Hetosa, Lode Hetosa, and Munisa. Significantly, the Zuway Dugda and Dodota woredas, as well as the Sire and Tiyo woredas, exhibit significantly lower moisture content during January, February, and March than they do during other times of the year. Although a moderate moisture content is noted during this period in the Hetosa, Lode Hetosa, and Munisa woredas, it is still relatively low in comparison to other months. According to this research, the best time to prepare for tillage is during these early months.

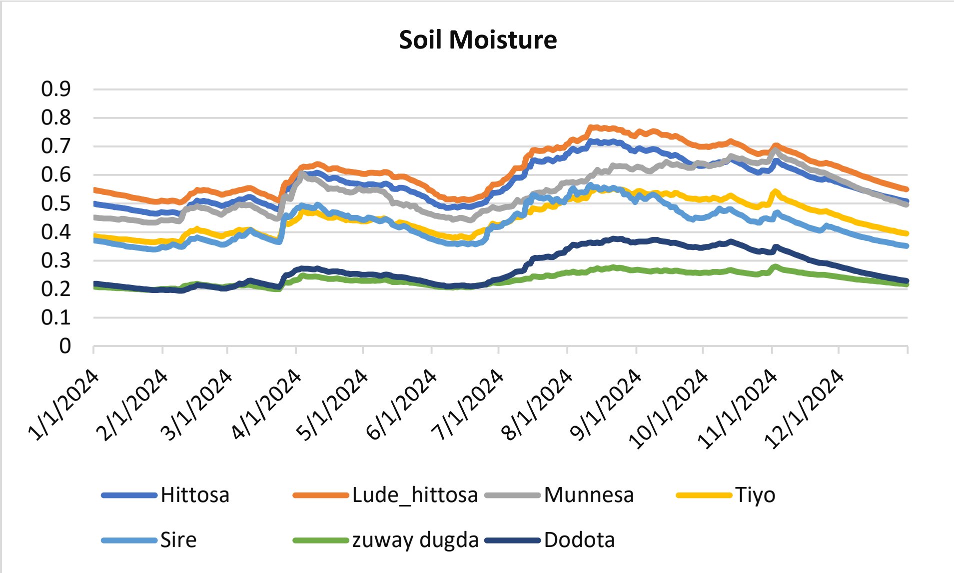


Figure 13. Predict soil moisture trends based on historical climate data

The study figure out the moisture content in the woredas of Sire, Tiyo, Hetosa, Lode Hetosa, and Munisa increases moderately as the April to June period progresses. Due to the case that increase in soil moisture on these months, it is more favorable for planting, which increases agricultural output. The following July through September sees a rapidly increase in the moisture content in the woredas of Sire, Tiyo, Hetosa, Lode Hetosa, and Munisa, which increases the growth of plants. The finding is important for crop development and scheduling the task depend on the result. Lastly, the data show a significant less soil moisture content throughout the woreda's under study from October to December, and it's suggested that a suitable condition for harvesting activity. Identifying the soil moisture content highly impacts on agricultural machinery planning and task allocation.

4.2.2. Topographical Analysis of the Hetosa Framers Cooperatives Union Members Woredas

Elevation: -With an emphasis on the districts of Zuway Dugda, Dodota, Hetosa, Tiyo, Lude Hetosa, Munisa, and Sire, this study utilized GIS-based elevation analysis to evaluate the deployment of agricultural machinery within the Farmers' Cooperatives Union. The findings highlight how important topographical differences are in determining the choice of machinery and operational effectiveness. Significant differences in landscape that affect the optimization of agricultural machinery were found.

The study analyze the elevation point of each Woreda's by using GIS-based elevation analysis. The woreda's included Zuway Dugda, Dodota, Hetosa, Tiyo, Lude Hetosa, Munisa, and Sire. The study identified different elevation point within the woreda's which needs some intervention of agricultural machinery selection and distribution based on the

elevation point. The data from seven woreda's included Dodota, Hetosa, Lude Hetosa, Munisa, Sire, Tiyo, and Zuway Dugda were analysed. Dodota Woreda showed an elevation range of 134 to 2,274 meters, signifying a change from lowland plains to mid-highland plains. The result shows that, there is impact on machinery selection in the woreda. And appropriate machinery selection needed in these areas. Hetosa woreda elevation range is between 1,734 to 4,082 meters. It is a mid-altitude farming zones and high-altitude obstacles to overcome. Lude Hetosa Woreda requires specialized equipment that can function at high elevations because it has the highest elevation at 4,199 meters and the lowest point at 1,601 meters. Munisa Woreda, which covers an elevation range of 1,938 to 3,810 meters, exhibits a moderate degree of adaptability in the use of machinery. With a range of 1,243 to 2,882 meters, Sire Woreda provides flexibility in farming practices by accommodating a variety of small and medium-sized machinery. To handle the difficulties presented by high-altitude conditions, Tiyo Woreda's elevation range of 1,773 to 3,984 meters necessitates cold-adapted equipment. Finally, Zuway Dugda Woreda's comparatively small elevation variation—between 1,631 and 2,258 meters—creates a more uniform terrain for the deployment of machinery.

The challenges of high-altitude farming, particularly above 3,000 meters, are highlighted by decreased engine efficiency caused by lower oxygen levels. Diesel engines with modified combustion systems must be employed to maintain performance in this situation (FAO, 2018). Furthermore, to ensure optimal performance from machinery, the temperature variations at these heights require the usage of coolants and lubricants (World Bank, 2019).

Slope:- Based on topographical features, the analysis of slope distribution across different woredas identifies unique opportunities and challenges for optimizing farm machinery. According to the data, Dodota and Ziway Dugda have the highest percentages of gentle slopes (0–8%), at 82.53% and 79.94%, respectively. As a result, these areas are ideal for using traditional farm equipment like tractors and harvesters without requiring major adjustments. Hetosa and Sire, on the other hand, have a moderate proportion of gentle slopes (67.04% and 70.64%, respectively), in addition to notable regions with moderate slopes (8–15%) at 28.50% and 23.06%. Implementing slope-adapted equipment, such as contour ploughs and low-power tractors, will improve farming efficiency in these areas.

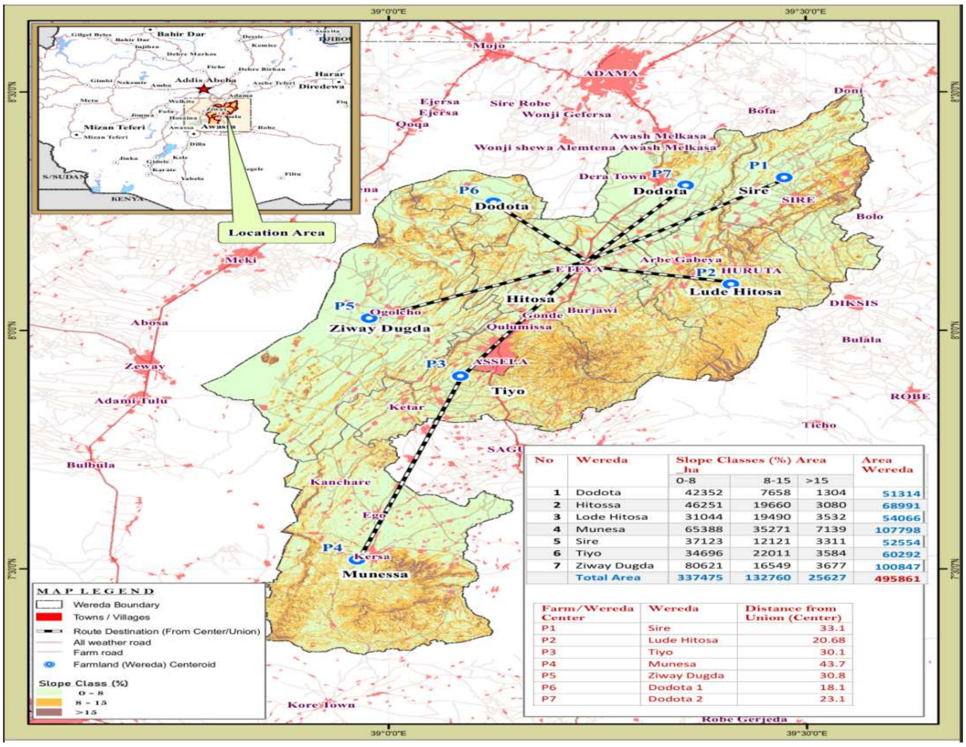


Figure 14. Slope of the Hetosa Framers Cooperatives Union Members Woredas

Lude Hetosa, Munisa, and Tiyo shows that there is a highest percentages of steep slopes (greater than 15%), ranging from 6.09% to 6.63%, while also having the lowest proportions of gentle slopes, ranging from 57.42% to 60.66%. These woredas' slope makes mechanization difficult, so terracing, conservation agriculture are required to reduce soil erosion.

Soil Type: - the study analyzed the soil types across the study woredas, the utilized classification system based on the Food and Agriculture Organization (FAO). The woredas included Dodota, Hetosa, Lude Hetosa, Sire, Munisa, Tiyo, and Zuway Dugda. The findings are summarized on the appendix 5.

In the Dodota Woreda the predominant soil type included Mollic Andosols, encompassing an area of 2,044.423 km², characterized as loamy soils. Lithic Leptosols, classified as sandy soils, constitute 1,563.169 km². Additionally, Vertic Cambisols, recognized as clay soils, cover 279.615 km². Hetosa Woreda the soil composition is notably diverse, consisting of Mollic Andosols (2,044.423 km²), Lithic Leptosols (1,349.522 km²), Vertic Cambisols (279.615 km²), Eutric Vertisols (1,039.949 km²), Haplic Luvisols (993.595 km²), and Chromic Luvisols (880.959 km²). These soils include loamy, sandy, and clay typologies, reflecting significant agricultural potential. Lude Hetosa Woreda this woreda also exhibits a variety of soil types, including Mollic Andosols (318.353 km²), Lithic Leptosols (1,112.544 km²), Vertic Cambisols (579.721 km²), Eutric Vertisols (3,871.929 km²), Haplic Luvisols (893.581 km²), and Chromic Luvisols (980.969 km²). Sire Woreda the soils present here include Lithic Leptosols (1,419.070 km²), Eutric Vertisols (3,915.340 km²), and Haplic Luvisols (416.905 km²), which suggest varied land management practices. Munisa Woreda a rich array of soil types characterizes this woreda, including Mollic Andosols (1,726.070 km²), Vertic Cambisols (161.635 km²), Eutric Vertisols (2,744.674 km²), Haplic Luvisols (281.914 km²), Chromic Luvisols (314.549 km²), and Humic Nitosols (464.857 km²). Tiyo Woreda the soil classification reveals Mollic Andosols (1,726.070 km²), Vertic Cambisols (279.615 km²), Eutric Vertisols (2,018.359 km²), Haplic Luvisols (993.595 km²), and Chromic Luvisols (880.959 km²). Zuway Dugda Woreda a diverse range of soil types is observed, including Mollic Andosols (1,726.070 km²), Lithic Leptosols (213.393 km²), Vertic Cambisols (279.615 km²), Eutric Vertisols (2,018.359 km²), Eutric Cambisols (164.364 km²), Luvic Phaeozems (858.510 km²), and Eutric Fluvisols (94.900 km²).

Soil types across the woredas identified the significant diversity and distribution of soils within this region, which holds critical implications for land use management and agricultural development. Understanding the soil physical character is essential for implement selection and optimizing machinery utilazation practices and maximizing agricultural productivity in the Dodota region.

Land Use Land Cover: - on the appendixes 6 shows that, the land use and land cover (LULC) types in the seven regions: Zuway Dugda, Dodota, Hetosa, Lude Hetosa, Munisa, Tiyo, and Sire. Each type of LULC is identified by an LCC Code, a description, and the corresponding area measurements in square kilometres (Area_km2) for each region.

From Appendix 4, the table shows that the woredas have different types of land use in the areas under study. Munisa (356.91 km2) and Lude Hetosa (259.93 km2) have the highest concentrations of cultivated and managed terrestrial areas (LCC Code 0003/0004), indicating significant agricultural activity. Munisa (269.86 km²) and Zuway Dugda (526.20 km²) have the most natural and semi-natural vegetation (LCC Code 0004//0003), indicating substantial natural cover. While closed-to-open shrubland is most common in Zuway Dugda (150.87 km2), rainfed herbaceous crops are mainly found in Munisa (258.43 km2) and Hetosa (136.74 km2), indicating a reliance on rainfed agriculture.

Munisa is the most agriculturally intensive woredas in terms of regional highlights, with the largest areas of cultivated land and rainfed crops. Zuway Dugda is distinguished by its substantial man-made waterbodies (128.69 km2) as well as its native shrubland and vegetation. Despite having a smaller total area, Tiyo has notable rainfed crops and shrubland. A variety of shrubland, herbaceous vegetation, and some cultivated areas can be found in Sire. The existence of bare spots, particularly in Dodota and Zuway Dugda, and sparse woody vegetation, which is concentrated in Hetosa and Dodota, are examples of special cases. Only Zuway Dugda and Dodota have artificial waterbodies. All things considered, Tiyo has the smallest farmed area (179.84 km2) and Munisa has the largest (907.80 km2). The largest areas in the region are Zuway Dugda (1087.65 km2) and Munisa (1082.47 km2), while Tiyo (240.38 km2) is the smallest. According to the data, some Woredas have a strong agricultural focus, while others have more intact natural environments. In areas with sparse and bare vegetation, there may be problems with water management and land degradation.

4.2.3. Length of Growing Period analysis, in the Hetosa Farmers Cooperatives Union members Woreda (LGP)

The main objective of establishing the length of the growing period is to gather preliminary information on the ability of precipitation and stored soil moisture to support crop growth within a given growing time. The study's findings indicate that there may be one, two, or three cropping seasons in a year. Instead of concentrating on the crops, the study examined the Woredas' growing season throughout this time.

Table 5. Length of Growing Period in the Hetosa Farmers Cooperatives Union members Woreda

East Arsi Woreda		Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
			31	28	30	30	31	30	31	31	30	31	30	31
	Eto	mm/day	5.04	5.4	5.61	5.25	4.73	4.4	4.03	3.73	4.18	4.42	4.51	4.65
	ETo	Mm	156.24	151.20	168.30	157.50	146.63	132.00	124.93	115.63	125.40	137.02	135.30	144.15
	ETo*0.5	Mm	78.12	75.60	84.15	78.75	73.32	66.00	62.47	57.82	62.70	68.51	67.65	72.08
	Eff rain	Mm	18.09	43.08	94.84	115.30	106.44	126.64	176.60	210.04	162.78	65.89	20.97	14.46
Assela			-60.03	-32.52	10.69	36.55	33.12	60.64	114.13	152.23	100.08	-2.62	-46.68	-57.62
			31	28	30	30	31	30	31	31	30	31	30	31
		mm/day	3.50	3.59	3.74	3.50	3.40	3.03	2.48	2.53	2.83	3.06	3.25	3.33
	ETo		5.09	5.44	5.79	5.67	5.34	4.55	4.59	3.97	4.2	4.6	4.58	4.59
	ETo*0.5		2.55	2.72	2.90	2.84	2.67	2.28	2.30	1.99	2.10	2.30	2.29	2.30
Degaga	Eff rain	Mm	16.84	30.32	49.05	66.22	63.51	70.37	130.46	106.25	69.81	38.30	7.50	4.89

			14.29	27.60	46.16	63.39	60.84	68.09	128.17	104.27	67.71	36.00	5.21	2.60
	No of Days		31	28	30	30	31	30	31	31	30	31	30	31
	Eto	mm/day	4.72	5.16	5.52	5.29	5.58	4.67	3.77	3.81	4.17	4.28	4.25	4.32
	ETo(mm)	mm	146.32	144.48	165.60	158.70	172.98	140.10	116.87	118.11	125.10	132.68	127.50	133.92
	ETo*0.5		73.16	72.24	82.80	79.35	86.49	70.05	58.44	59.06	62.55	66.34	63.75	66.96
	Eff rain	mm	9.30	30.69	46.18	52.97	55.52	67.32	195.20	199.64	93.73	28.68	10.28	5.11
Huruta			-63.87	-41.55	-36.62	-26.38	-30.97	-2.73	136.77	140.58	31.18	-37.66	-53.47	-61.85
			31	28	30	30	31	30	31	31	30	31	30	31
	Eto	mm/day	4.72	5.17	5.52	5.31	4.9	4.62	4.21	3.82	4.17	4.29	4.26	4.32
	ETo(mm)		146.32	144.76	165.60	159.30	151.90	138.60	130.51	118.42	125.10	132.99	127.80	133.92
	ETo*0.5		73.16	72.38	82.80	79.65	75.95	69.30	65.26	59.21	62.55	66.50	63.90	66.96
	Eff rain	mm	21.06	44.20	86.84	81.74	88.22	90.52	124.65	134.15	103.45	37.59	12.57	10.31
Kulumsa			-52.10	-28.18	4.04	2.09	12.27	21.22	59.39	74.94	40.90	-28.91	-51.33	-56.65
			31	28	30	30	31	30	31	31	30	31	30	31
	Eto	mm/day	5.03	5.7	6.1	5.88	5.68	5.64	5.09	4.64	4.86	5.22	4.96	4.82
	ETo(mm)		155.93	159.60	183.00	176.40	176.08	169.20	157.79	143.84	145.80	161.82	148.80	149.42
	ETo*0.5		77.97	79.80	91.50	88.20	88.04	84.60	78.90	71.92	72.90	80.91	74.40	74.71
	Eff rain	mm	11.00	20.00	43.00	52.00	62.00	67.00	189.00	196.00	96.00	24.00	13.00	5.00
Melkasa			-66.97	-59.80	-48.50	-36.20	-26.04	-17.60	110.11	124.08	23.10	-56.91	-61.40	-69.71

			31	28	30	30	31	30	31	31	30	31	30	31
	Eto	mm/day	4.1	4.22	4.39	4.28	4.23	4.25	3.39	3.49	3.36	3.97	4.07	3.67
	ETo(mm)		127.10	118.16	131.70	128.40	131.13	127.50	105.09	108.19	100.80	123.07	122.10	113.77
	ETo*0.5		63.55	59.08	65.85	64.20	65.57	63.75	52.55	54.10	50.40	61.54	61.05	56.89
	Eff rain	mm	12.00	47.00	44.00	85.00	41.00	72.00	132.00	118.00	89.00	32.00	11.00	6.00
Ogolocho			-51.55	-12.08	-21.85	20.80	-24.57	8.25	79.46	63.91	38.60	-29.54	-50.05	-50.89

Length of growing period(LGB) for different woredas were determined by using the Peris Moretese Formula and it depending on meterological data from several station. Assela metrology station represent Tiyo Woreda's growing period started from march to September. And Degaga meteorological station indicated Munisa Woreda experienced a year round growing period from January to December. The Huruta station metrological data result shows Lude Hetosa Woredas' growing period starts from July to December. Further, the Kulumsa station showed that Hetosa Woreda's growing period included March to September. The Melkasa station identified a growing period of July to September for both Dodota and Sire Woredas, while the Ogogolcha station indicated that Zuway Dugda Woreda's growing period starts from June to September. The study results were used to schedule planting activities in each woreda according to their respective growing periods.

4.3. Agricultural machinery utilization assessment result

Hetosa Farmers' Cooperative Union utilizes a variety of machinery from well-known brands such as John Deere, New Holland, Claas, Nardi, Balldan, and Leamkon to support different farm operations. These included ploughing, seeding, and harvesting. And some of the machines are equipped with GPS, and some are not equipped because of the machinery Age. The union has established thorough documentation practices, maintaining detailed records of machinery costs, service histories, and depreciation. However, significant challenges persist. The union lacks sufficient machinery to meet the needs of farmers across its seven woredas, resulting in delays in service provision. Most farmland is fragmented land plots between 0.5 to 1 hectare. Furthermore, the estimated travel time from the union to the fueling station ranges from 40 to 60 minutes. This time is essential for refueling both the tractor and the combine harvester, contributing to an average of 120 to 130 hours of travel annually. For five tractors, a total of 625 hours is utilized, while seven combine harvesters account for 875 hours. The labor cost associated with the tractor is 51605, whereas the labor cost for the combine harvester is 72247. Consequently, the total loss incurred by the union due to unproductive labor amounts to 123,852 birr.

For machinery operation, one hour of tillage work covers 1.7 hectares for a tractor with 130-150 horsepower. In terms of planting operations, one hour covers 3 hectares, while combining harvesting operations covers 2.5 hectares per hour. Therefore, for tillage operations, the total area covered by the tractor is calculated as follows: 1.7 hectares multiplied by 625 hours, which equals 1,062.5 hectares. For the combine harvester, the total area covered is 2.5 hectares multiplied by

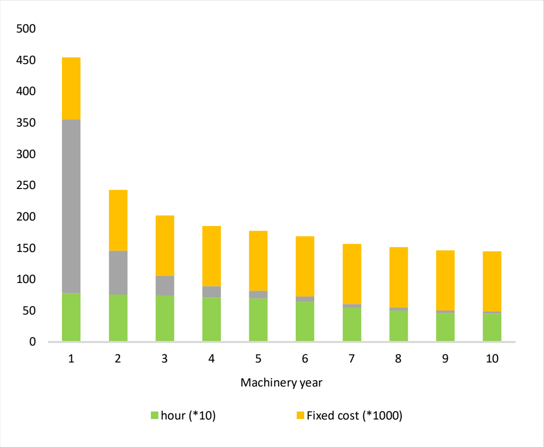
875 hours, resulting in 1,487.5 hectares. When these figures are converted into economic terms, the union experiences a loss of 3,329,025 birr from tractor tillage operations. Moreover, for combine harvesting, with an average of 14-18 quintals per hectare, an average yearly loss of 2,187.5 hectares results in a further loss of 2,156,000 birr for the union. The seven woredas are planting different crops, including maize, wheat, barley, sorghum, and teff. Hetosa farmers cooperatives union delivered services for all crop season and various operations. The operations include primary tillage, seedbed preparation, and harvesting. However, teff and maize have not received planting operations from the union, and teff is also excluded from the harvesting operations. The variety of seeds available also impacts task scheduling. Inefficient pre-planned operations affect agricultural machinery utilization. Furthermore, the absence of a digital registration system complicates task scheduling, while delays in the delivery of essential inputs, such as fertilizers and seeds, disrupt planned activities.

Moreover, the lack of spare parts and aging machinery, which have been in use for over 12 years, has made maintenance economically unviable due to high costs, increased fuel consumption, and frequent downtime. Soil conditions, including variations in land slope and weather patterns, further influence machinery performance, particularly when scheduling tasks.

4.4. Calculation of Machinery Cost in Hetosa Farmers Cooperatives Union

4.4.1. Calculation of Fixed cost and Variable cost

Based on the literature reviewed and the mathematical modeling in Chapters 2 and 4, respectively, the study calculated the 2012/19-2024/25 fixed and operational costs. This calculation helps to analyze the Htiosa Farmers Cooperatives Union's current state of machinery utilization. It also helps estimate the operation cost and plan for future work.


500
450
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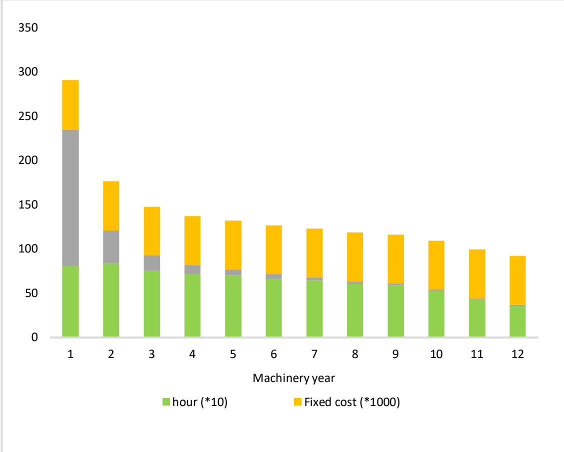
1 2 3 4 5 6 7 8 9 10
Machinery year
hour (*10)
Fixed cost (*1000)

a)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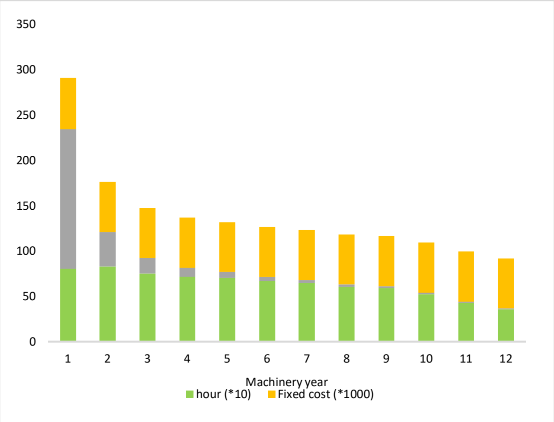
Machinery year
hour (*10)
Fixed cost (*1000)

b)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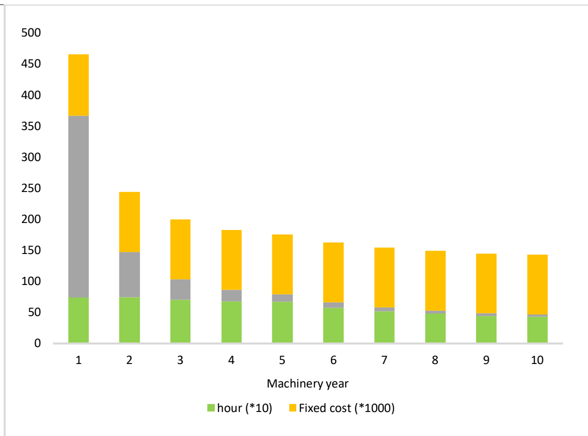
Machinery year
hour (*10)
Fixed cost (*1000)

c)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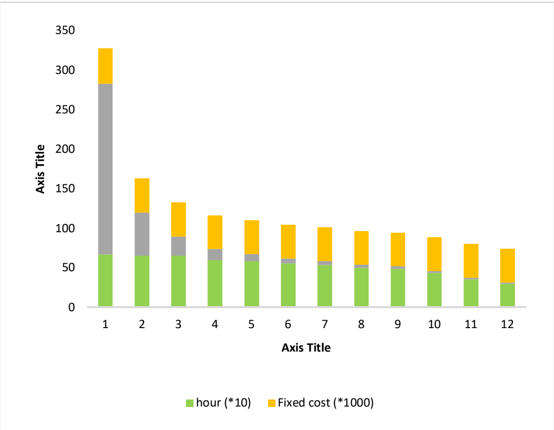
Machinery year
hour (*10)
Fixed cost (*1000)

d)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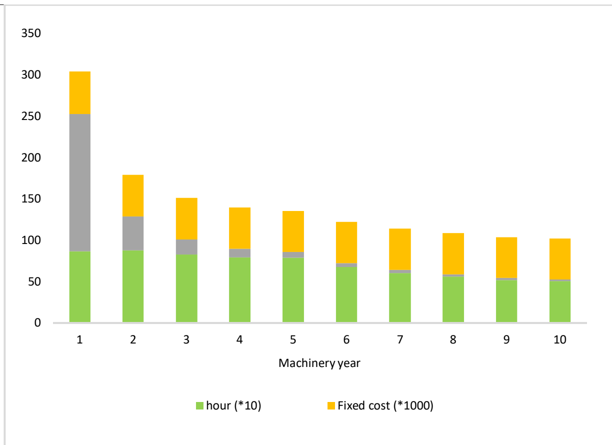
Axis Title
hour (*10)
Fixed cost (*1000)

e)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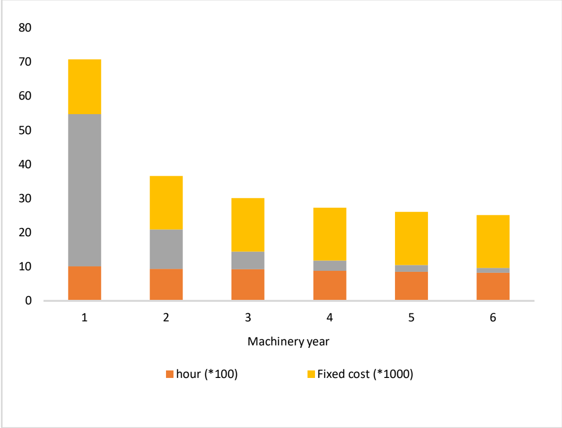
1 2 3 4 5 6 7 8 9 10
Machinery year
hour (*10)
Fixed cost (*1000)

f)



g)

Figure15 tractor fixed cost per year in Ethiopian Birr

The result indicated that depreciation was directly related to the machinery year and the total machinery engine hours. From the figure, some machinery needs to be replaced with new machinery. And the chart bar g indicated that even if the machine is used for six years, the total engine hours of the machine are like the oldest machine. Due to this, the machinery is rapidly deprecated.

Likewise, the variable cost for Hetosa Farmers Cooperatives Union for the year between 2012/19-2024/25 is given in Table 5.1.

The Calculated tractor variable cost described in the appendix 6 the total operation cost of the machine, and it includes Fuel cost, labor cost, lubricant cost, and repair and maintenance cost. The table shows that the maintenance and labor costs are high.

4.5. Optimization of Operation Cost

As discussed in the last chapter, the primary objective is to optimize the operation cost of the machine by reducing the fuel and labor costs of the machine. To meet the objective the study reduced the weighted sum of the total distance covered by all agricultural machinery and minimized the variability in the distance traveled by each machine. To do this, one must find the optimum path followed by machinery, considering the road network of the place. The possible road network was studied by the Ethiopian Road Authority. To analyze the study area woreda, this research extracted and digitized for each study woreda by using network analysis using ArcGIS. The area polygon can be clipped and the origin and destination of each Woreda can be created. Then after using OD-cost matrix analysis, we can generate the shortest path profile of 7

East Arsi Woreda. Figure 5.3 (a) and (b) show the extracted road network from the Ethiopian road authority and the generated shortest path profile of the 7 Arsi Woreda using OD-cost matrix analysis, respectively.

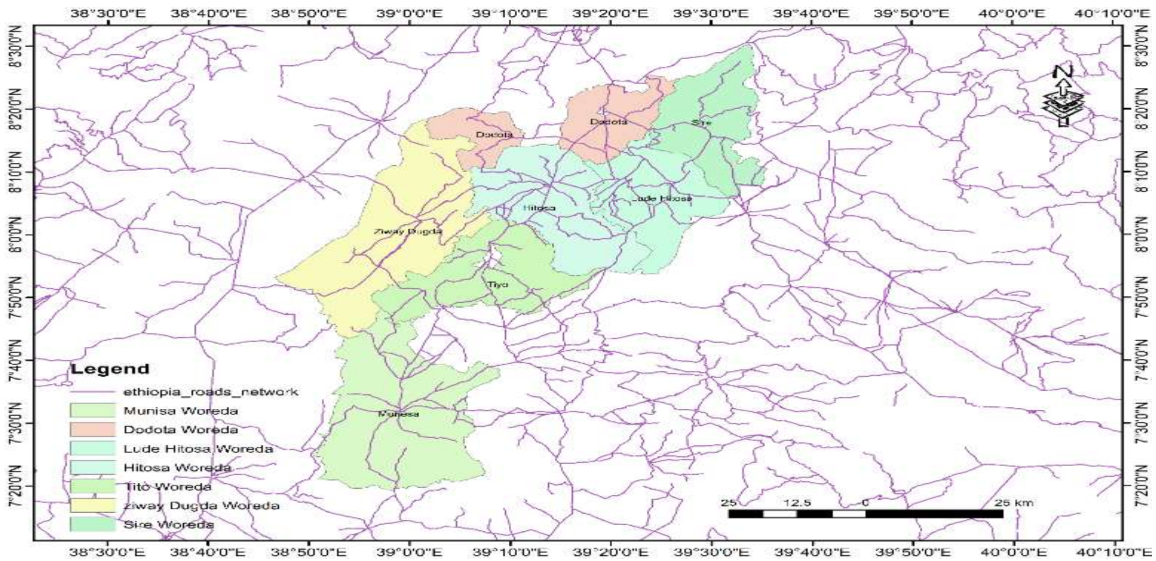


Figure16.The extracted road network from the Ethiopian road authority

a)

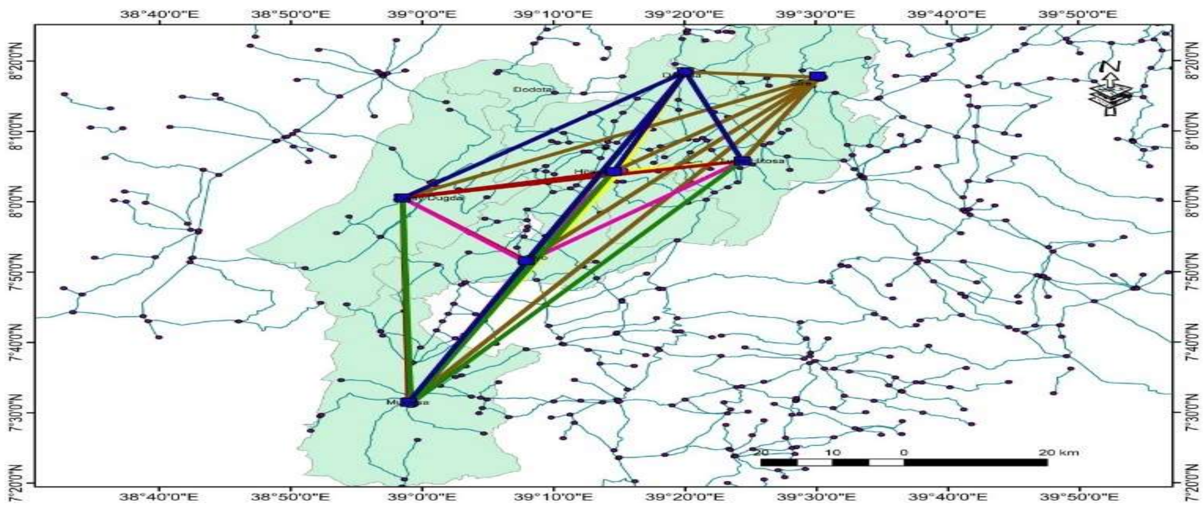


Figure17.The generated shortest path profile of the 7 Arsi Woreda using OD-cost matrix analysis

The distance of each road network for the 7 Arsi woreda is shown in Table 5.2. This real ground road data is fed to the Tabu search algorithm to determine the optimum path that must be followed by the machinery. As an example, P_1P_2 represents the shortest distance recovered by the OD-cost matrix analysis from P_1 to P_2.

Table 6. The shortest distance or road from one Woreda to another analyzed by OD-cost matrix analysis

	P_1	P_2	P_3	P_4	P_5	P_6	P_7
P_1	0	56.31672576	45.01569832	43.89874004	95.69784709	47.70837356	30.74941506
P_2	56.31672576	0	65.6974399	83.09111399	134.890221	86.50564173	24.03981384
P_3	45.01569832	65.6974399	0	73.31955929	125.1186663	76.73408703	41.65960194
P_4	43.89874004	83.09111399	73.31955929	0	51.52231907	55.99327455	59.32808812
P_5	95.69784709	134.890221	125.1186663	51.52231907	0	80.3465981	111.1761742
P_6	47.70837356	86.50564173	76.73408703	55.99327455	80.3465981	0	62.47600645
P_7	30.74941506	24.03981384	41.65960194	59.32808812	111.1761742	62.47600645	0

Where: P_1 : Hetosa (Depot), P_2 : Sire, P_3 : Lodo Hetosa, P_4 : Tiyo, P_5 : Munessa, P_3 : Dodota, P_7 : Dodota

Table 7. Position and distance of each kebele from the depot (Eteya)

		Location ID	Location of the farm field				
	Woreda		distance	X	Y	Area	Angle(rad)
P_1	Hetosa (Depot)	1	0	0	0	`-	-
P_2	Sire	2	33.100	26.778	19.456	49.244	0.63
P_3	Lode Hetosa	3	20.680	19.668	-6.390	50.534	5.97
P_4	Tiyo	4	30.100	-16.394	-25.244	56.707	4.14
P_5	Munessa	5	43.700	-17.774	-39.922	100.659	4.29
P_6	Ziway Dugda	6	30.800	-27.914	-13.017	97.17	3.58
P_7	Dodota	7	18.100	-12.799	12.799	50.01	2.36

4.5.1. Path Optimization of Agricultural Machinery for the 7 East Arsi Woredas

Efficient path optimization of agricultural machinery is crucial for enhancing productivity and reducing operational costs in ploughing activities. Developing an optimized route plan for agricultural machinery, considering various field locations, areas, and terrain conditions, is crucial for improved ploughing operations. The Tabu search algorithm is used to obtain this optimum path. Some of the predefined parameters that have been obtained from real-time measuring of the fuel cost per hectare and time of travel for the agricultural machinery in the union are given as follows:

The tractor travels 1.1km/hr. and fuel consumption of 10 liters/11km (Newholland (T1-150) and 8.5 liters/10km Johndeere (T2-130).

ploughing rate = 1.75 hectare/hr. (including the downtime)

- Planting rate: 3 hectares/hr. (including the downtime)
- Harvesting rate: 2.5 hectares/hr. (including the downtime)
- The area is obtained from the ArcGIS data
- The fuel consumption rate is 33-35 liters/ per hectare for Tillage operation
- Tractor number =3 (Two Johndeere (T2-130) and Newholland(T1-150))

Figure 18.a) Real-time measuring of ploughing rate, fuel consumption, and tractor travel speed

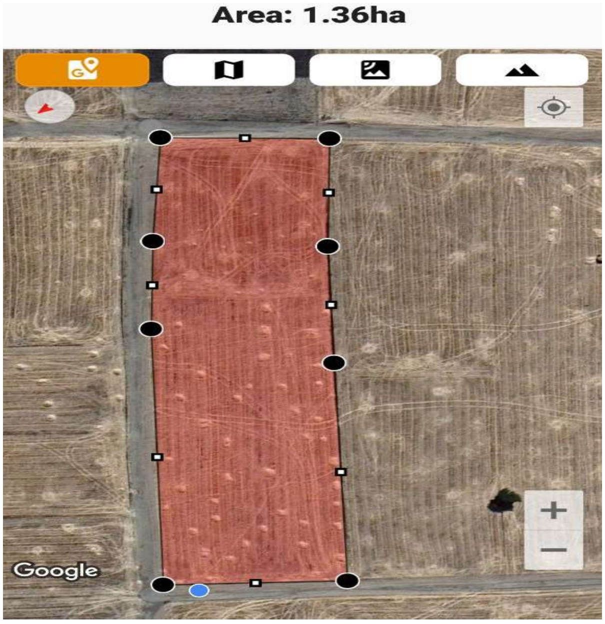


Figure19.(b) Field area measurement using GIS

Using MATLAB Code, as demonstrated in appendix A, the Tabu search algorithm, as presented in Table 4.13, is used. The algorithm tends to find the best path that minimizes the distance that tractors travel, as seen in the figure below, while taking the constraints from the data that was measured above and the three movements to search for the neighboring results.

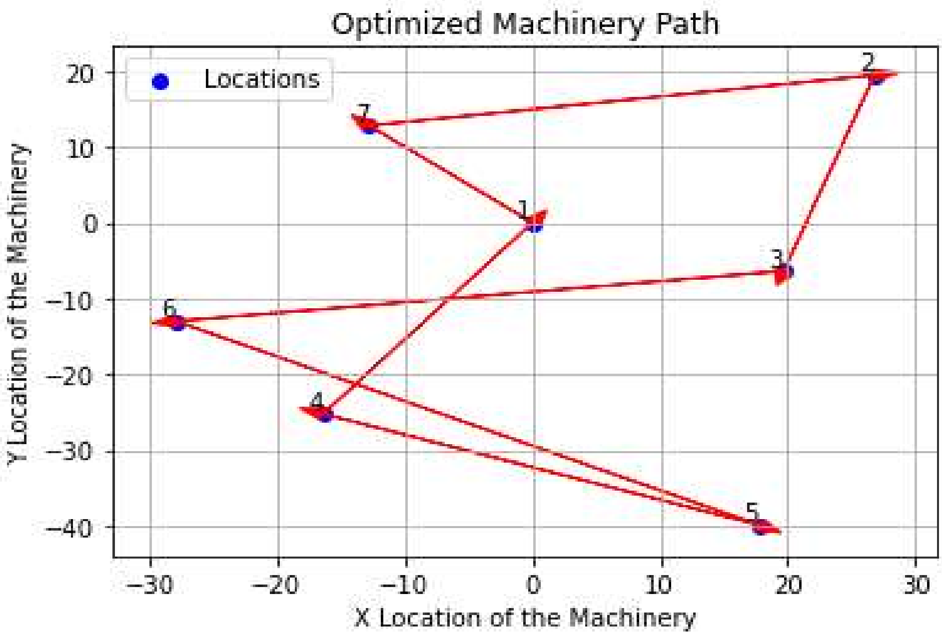


Figure20.Optimized tractor path for the 7 East Arsi Woredas

Figure 4.5 illustrates the optimal path to minimize the union's operational time and cost. Unlike the random path approach, this optimized route provides good fuel costs, downtime, and ploughing area to enhance efficiency.

Fuel savings achieved through optimized path following

Optimizing the path followed by agricultural machinery in Hitossa Town, which comprises nine distinct districts, can significantly enhance fuel efficiency and reduce operational costs. Consequently, agricultural machinery consumes less fuel, reducing both costs and environmental impact. Implementing Tabu Search in path optimization for Hitossa Town's agricultural machinery demonstrates a practical and effective approach to achieving fuel savings across its diverse districts. The following figures show how fuel saving is achieved.

For the Newholland 150 HP tractor, the travel distance per the manual:

- On flat terrain with no load: 15-20 km/h
- On flat terrain with a moderate load: 10-15 km/h
- On rough terrain or with a heavy load: 5-10 km/h

For the Johndeere 130 HP tractor, the travel distance as per the manual:

- On flat terrain with no load: 14-18 km/h
- On flat terrain with a moderate load: 9-14 km/h
- On rough terrain or with a heavy load: 4-9 km/h

Considering the flat terrain with moderate load, the total distance traveled and fuel consumption by the 130 hp and 150 hp tractors are depicted in Figure 5.14. From the figure, it can be easily deduced that the distance traveled, and fuel consumption are higher for random operation techniques

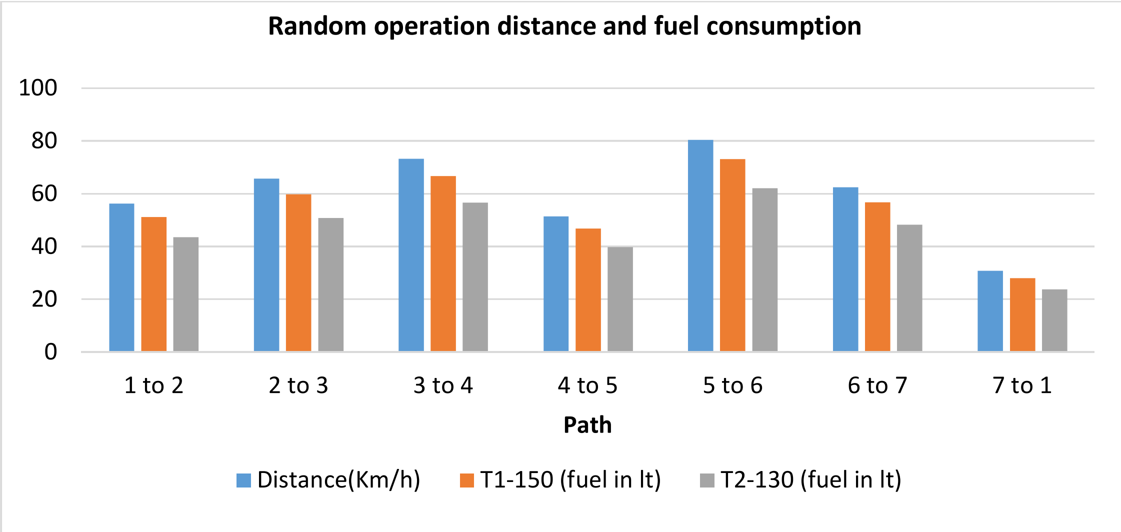


Figure21.Distance covered and Fuel consumption for (a) random operation

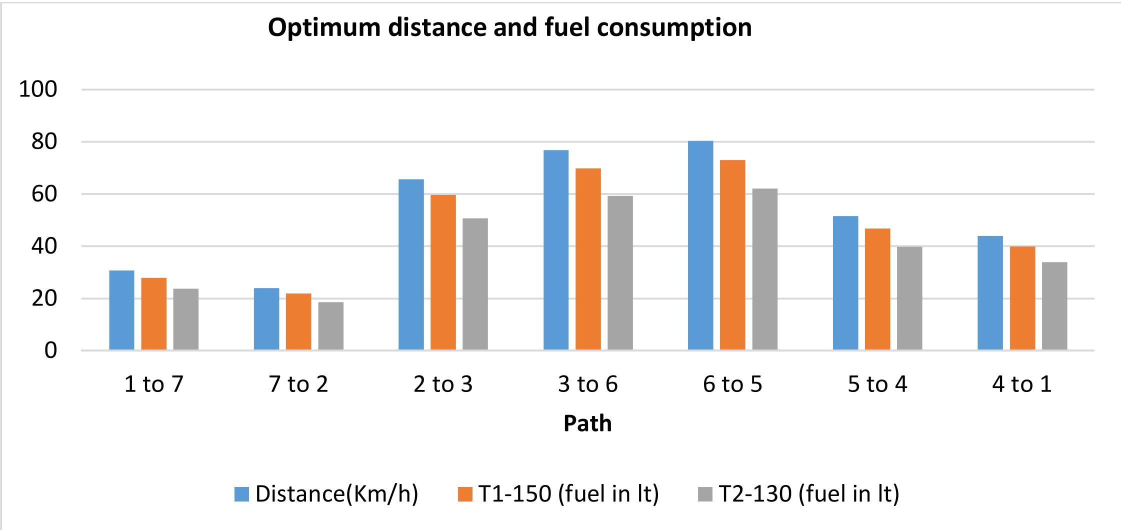
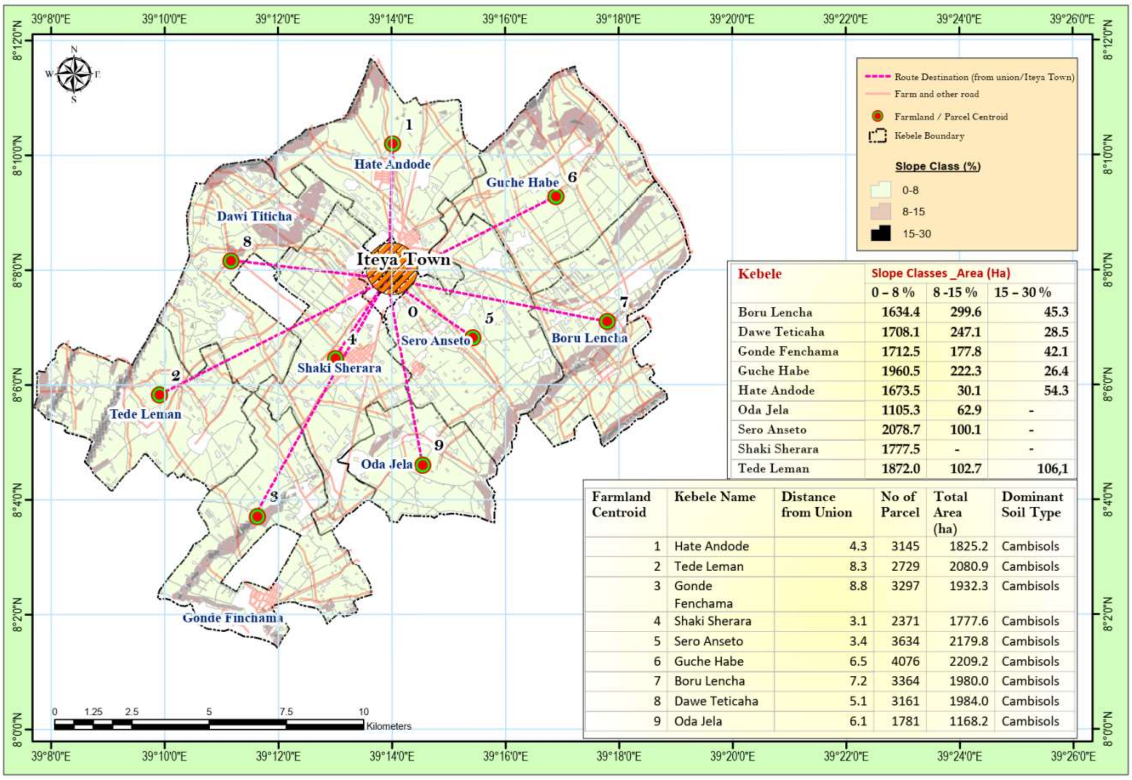


Figure22.Fuel consumption for optimum operation

The results indicate a reduction in fuel consumption of up to 11.28 percent which implies a great reduction in operational cost of the Union. Additionally, the decreased total distance traveled by the tractor not only extends its lifespan but also lowers its carbon emissions which have a great impact on the environmental protection perspective.

4.5.2. Path Optimization of Agricultural Machinery for the Hetosa Woreda Kebele

Following the method, we approach to evaluate the optimum path and operation for the 7 East Arsi Woredas, we can determine the optimum path followed by the machinery for the Iteya town and Kebele around it. Again, the Tabu search algorithm is used to obtain this optimum path. Some of the predefined parameters that have been obtained from real-time measuring of the fuel cost per hectare and time of travel for the agricultural machinery in the union is used in the same way as the analysis of the 7 Woreda analysis. The geographic visualization using ArcGIS and the slop class area in the 9 rural kebele of Iteya town is depicted in Figure 6.5 (a) and (b) as shown below.



Kebele	Slope Classes _Area (Ha)		
	0 – 8 %	8 -15 %	15 – 30 %
Boru Lencha	1634.4	299.6	45.3
Dawe Teticaha	1708.1	247.1	28.5
Gonde Fenchama	1712.5	177.8	42.1
Guche Habe	1960.5	222.3	26.4
Hate Andode	1673.5	30.1	54.3
Oda Jela	1105.3	62.9	-
Sero Anseto	2078.7	100.1	-
Shaki Sherara	1777.5	-	-
Tede Leman	1872.0	102.7	106,1

Farmland Centroid	Kebele Name	Distance from Union	No of Parcel	Total Area (ha)	Dominant Soil Type
1	Hate Andode	4.3	3145	1825.2	Cambisols
2	Tede Leman	8.3	2729	2080.9	Cambisols
3	Gonde Fenchama	8.8	3297	1932.3	Cambisols
4	Shaki Sherara	3.1	2371	1777.6	Cambisols
5	Sero Anseto	3.4	3634	2179.8	Cambisols
6	Guche Habe	6.5	4076	2209.2	Cambisols
7	Boru Lencha	7.2	3364	1980.0	Cambisols
8	Dawe Teticaha	5.1	3161	1984.0	Cambisols
9	Oda Jela	6.1	1781	1168.2	Cambisols

Figure22.a)Geographic visualization using ArcGIS

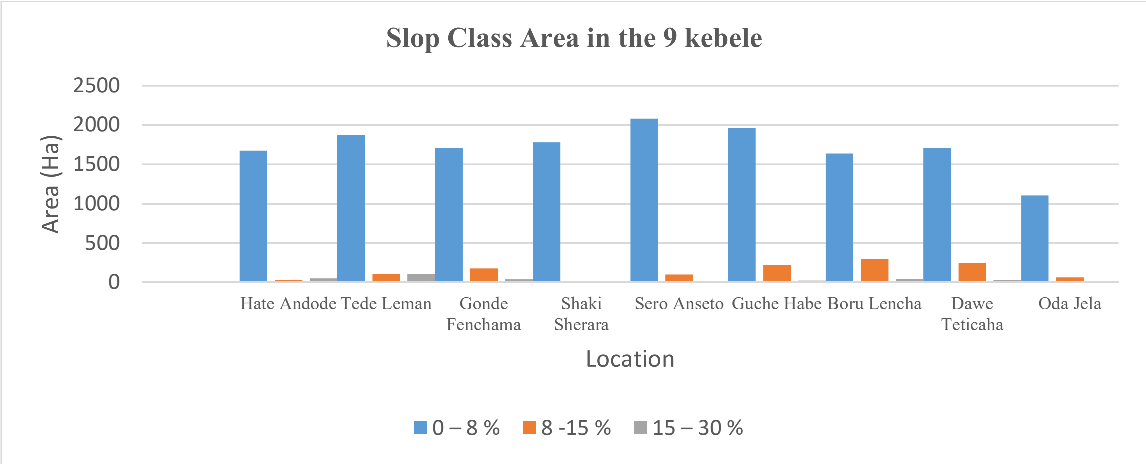


Figure23. Slope class area in the 9 rural kebeles of Iteya town

Table 4.5 illustrates the location ID's assigned to each Woreda and the coordinates of each farming field relative to the Hitossa Union depot (0,0) in the Iteya town.

Table8.Position and distance of each kebele from the depot

Kebele	Location ID	Location of the farm field			Area	Angle(rad)
		Distance	**X**	**Y**		
Hetosa (Depot)	1	**0**	**0**	**0**	**`-**	**-**
Boru Lencha	2	4.3	4.220997	-0.82048	19.347	6.09
Dawe Teticaha	3	8.3	-8.25453	0.867586	19.55	3.04
Gonde Fenchama	4	8.8	-4.4	-7.62102	18.902	4.19
Guche Habe	5	3.1	2.809554	1.310117	21.828	0.44
Hate Andode	6	3.4	0.118658	3.397929	17.709	1.54
Oda Jela	7	6.5	1.128713	-6.40125	11.682	4.89
Sero Anseto	8	7.2	5.824922	-4.23205	21.798	5.65
Shaki Sherara	9	5.1	-2.85188	-4.22809	17.776	4.12
Tede Leman	10	6.1	-5.43514	-2.76934	19.748	3.61

Likewise, Figure 4.16 illustrates the optimal path to minimizing the operational time and cost for the union. Unlike the random path approach, this optimized route gives good and optimized fuel costs, downtime, and ploughing area to enhance efficiency.

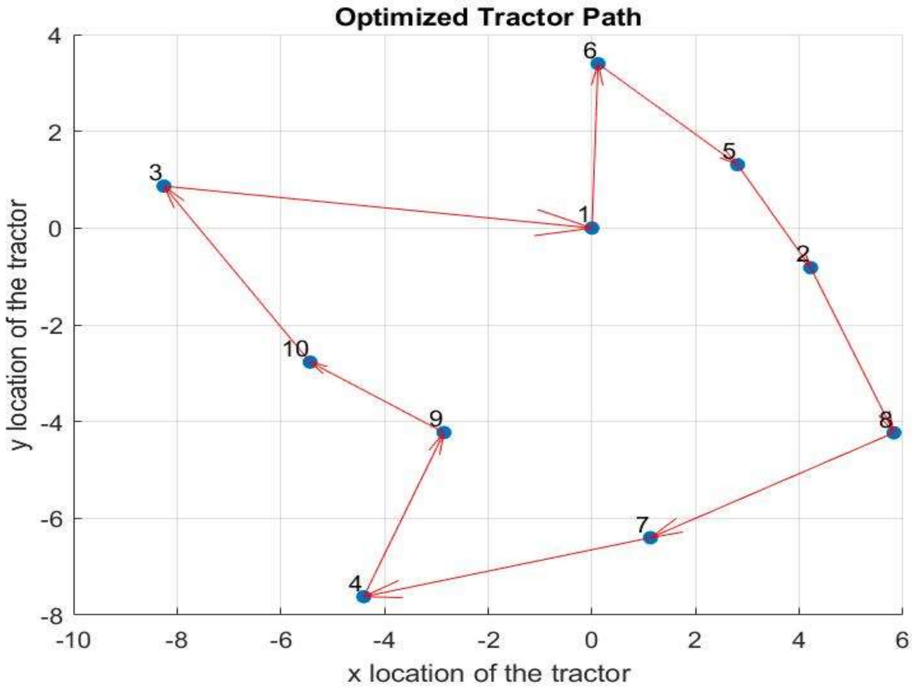


Figure 24.Optimized tractor path for the 9 rural kebeles of Iteya town

Fuel Savings Achieved Through an Optimized Path for The 9 Rural Kebeles of Iteya

Implementing Tabu Search in path optimization for Hitossa Town's agricultural machinery demonstrates a practical and effective approach to achieving fuel savings across its diverse districts. Considering flat terrain with moderate load, as for the woreda analysis, the total distance traveled and fuel consumption by the 130 hp and 150 hp tractors are depicted in Figure 4.17. From the figure, it can be easily deduced that the distance traveled, and fuel consumption is higher for random operation techniques

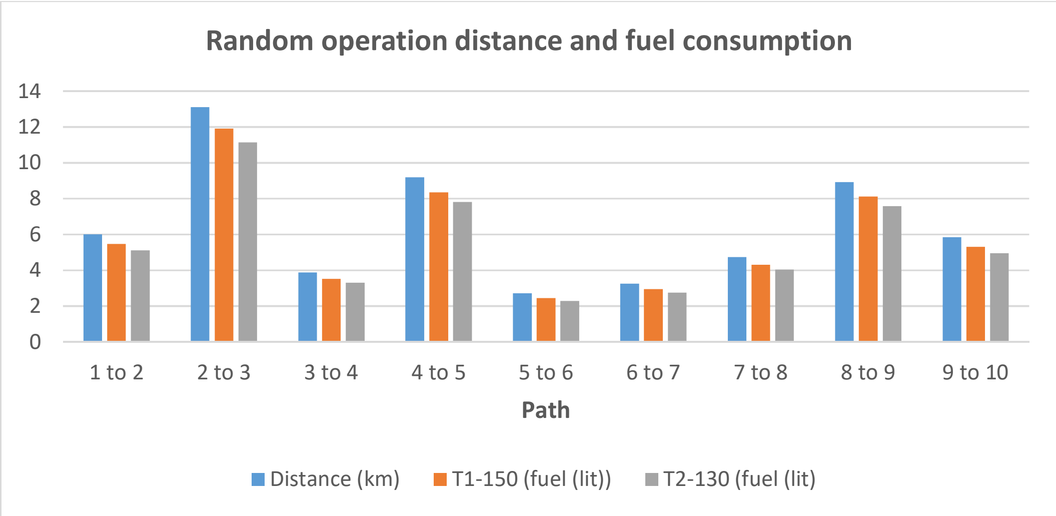


Figure25.Distance covered and Fuel consumption for random operation

a)

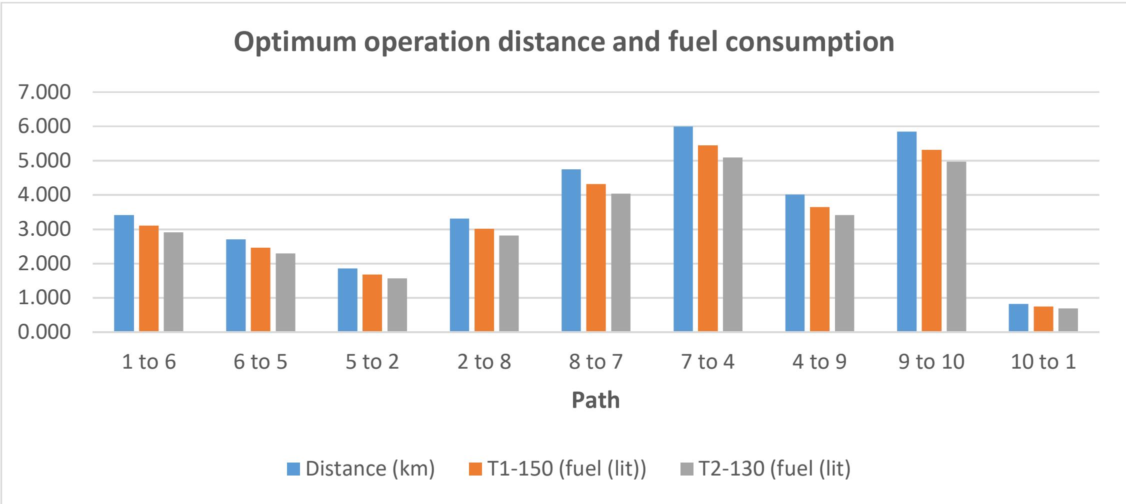


Figure26.Distance covered and Fuel consumption for optimum operation

The results indicate a reduction in fuel consumption of up to 23.34 percent, which implies a great reduction in operational costs of the union.

4.6. Machinery and equipment required per hectare for the Hetosa farmers' cooperative union.

The Hetosa farmers' cooperative union encompasses 7 Woredas of east Arsi. These Woreda have diverse land and vegetation types that must be examined to get effective land operation and management. In this specific section, the land types and covering area of each land type is examined to determine the total cultivated area per hectare and the number of tractors to cover the farm plot for seedbed preparation and tillage operation. The Land use Land cover, the area covered in each Woreda, and the farm plot area for each Woreda is filtered using ARC-GIS. To identify the total cultivated area of Hetosa farmer's cooperatives union members. First, the study used the woredas' land use and land cover area and filtered the cultivated area after that by using field observation data recorded. The research calculated for each operation the machine working hours per hectare, and the study used ten working hours per day. And by using metrological historical data and serving data, the study identified the total working days. From the calculation, the research identified daily farm operation work per hectare multiplied by annual operational days. Finally, the study identified the total machinery required for each woreda.

Table9.Initial consideration to determine the total number of machines required for each woreda

Machinery type	**HP**	**Width**	**Ha/Hr**	**Working Hr/day**	**An annual working day**
Tractor with d plough	130	5 bottoms	1.3	10	120
Tractor with M plough	150	5 bottoms	1.5	10	120
Combine Harvester	220		1.65	10	150
Tractor with raw seeder 1	150	3m	3	10	120
Tractor with raw seeder 2	130	2.6m	2.5	10	120

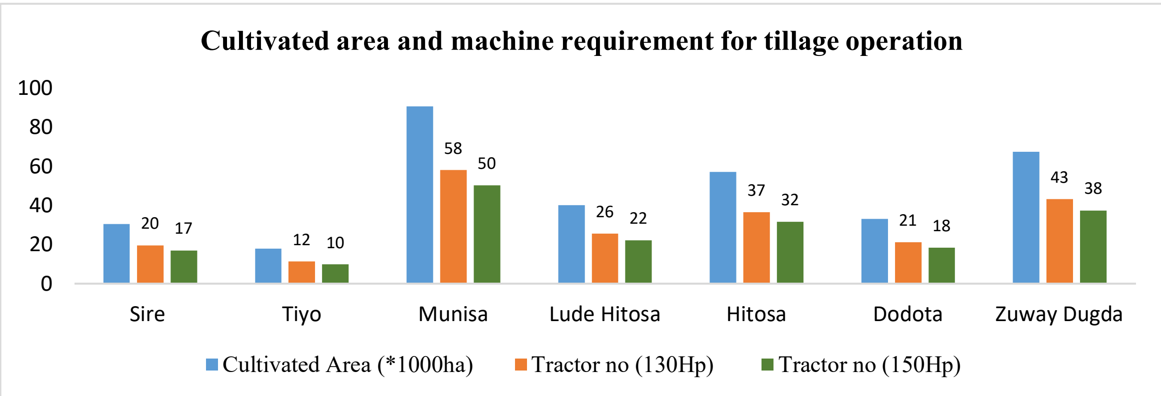


Figure27.Calculation of total cultivated area and machine requirement for tillage operation with 5-bottom disk plough

According to the table, approximately 20 tractors with 130 hp or 18 tractors with 150 hp are needed for Sire woreda for tillage operations. The above description indicated the total required number of machines for each Woreda. From the bar chart, Munisa Woreda, Zuway Dugda woreda, and Hetosa Wored need more machinery distribution consecutively. On the same side, Lude Hetosa, Dodota, and Sire need medium distribution of machinery compared to the four woredas and Tito woreda needs less machinery distribution compared to the other six woredas. This does not mean all this machinery is covered by Hetosa Union. It is important to utilize the service provider's machines in the woreda. In addition to this by optimizing task scheduling and proper distribution, we can minimize the total number of required machines.

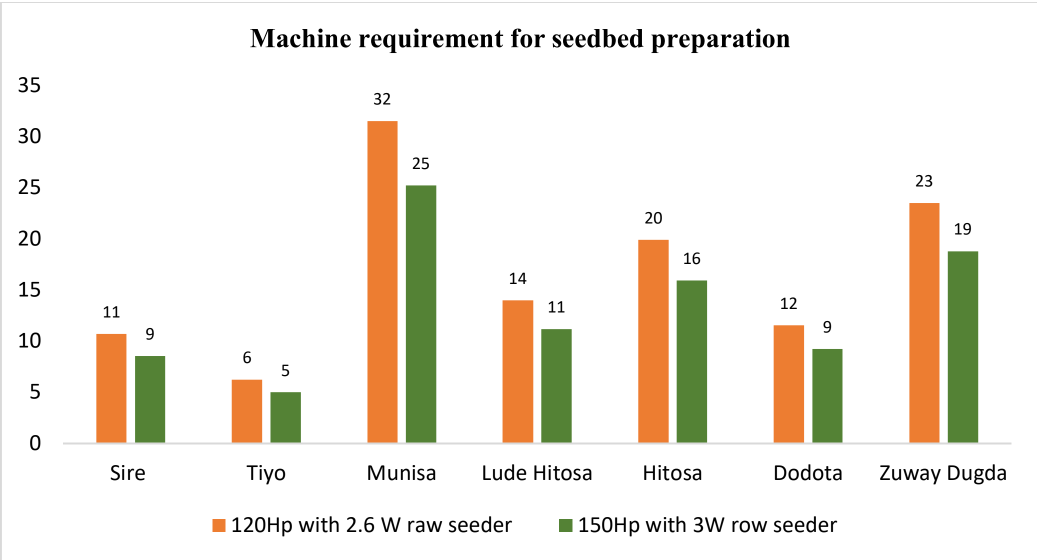


Figure28.Machine requirements for seedbed preparation

From the table, approximately 11 tractors with 130 hp or 9 tractors with 150 hp are needed for the Sire Woreda for seedbed preparation. For Tiyo woreda, approximately 6 tractors, 130 hp, or 4 tractors, 150 hp are required. For Munisa woreda, approximately 31 tractors 130 hp or 26 tractors 150 hp are needed. For Lude Hetosa Woreda, approximately 14 tractors, 130 hp, or 11 tractors, 150 hp are required. For Hetosa woreda, approximately 20 tractors 130 hp or 16 tractors 150 hp are necessary. For Dodota Woreda, approximately 11 tractors 130 hp, or 9 tractors, 150 hp are required. For Zuway Dugda woreda, approximately 23 tractors 130 hp or 19 tractors 150 hp are needed. The total number of tractors covering the area is 117 for 130 hp and 94 for 150 hp for seedbed preparation. From the bar chart, the study considered Munisa, Zuway dugda, Hetosa Woreda have high machinery needs, and the lodeHetosa, Dodota, Sire need the minimum number of machineries, and the remaining six woredas need less machinery compared to the other six woredas.

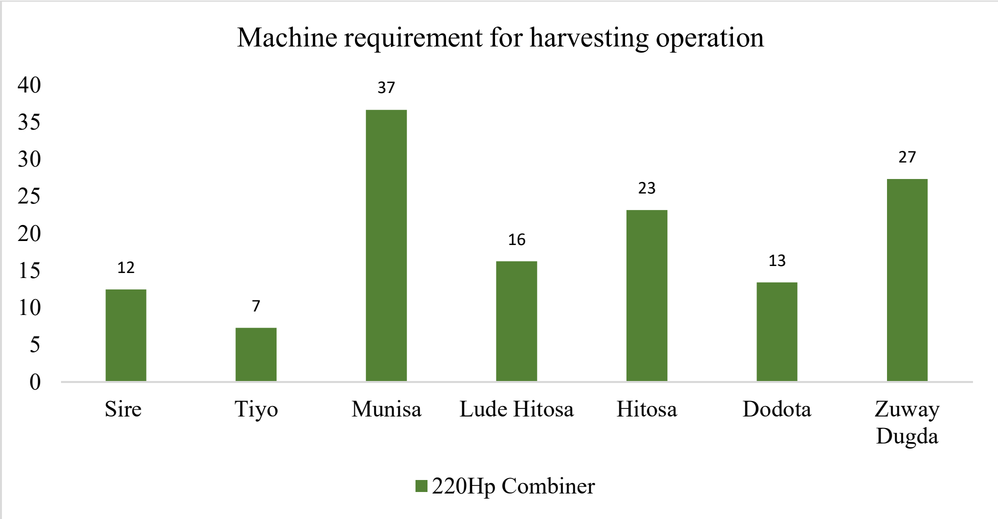


Figure29.Machine requirements for harvesting operation

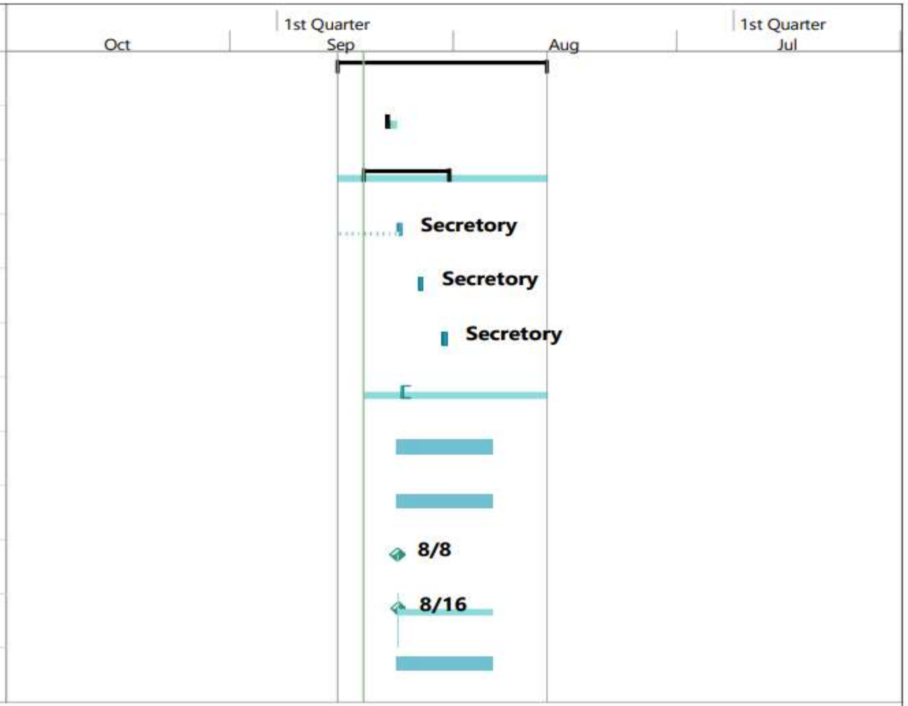
According to the table, approximately 13 combine harvesters and 220 hp are needed for the Sire woreda for harvesting. For Tiyo woreda, approximately 8 combine harvesters, 220hp are needed for Sire woreda for harvesting. For Munisa woreda, approximately 37 combine harvesters 220hp are needed for the sire woreda for harvesting. For Lude Hetosa Woreda, approximately 16 to 13 combine harvesters and 220 hp are needed for Sire Woreda for harvesting. For Hetosa woreda approximately 23.1 13 combine harvesters, 220 hp are needed for Sire woreda for harvesting. For Dodota Woreda approximately 14 13 combine harvesters 220 hp are needed for sire woreda for harvesting. For Zuway Dugda woreda, approximately 27 13 combine harvesters 220 hp are needed for sire woreda for harvesting. The total number of combined harvesters to cover the area is 137 for 220 hp. The same with the above discussion Munisa, Zuway dugda, Hetosa Woreda are high machinery needs, and the lodeHetosa, Dodota, sire need a medium number of machineries, and the remaining six woreda need less machinery compared to the other six woredas.

4.7. Task Schedule for Agricultural Machinery

By combining project management, resource evaluation, and geospatial analysis, this study wanted to improve agricultural operations for the Hetos Farmers' Cooperatives Union. Climate and weather patterns influenced planting and harvesting schedules to reduce the risks of droughts and excessive rainfall, while thorough mapping of cultivable land across different woredas identified appropriate regions for mechanized and labor-intensive farming. Operational bottlenecks were avoided by assessing the labor and farm equipment that were available, and a balanced task distribution among cooperative members was made possible by an analysis of peak seasonal demands. A one-year operating schedule was created using Microsoft Project after crop rotation patterns were modified to increase soil fertility and productivity. This involved encouraging cooperatives to share equipment and allocating workers strategically to prevent overwork during peak times. This involved encouraging cooperatives to share equipment and allocating workers strategically to prevent overwork during peak times. By combining GIS-based land analysis with project management software, idle time was reduced by 30%, weather-related disruptions were reduced through flexible scheduling, and a scalable model for other cooperatives dealing with comparable issues was produced. All things considered, the results show that data-driven agricultural scheduling greatly increases cooperative farming productivity, setting up the Hetos Union for profitability, better resource efficiency, and greater resistance to logistical and climatic difficulties.

Table11.Task scheduling for the agricultural machineries for Hetosa farmars Union

ID		Task Mode	Task Name	Duration
1			Operational Work scheduling	934 days
2			Planing	1.6 days
12			Implementing	319.4 days
13			customer registration 1	9.6 days
14			customer registration 2	9.6 days
15			customer registration 3	9.6 days
16			Repair and maintenance	
17			Daily repair and maintenance	5 days
624			Daily repair and maintenance	5 days
1231			Daily repair and maintenance	5 days
1233			weekly repair and maintenance	64 hrs
1842			Daily repair and maintenance	5 days



Project: scheduling Hitosa
Date: Sun 1/5/25

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

Page 1

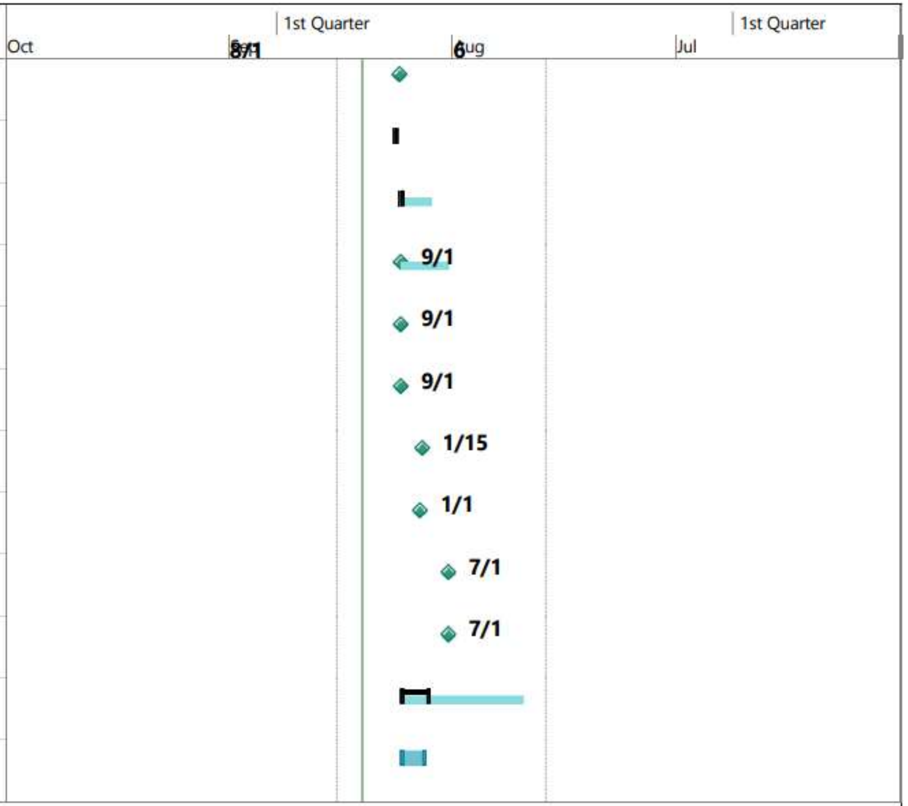
ID		Task Mode	Task Name	Duration	Oct / Sep / 1st Quarter Aug / Jul / 1st Quarter
2449			**Daily repair and maintenance**	**5 days**	
2451			**weekly repair and maintenance**	**64 hrs**	**8/16**
2453			**Daily repair and maintenance**	**5 days**	**9/11**
2455			**weekly repair and maintenance**	**64 hrs**	**8/8**
2457			**Daily repair and maintenance**	**5 days**	**9/11**
2459			**weekly repair and maintenance**	**64 hrs**	**8/16**
3068			**Daily repair and maintenance**	**5 days**	
3675			**Daily repair and maintenance**	**5 days**	**9/11**
3677			**weekly repair and maintenance**	**64 hrs**	**8/16**
4286			**Daily repair and maintenance**	**5 days**	**9/11**
4288			**weekly repair and maintenance**	**64 hrs**	**8/16**
4897			**Daily repair and maintenance**	**5 days**	**9/11**

Project: scheduling Hitosa
Date: Sun 1/5/25

Task, Split, Milestone, Summary, Project Summary, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, External Tasks, External Milestone, Deadline, Progress, Manual Progress

Page 2

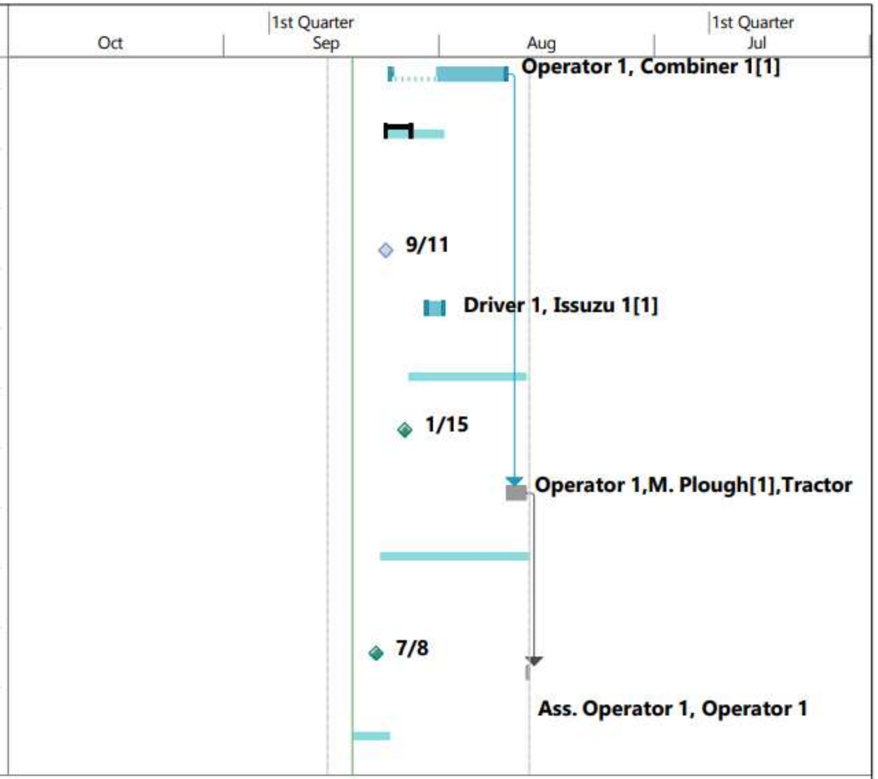
ID		Task Mode	Task Name	Duration
4899			**weekly repair and maintenance**	**64 hrs**
4901			**Monthly repair and maintenance for**	**576 hrs**
4903			**Annually repair and maintenance**	**15 days**
4914			**Seasonal Task**	**6 days**
4915			**Pre-Harvesting season**	**2 days**
4916			Lubricate all moving	2 days
4917			**Pre-Tillage season**	**2 days**
4918			Lubricate all moving	2 days
4919			**Pre-planting season**	**2 days**
4920			Lubricate all moving	2 days
4921			**Harvesting**	**143.9 days**
4922			Fuel	1208 hrs



Project: scheduling Hitosa
Date: Sun 1/5/25

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

ID		Task Mode	Task Name	Duration
4923			harvesting activity	125.1 days
4924			**Transporting**	**142.4 days**
4925			Fuel	1208 hrs
4926			Loading unloading pr	427 hr
4927			Transport and store t	95 days
4928			**Tillage operation**	
4929			Fuel	90hrs
4930			Primary tillage activit	119 day
4931			**Row Seeding operation**	
4932			Fuel	7 days
4933			seedbed preparation	15.5 days
4934			**Seasonal Task**	



Project: scheduling Hitosa
Date: Sun 1/5/25

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

Page 4

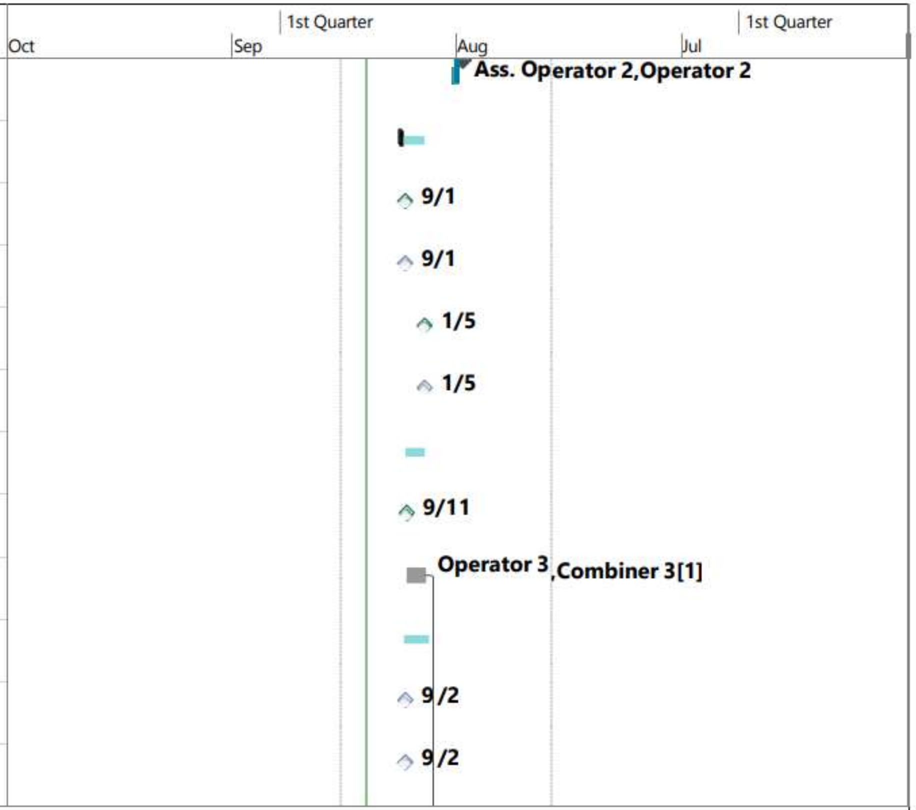
ID	Task Mode	Task Name	Duration	Oct / Sep / 1st Quarter Aug / Jul / 1st Quarter
4941		**Harvesting**		**Operator 2,Combiner 2[1]**
4942		Fuel	1208 days	**9/11**
4943		harvesting activity	97 days	**Operator 2[108%]**
4944		**Transporting**		
4945		Fuel	78hrs	**9/2**
4946		Loading unloading	261 hrs	**9/2**
4947		Transport and store	87 days	**Driver 2,Isuzu 2[1]**
4948		**Tillage operation**		
4949		Fuel	106 hrs	**9/2**
4950		Primary tillage activity	128.45 days	**D. Plough 2[1],Tractor 2[1]**
4951		**Row Seeding operation**	**0 days**	**7/23**
4952		Fuel	10.6 hrs	**7/23**

Project: scheduling Hitosa
Date: Sun 1/5/25

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

Page 5

ID		Task Mode	Task Name	Duration
4953			seedbed preparation	12.8 days
4954			**Seasonal Task**	**4 days**
4955			**Pre-Harvesting season**	**2 days**
4956			Lubricate all moving	2 days
4957			**Pre-Tillage season**	**2 days**
4958			Lubricate all moving	2 days
4959			**Harvesting**	
4960			Fuel	83 hrs
4961			harvesting activity	100 days
4962			**Transporting**	
4963			Fuel	100.6 hrs
4964			Loading unloading	0 hrs



Project: scheduling Hitosa
Date: Sun 1/5/25

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

Page 6

ID		Task Mode	Task Name	Duration	Oct / 1st Quarter Sep / Aug / 1st Quarter Jul
4965			Transport and store	120.8 days	Driver 3,Issuzu 3[1]
4966			**Tillage operation**		
4967			Fuel		
4968			Primary tillage activit	98 days	D. Plough 2[1],Operator 3,Tractor 3[1]
4969			**Seasonal Task**	**4 days**	
4970			**Pre-Harvesting seaso**	**2 days**	8/8
4971			Lubricate all movin	2 days	8/8
4972			**Pre-Tillage season**	**2 day**	8/8
4973			Lubricate all movin	2 days	8/8
4974			**Harvesting**	**120.8 days**	
4975			Fuel	106 hrs	9/11
4976			harvesting activity	120.8 days	Ass. Operator 4,Operator 4

Project: scheduling Hitosa
Date: Sun 1/5/25

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

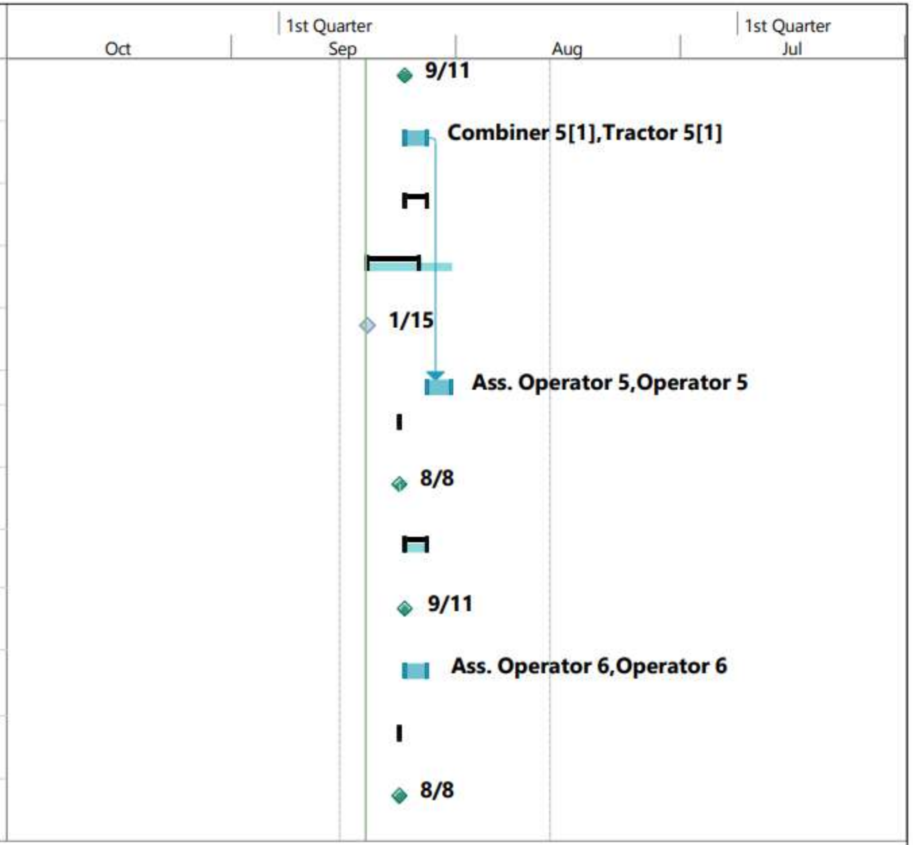
Page 7

ID		Task Mode	Task Name	Duration	Oct / 1st Quarter Sep / Aug / 1st Quarter Jul
4977			**Transporting**	**120.8 days**	
4978			Fuel	79 hrs	9/11
4979			Loading unloading	285 hrs	9/11
4980			Transport and store	95 days	Driver 4,Issuzu 4[1]
4981			**Tillage operation**	**120 hrs**	
4982			Fuel	103 hrs	2/8
4983			Primary tillage activit	124.8 days	D. Plough 3[1],Operator 4,Tractor 4[1]
4984			**Seasonal Task**	**4 days**	
4985			**Pre-Harvesting seaso**	**2 days**	8/8
4986			Lubricate all movin	2 days	8/8
4987			**Pre-Tillage season**	**2 day**	8/8
4989			**Harvesting**	**120.8 days**	

Project: scheduling Hitosa
Date: Sun 1/5/25

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

ID		Task Mode	Task Name	Duration
4990			Fuel	100 hrs
4991			harvesting activity	120.8 days
4992			**Transporting**	**120.8 days**
4996			**Tillage operation**	**1325 hrs**
4997			Fuel	110 hrs
4998			Primary tillage activity	132.5 days
4999			**Seasonal Task**	**2 days**
5000			**Pre-Harvesting seaso**	**2day**
5002			**Harvesting**	**120.8 days**
5003			Fuel	100 hrs
5004			harvesting activity	120.8 days
5005			**Seasonal Task**	**8 hrs**
5006			**Pre-Harvesting season**	**2day**

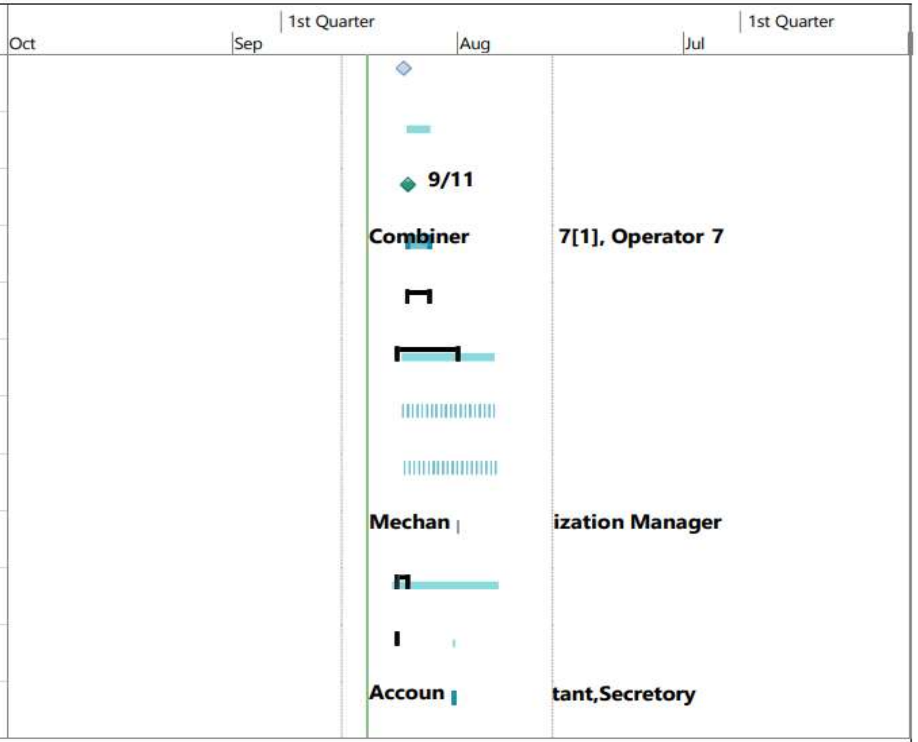


Project: scheduling Hitosa
Date: Sun 1/5/25

Task		Inactive Summary		External Tasks	
Split		Manual Task		External Milestone	
Milestone		Duration-only		Deadline	
Summary		Manual Summary Rollup		Progress	
Project Summary		Manual Summary		Manual Progress	
Inactive Task		Start-only			
Inactive Milestone		Finish-only			

Page 9

ID		Task Mode	Task Name	Duration
5007			Lubricate all moving	2 days
5008			**Harvesting**	
5009			Fuel	100.6 hrs
5010			harvesting activity	120.8 days
5011			**Transporting**	**120.8 days**
5015			**Report Preparetion**	**3155 hrs**
5016			**monthly Financial rep**	**495.5 days**
5037			**monthly technical re**	**12 days**
5058			Annually Reportw	3.2 days
5059			**monitering and evaluation**	**398 hrs**
5235			**clouthing**	**6 hrs**
5236			end of year meating	7 hrs



Project: scheduling Hitosa
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Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
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Summary	Manual Summary Rollup	Progress
Project Summary	Manual Summary	Manual Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

The above diagram indicates that the optimum task scheduling in the Hetosa Farmers Cooperatives union is for daily, monthly, yearly, and seasonal activities. To optimize the schedule, the study employed all resources in the union related to mechanization. And the study breaks down all the union activity by duration and assesses all activity with resources. The total agricultural operational season is considered based on the data collected in the union and from field observation. To utilize the agricultural machinery and agricultural season, the study employed seasonal labor and overtime for a fixed-time employer during the peak time. The above page indicates the work sequences, duration, and the resources utilized in the union, and on the right side, the Gantt chart is described in detail.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study highlights that optimizing machinery utilization requires not only appropriate equipment selection but also a comprehensive understanding of terrain conditions.Full package mechanization economically beneficial in regions of Zuway, Dugda and Dodota, However small scale mechanization-adaption with strategic scheduling is essential in complex areas such as Munisa and Tiyo. Furthermore, incorporating slope data into task scheduling can enhance operational efficiency, improve machinery utilization, reduce downtime, and facilitate better management of maintenance and resources. These findings offer a framework for cooperatives and farmers to enhance agricultural productivity effectively.

To optimize agricultural machinery utilization, the study assessed all agricultural machinery available in the union. By identifying the constraint, the study meets the objective. The primary objective was to optimize the operation cost of the machine in Hetosa farmers' cooperative union. Operation cost includes labor cost, fuel cost, maintenance cost, and lubrication cost. To optimize the operation cost the study considered these variables. By optimizing the distance and the time, the study optimized the total fuel cost and unproductive labor cost. To utilize this, the study uses both network analysis and tabu search algorithm. By identifying the shortest route between woreda, the study analyzes the shortest path and route. The result indicated that the total reduction of fuel consumption is 11.28%, which implies a great reduction in the operational cost of the Union. And from Hetosa woreda the results indicated a reduction in fuel consumption of up to 23.34 percent, which implies a great reduction in operational cost of the union. By reducing the distance not only fuel consumption but also the study reduced uneconomic working time.

From the overall assessment and the results of fixed cost and variable cost, some machinery has high fuel consumption, frequent downtime, and elevated maintenance costs, which significantly increase operational expenses. Additionally, the aging machinery, such as the two tractors, and three combine harvesters cannot be equipped with GPS technology due to incompatibility with their older features. This affects operational cost management and overall utilization.

Operational inefficiencies, like using large machinery with small implements and facing resource limitations for power-intensive operations, indicate the need for an optimized machinery selection process.

In addition, the study analyzed significant economic travel time and labor costs associated with refueling tractors and combine harvesters. The total annual unproductive labor cost from five tractors and seven combine harvesters the union loss 123,852 birr. This loss comes from uneconomic work, 625 hours of total tractors and 875 hours of total combine harvesters. To convert this time into operational work the time used for 1,062.5 hectares for tillage and 1,487.5 hectares for harvesting. Because of this, the Hetosa farmers' cooperative union incurs economic losses of 3,329,025 birr for tractor tillage operations and 2,156,000 birr for combine harvesting. To enhance operational efficiency, it is recommended that Hetosa Union consider the establishment of a fuel storage facility within the union compound. This strategic move would minimize the time required to refuel machinery, thereby maximizing overall operational time.

To find the machinery and equipment required per hectare for Hetosa farmers' cooperative union members, the research utilized land use land cover of the 7 East Arsi woreda from the Ministry of Agriculture data. By extracting the cultivated land from the total land cover the study identified the total cultivated land in the seven woredas. From the field observation, the research identified the total operational time per hectare for each operation. By calculating each operation by using the available tractor, implement, and combiner. The research was conducted with the machinery required per woreda. The woredas included Zuway Dugda, Dodota, Hetosa, Lude Hetosa, Munisa, Tiyo, and Sire. and it covered 67657.65, 33183.48, 57296.8373 40255.61, 90780.38, 17984.23 and 30764.964 hectares of cultivated land continuously. The total sum of cultivated land equals 337923.2 ha. By calculating this, the research conducted the total number of tractors for each woreda.

The last objective was to optimize the task schedule in Hetosa Farmers Cooperatives union. The study utilized daily, monthly, yearly, and seasonal activity. To optimize the schedule, the study employed all resources in the union related to mechanization. And the study brake down all the union activity with duration and assented all activity with resources. The resource included human resources, material resources, and financial resources. By prioritizing a task, the MS project gives the optimum task schedule. The total agricultural operational season is considered as per the data collected in the union and from the field observation. To utilize the agricultural machinery and agricultural season, the study employed seasonal labor and overtime for fixed-time employers during the peak time.

5.2. Recommendation

This study identified various issues with agricultural machinery utilization. Currently Hetosa Farmers' Cooperative Union faced the challenge indicated the need for targeted interventions to optimize machinery utilization. From the finding the study mentioned on the bellow recommendation :

- A shortage of machinery eliminated the productivity of the union. It is important to invest the machine to fill the demands needs and to get efficient service. Further, fragmented land plots create unique operational challenges. So the government should demonstrate and encourage cluster farming to utilize machinery effectively.
- Due to the Age, the union needs to replace old machinery with new machinery. The current machinery states included high fuel consumption, frequent downtime, and increased maintenance costs, which significantly increase operational expenses.
- The low practice of a modern task scheduling method in Agricultural industry limits the union's ability to allocate resources efficiently, emphasizing the potential benefits of digital integration to streamline operations. Both the government and other stakeholders should focus on developing proper task scheduling software and practicing digitalization and collaborate on implementing a machinery management system.
- The study recommended that Hetosa Union consider the establishment of a fuel storage facility within the union compound. This strategic move would minimize the time required to refuel machinery, thereby maximizing overall operational time.
- Unscheduled delivery of fertilizers and seeds affects farming operation task allocation. This highlighting the importance of strengthening supply chain collaborations with government entities.
- To Incraes the utilization of machinery in Hetosa Farmers Cooperatives union, it is important that, to assess the available equipment across the seven woredas. And Collaboration with service providers may facilitate optimal machine usage and

ensure access to a diverse and profitable array of machinery types. This strategic partnership will enable the achievement of operational objectives and promote efficient resource management in the region.

- Agricultural planners and farm machinery scheduler, it is important to utilize GIS-based topography analysis to enhance machinery performance, promote sustainable land use, reduce erosion, and improve productivity in the East Arsi Zone. This integration is crucial for effective mechanization across diverse topography.

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Appendix 1: MATLAB code for tabu search algorithm implementation

```
%% Define locations (including depot): [location_id, x_coordinate, y_coordinate, area]
locations = [1, 0, 0, 0;   % Depot (Hetosa) with no area
             2, 4.22, -0.82,   19.347;       % Field Boru Lencha
             3, -8.254, 0.867,  19.55;       % Field Dawe Teticaha
             4, -4.4, -7.62,   18.902;       % Field Gonde Fenchama
             5, 2.809, 1.31,   21.828;       % Field Guche Habe
             6, 0.118, 3.398,  17.709;       % Field Hate Andode
             7, 1.129, -6.401, 11.682;       % Field Oda Jela
             8, 5.825, -4.232, 21.798;       % Field 8 with area Sero Anseto
             9, -2.852, -4.228, 17.776;   % Field 9 with area Shaki Sherar
             10, -5.435, -2.77, 19.75];      % Field 10 with area Tede Leman
%% Parameters
num_locations = size(locations, 1);
max_iter = 1000;          % Maximum number of iterations
tabu_size = 20;           % Size of the tabu list
ploughing_rate = 1;       % Ploughing rate (time per unit area)
%% Calculate distance matrix
distances = zeros(num_locations, num_locations);
for i = 1:num_locations
    for j = 1:num_locations
        distances(i, j) = sqrt((locations(i, 2) - locations(j, 2))^2 + (locations(i, 3) - locations(j, 3))^2);
    end
end
%% Calculate ploughing time
ploughing_times = locations(:, 4) * ploughing_rate; % Time required for each field
%% Run Tabu Search
best_path = tabu_search_vrp(distances, ploughing_times, max_iter, tabu_size);
% Display the best path
disp('Best Path:');
disp(best_path);
disp('Total Distance:');
disp(calc_total_distance(best_path, distances));
%% Supporting functions
function best_path = tabu_search_vrp(distances, ploughing_times, max_iter, tabu_size)
    num_locations = size(distances, 1);
    initial_path = [1, randperm(num_locations-1) + 1, 1]; % Initial path starting and ending at the depot
    best_path = initial_path;
    best_cost = calc_total_distance(best_path, distances);
    current_path = initial_path;
    tabu_list = zeros(tabu_size, num_locations+1);
    for iter = 1:max_iter
        neighborhood = generate_neighborhood(current_path);
        best_candidate = [];
        best_candidate_cost = inf;
        for i = 1:size(neighborhood, 1)
            candidate = neighborhood(i, :);
```

```
            candidate_cost = calc_total_distance(candidate, distances);
            if candidate_cost < best_candidate_cost && ~is_in_tabu_list(candidate, tabu_list)
                best_candidate = candidate;
                best_candidate_cost = candidate_cost;
            end
        end
        current_path = best_candidate;
        tabu_list = update_tabu_list(tabu_list, best_candidate, tabu_size);
        if best_candidate_cost < best_cost
            best_path = best_candidate;
            best_cost = best_candidate_cost;
        end
        % Display progress
        fprintf('Iteration %d: Best Cost = %.4f\n', iter, best_cost);
    end
end
function neighborhood = generate_neighborhood(path)
    num_locations = length(path) - 1; % Exclude the last element (return to depot)
    neighborhood = [];

    for i = 2:num_locations-1 % Exclude the depot (first and last location)
        for j = i+1:num_locations
            neighbor = path;
            neighbor([i, j]) = neighbor([j, i]); % Swap two locations
            neighborhood = [neighborhood; neighbor];
        end
    end
end
function total_distance = calc_total_distance(path, distances)
    total_distance = 0;
    num_locations = length(path)
    for i = 1:num_locations-1
        total_distance = total_distance + distances(path(i), path(i+1));
    end
end
function in_tabu = is_in_tabu_list(path, tabu_list)
    in_tabu = false;
    for i = 1:size(tabu_list, 1)
        if isequal(path, tabu_list(i, :))
            in_tabu = true;
            break;
        end
    end
end
function tabu_list = update_tabu_list(tabu_list, path, tabu_size)
    if size(tabu_list, 1) >= tabu_size
        tabu_list = tabu_list(2:end, :); % Remove the oldest entry if tabu list is full
    end
    tabu_list = [tabu_list; path]; % Append new path
end
```

Appendix 2: Questionnaires

Adama Science and Technology University

School of Mechanical, Chemical and Materials Engineering

Dear Respondent, you are kindly requested to participate in a research study to partially fulfill my master's degree in Agricultural Machinery Engineering. The study aims to optimize Agricultural Machinery Utilization in the Hetosa Farmers' Cooperative Union, Oromia Region. This questionnaire is prepared to gather Agricultural Machinery Engineering's perception regarding this relationship, and your genuine response is invaluable for the research's success. Your sincere response is crucial for the research outcome since this questionnaire is designed to learn about the Agricultural Machinery Engineering of this relationship. I respectfully request that you read the following instructions carefully before answering each of the questions stated below. Please note that all your responses will be kept completely confidential and only used for this study.

Do not provide your name or any other personal information on the questionnaire. For any clarification needed, please contact me at:

Thank you in advance for your time.

Part .1: Questionnaires for the Mechanization Department head, operators, and supervisor.

1. Date of interview______________________
2. Sex: ________________________________
3. Position: ____
4. Business name: ____________________________________
5. Location (where registered): Region______________ Zone______________ Woreda__________
6. Business ownership type: Cooperative Union
7. How long since you have been engaged in agricultural machinery service? __________________Years
8. Which agricultural machinery service do you provide currently? (multiple answers possible)

1) Land Preparation 2) Harrowing 3) Row planting 4) Fertilizer application 5) Chemical sprayer 6) Harvesting and Threshing 7) Transportation

9. How long do you travel from your base area to provide service?
10. Where do you get your machine serviced/maintained?
    a) location
    b) How long do you travel looking for maintenance access (specify one-way distance in KM)
    c) What sort of support can be received from local Agriculture/Government officials?
    d) What is impeding you from expediting your service and reaching more farmers/serving more land?
11. Is there any payment request in the woreda? How does this affect your service provision business?
12. Who is your main customer? (Rank it - to know the majority of users)
    a) large farms (Commercial farms) (>10 ha)
    b) medium farms (2-10 ha)
    c) semi-medium farms (1-2 ha)
    d) small farms (less than 1 ha)
    e) subsistence farms (<0.5ha)
13. Please list the woredas where you provided the service last production year (estimate # days).

Type of Machinery service	**Within Zone**	
	List of woredas	**Number of days worked Last season**
12.1 Land preparation (Primary tillage and harrow)		
12.2 Harvesting and Threshing		

14. Please indicate the number of employees hired by your organisation about machinery service.

Type of employment and qualification/level of study	**Sex**		**Position**			
	Male	**Female**	**Operators**	**Assistant operator**	**Time keeper /cashier**	**Technician/ Mechanic**
A) Casual/temporary labor						
B) Permanent (hired for more than a year)						
1)Less than 10th grade						
2)11-12 grade						
3)Vocational education and training						
4)BSc degree and above						
5) Others specify						

15. Please provide us details of the machinery you own currently

Type of Implements and Equipment	**Qty**	**Status (mark as✔)**		**Reason for nonfunctioning**
		Functional	**Nonfunctional**	
Disc Plough				
Disc harrow				
Mould Board				
Planter/seeder				
Sprayer				

Sheller				
Threshers				
Add, if any other				

Type of machine	**Number**	**Engine capacity in Horsepower (Hp)**	**Brand**	**Year purchased**
Tractor				
Tractor (1)				
Tractor (2)				
Tractor (3)				
Tractor (4)				
Combine harvester				
Combiner (1)				
Combiner (2)				
Combiner (3)				
Combiner (4)				
Implements	Number	Specification (size, capacity...)	Brand *	Year purchased
Mould board plough				
Disc plough				
Disc Harrow				
Chisel plough				
seed planter				
Fertilizer /manure spreader				
Chemical sprayer				
Bailer				
Others specify				

*1) Johndeere 2) Claas 3) New Holland 4) YTO 5) Mhandra 6) Belarus 7) Massey Ferguson 8) DEUTZ 8. CASE 9) Others specify; **=1) China 2) Italy 3) Brazil 4) Germany 5) India 6) Netherlands 7) USA 8. Ethiopia 9) Others specify.

16. Where do you undertake repair and maintenance services for your machinery?
   e) location
   f) How long have you traveled looking for maintenance access (specify one-way distance in KM)

Type of machine and parts	Minor repair*	Major repair*	Where you got Spare part? 1= from dealers 2=overseas/OEM 3=local spare parts shops
A. Tractor			
Injection pump			
Electric system			
Implements(ploughs)			
Regular service (oil filter, fuel filter change)			
B. Combine harvester			
Cutter bar			
Replacement of the chain Belts bearing, sealing)			
Electric system			
Regular service (oil filter change)			

*1) Take to Dealers workshop 2) at own workshop 3) outsource to private Garage.

17. Please indicate the price you charged for the following service over the last consecutives five years in your area/zone.

Name of Wored a	**Ploughing (Birr/ha)**		**Harrow (Birr/ha)**		**Row planting (Birr/ha)**		**Chemical spray (Birr/ha)**		**Balling, birr per bale**		**Other service, if any**	
	low	High	low	High	low	hig h	low	hig h	Lo w	hig h	low	hig h

18. Please provide the reason for the price variation for the same type of service in the same area in the same season.____

19. Please indicate the lowest and highest prices you charged for harvesting and threshing last production season in your area.

Name of Woreda	**Harvesting and threshing (Birr/qt)**		**Grain Transportation from farm to home (Birr/qt)**	
	low	High	low	High

20. In your last season's services, how much land size do you cover in cluster areas (FPCs)?

21. On an average day, how many hectares do you serve?

    a) Ploughing

        i. primary ploughing (ha/day) ------------------

        ii. secondary ploughing (ha/day) -------------------

    b) Harvesting (ha/day or (Qtal/day) --------------------

    c) planting (ha/day) ------------------------------

    d) spraying (ha/day) ----------------------------

22. How long in the year is your machine remuneration (months or days/year (approximately)

a) 1-2 months

b) 2-3months

c) 4-6 months

d) >6months

e) full year

23. Existence of Support services

24. Finance access

25. Access to spare parts
26. Access to R&M
27. What would you like to do to improve service delivery to your customers/farmers?

    ____

28. What do your customers/farmers complain about your service, what do they ask for?____
29. Are there critical skills you/your staff lack in providing agricultural machinery service to farmers efficiently and effectively? 1. Yes 2. No
30. If Yes, List?____
31. Looking into your business, which organizational and operational areas need to improve in your opinion? (Business management, financial management, marketing, record keeping) And why? ______________________________
32. What constraints did you face in providing agricultural machinery service to smallholder farmers? (Rank in order of priority)

Constraint	**Rank in order of priority (1= the most important/severe constraint; 8=least)**
1)Lack of knowledge and skill on how to operate the machinery, repair, and maintain the machine	
2)Lack of Repair and Maintenance services in area of operation	
3)High cost of repair and maintenance	
4)Lack of spare parts	
5)High purchase price of agricultural machinery	
6)Lack of access to finance	
7)Limited financial management capacity	
8) high sale tax, income tax	
9)scarcity of hard currency to import machine/spare parts	

33. What policies or regulations/strategies would you suggest to improve agricultural machinery service in Ethiopia? ____

30. Does the department have a well-defined and documented policy on machinery usage?

31. Does the department maintain a record of machinery costs along with its useful life?

32. Do you believe that GPS technology is important for machinery utilization? If so, how? Is your machinery equipped with GPS technology? If yes, for what purposes do you use it, and if not, why is that?

33. For which types of agricultural operations do most farmers require mechanization services, and what are the underlying reasons for this demand?

34. Does the Woreda farm plots' soil condition impact the machinery's capacity? If so, which specific machinery is most adversely affected?

35. Which agricultural operations are critical concerning the timely utilization of machinery?

A. Primary Tillage B. Secondary Tillage C. Planter D. Harvester E. Chemical Application

36. Which types of agricultural operations are characterized by higher power consumption?

A. Primary Tillage B. Secondary Tillage C. Planter D. Harvester E. Chemical Application

37. Do you record all service and maintenance costs associated with the machinery?

38. Based on your service cost records, is there a necessity to replace certain farm machinery?

39. Does the department possess guidelines for the optimization of farm machinery selection?

40. Does the department recognize the benefits of optimized machinery selection?

41. Is the department utilizing effective task scheduling methodologies for the distribution of tasks?

42. What constraints inhibit the effective implementation of task scheduling?

43. Is there a belief that the available machinery within the Hetosa Farmers' Cooperative Union adequately meets the needs of the farmers?

Part.2: Structured Interview for Crop Department

Date: __________

Sex: __________

Age: __________

Department: _________________

Job Title: ___________________

Work Experience: ___________

Qualification: _____________________

1. What type of crops do farmers cultivate in the Hetosa union members' woreda?
2. When do farmers plant each crop type, and what factors determine the planting period?
3. Where and how do farmers obtain specific seeds for each type of crop they plant?
4. What is the seed application rate per hectare for each crop type?
5. Where and how do farmers access specific fertilizers (such as DAP, urea, etc.) for the crops they plant?
6. Where and how do farmers access specific herbicides, pesticides, or insecticides for the crops they plant?
7. When and how do farmers apply each of the above inputs? Do farmers receive support from extension agents regarding the timing and method of application?
8. Do you know soil structure, strength, compaction, and moisture content? If not, why?
9. Have the soils in the woreda been assessed or mapped? If yes, by whom? If not, why not?

Part.3: Structured Interview for Developmental Agent and Extension Worker

Date: __________

Sex: __________

Age: __________

Department: ___________________________________

Job Title: ___________________

Work Experience: ___________

Qualification: _____________________

1. Which type of crop yield do farmers require most?

2. What method do farmers use to allocate land for each type of crop?

3. What is your opinion on different crop production? Is it a risk or an advantage?

4. Do farmers face budget constraints in crop production, particularly when purchasing fertilizers, seeds, herbicides, and other farming inputs?

5. Does the Developmental Agent (DA) have insights on optimizing cropland allocation?

6. Does the DA believe that optimizing cropland allocation is beneficial?

Part.4. Structured Interview for Finance Staff

Date________Sex________Age___Department________Jobtitle_____Workexperience____ Qualification_________________

1. What has been the price of primary tillage services provided by the Hetosa Farmers' Cooperative Union over the last five years?

2. What has been the price of secondary tillage services offered by the Hetosa Farmers' Cooperative Union over the past five years?

3. What has been the price of row seeding/planting services delivered by the Hetosa Farmers' Cooperative Union in the last five years?

4. What has the price of harvesting services provided by the Hetosa Farmers' Cooperative Union been over the last five years?

5. What have the wage costs related to agricultural machinery over the past five years?

Appendix 3: Observation checklist

1. Woreda: ---
2. Kebele: ---
3. Date of data collection ---------------------------------
4. Machinery brand and year of manufacturing ---
5. Model ---------------------------------
6. Crop Type …………….
7. Farmers land size (ha)
8. How much do you charge for your services? -------------------/birr/ha
9. Operator's name and experience
10. Total operating hours
11. Total Idle Time

Observation check list Table for Combiner

Farmers	**Travel from your base area to Fuel station**		**Fuel station**	**Travel from Fuel station to farmland**		**Harvesting time**		**Idle time**		**Travel from farmland to farmland**		**Travel from farmland to base area**
	Start time	End time		Start time	End time	Start time	End time	Star t time	End time	Star t time	End time	
Farmer 1												
Combiner speed												
Farmer 2												
Combiner speed												
Farmer 3												
Combiner speed												

Observation check list Table for Tractor

Farmers	**Travel from base area to Fuel station**		**Fuel station**	**Travel from Fuel station to farmland**		**Tillage time**		**Idle time**		**Travel from farmland to farmland**		**Travel from farmland to base area**
	Start time	End time		Star t time	End time	Star t time	End time	Star t time	End time	Star t time	End time	
Farmer 1												
Tractor speed												
Farmer 2												
Tractor speed												
Farmer 3												
Tractor speed												

Appendix 4. Dominant soil Type and category and Land Use Land Cover in the seven Woredas(Km2)

Soil Type	Soil Category	Dodota	hetosa	lude hetosa	Sire	Munisa	Tiyo	Ziway Dugda
Mollic Andosols	Loamy	2044.423	2044.423	318.353	0	1726.07	1726.07	1726.07
Lithic Leptosols	Sandy/Rocky	1563.169	1349.522	1112.544	1419.07	161.635	0	213.393
Vertic Cambisols	Clay	279.615	279.615	579.721	0	0	279.615	279.615
Eutric Vertisols	Clay		1039.949	3871.929	3915.34	2744.674	2018.359	2018.359
Haplic Luvisols	Loamy		993.595	893.581	416.905	281.914	993.595	0
Chromic Luvisols	Loamy		880.959	980.969		314.549	880.959	0
Eutric Leptosols	Sandy/Loamy					0		0
Humic Nitosols	Loamy-Clay					464.857		0
Vitric Andosols	Loamy							0
Eutric Cambisols	Loamy							164.364
Luvic Phaeozems	Loamy							858.51
Eutric fluvisols	Sandy-Loamy							94.9

Appendix 5. Crop Types and Agricultural Operation Season in The Hetosa Members Woreda

Table10.Crop season in Hetosa Farmers' cooperatives union Members woredas

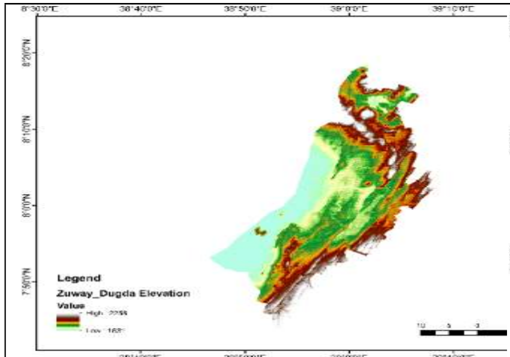
Crop Type	Primary Tillage	Secondary Tillage	Seedbed Preparation	Harvesting
Maize	Feb –Apr	Feb –Apr	Half March -Half Apr	Sep12-Nov15
Wheat	Apr-July	Apr-July	Half June – Half July	Oct22--Feb22
Barley	Apr-July	Apr-July	Aug First -Aug End	Nov 8-Feb 23
Sorghum	Apr-July	Apr-July	July First-July End	Oct22-Des8
Teff	Apr-July	Apr-July		
Maize	Feb –Apr	Feb –Apr	Half March -Half Apr	Sep12-Nov15

LCCCode	Land use Land cover Description	Area_km2						
		Zuway Dugda	Dodota	Hetosa	Lude Hetosa	Munisa	Tiyo	Sire
7	Natural And Semi-Natural Aquatic or Regularly Flooded Vegetation	-	5.947413	-	-	-	-	-
11	Bare Area(s)	3.008281	9.611293	1.015648	0.67688	0.376508	0.940086	1.107645
11498	Rainfed Herbaceous Crop(s)	58.74099	26.299985	136.740975	38.270382	258.426741	76.342161	14.594866
21450	Closed to Open Shrubland (Thicket)	150.865546	48.524209	28.331353	41.368171	56.885083	37.655762	43.467449
0003 / 0004	Cultivated and Managed Terrestrial Area(s) / Natural And Semi-Natural Primarily Terrestrial Vegetation	89.677288	111.234597	52.804075	259.925446	356.910734	36.54601	145.19316
0004 // 0003	Natural And Semi-Natural Primarily Terrestrial Vegetation / Cultivated and Managed Terrestrial Area(s)	526.197659	185.512364	220.038732	102.697692	269.855909	27.634083	145.28386
20049 // 20058	Sparse Woody Vegetation /Herbaceous Sparse Vegetation	0.924614	58.97913	145.43067	1.662573	-	0.188084	0.823765
20132-3012	Broadleaved Deciduous (40 - (20-10)%) Woodland	8.135456	3.790866	1.463326	18.849678	42.423396	15.422645	1.311809
21446 // 21450-	Closed to Open Trees / Closed to Open (100-40)% Shrubland (Thicket) / Herbaceous Closed to Open Vegetation	118.715516	55.229663	20.94463	59.22822	16.192834	39.131951	174.12735

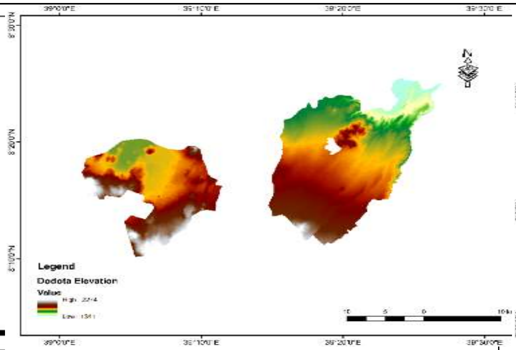
121340 / 21454								
21454 // 21446 // 21450	Sparse Woody Vegetation // Herbaceous Sparse Vegetation	0.522863	2.182914	17.953921	-	22.610391	-	**0.15**
21454 // 21465	Herbaceous Closed to Open Vegetation / Closed to Open Lichens/Mosses	-	0.657506	-	-	-	-	1.606827
7001 // 8001	Artificial Waterbodies / Natural Waterbodies	128.686832	11.196799	-	-	-	-	-
21496 // 21497-15048	Broadleaved Evergreen Closed to Open Trees / Semi-Deciduous Closed to Open Trees	-	-	-	17.717088	58.787676	6.521585	0.513543
Farm plot		**676.5765**	**331.8348**	**572.968373**	**402.5561**	**907.8038**	**179.8423**	**307.64964**
Total		**1087.654864**	**519.166739**	**624.72333**	**540.39613**	**1082.469272**	**240.382367**	**528.17744**

Appendixes 6. Topographical Analysis of the Hetosa Framers Cooperatives Union Members Woredas

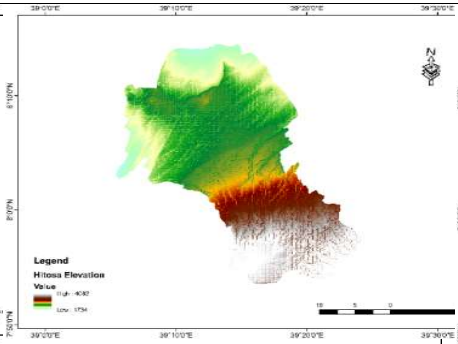
A. Elevation



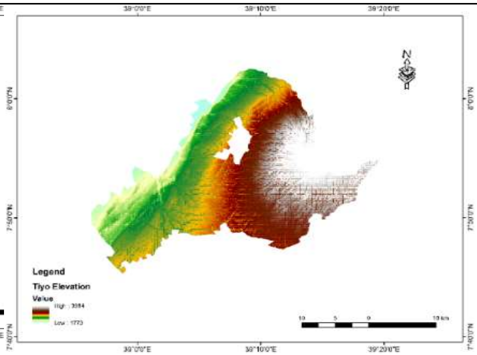
a) Zuway Dugda Elevation



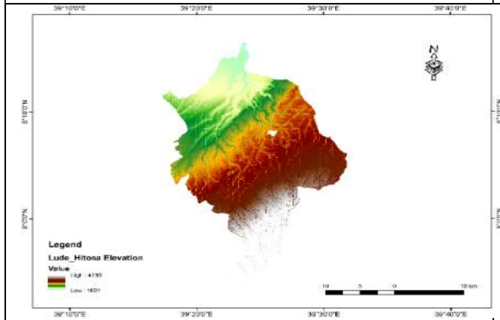
b) Dodota Elevation



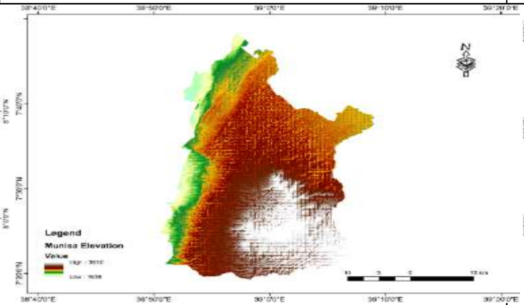
c) Hetosa Elevation



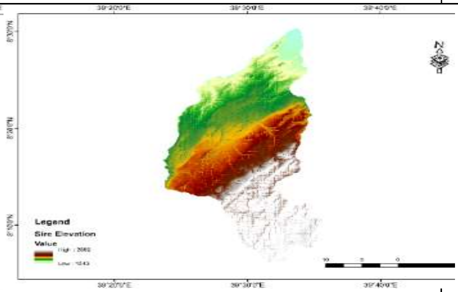
d) Tiyo Elevation



e) Lude Hetosa Elevation

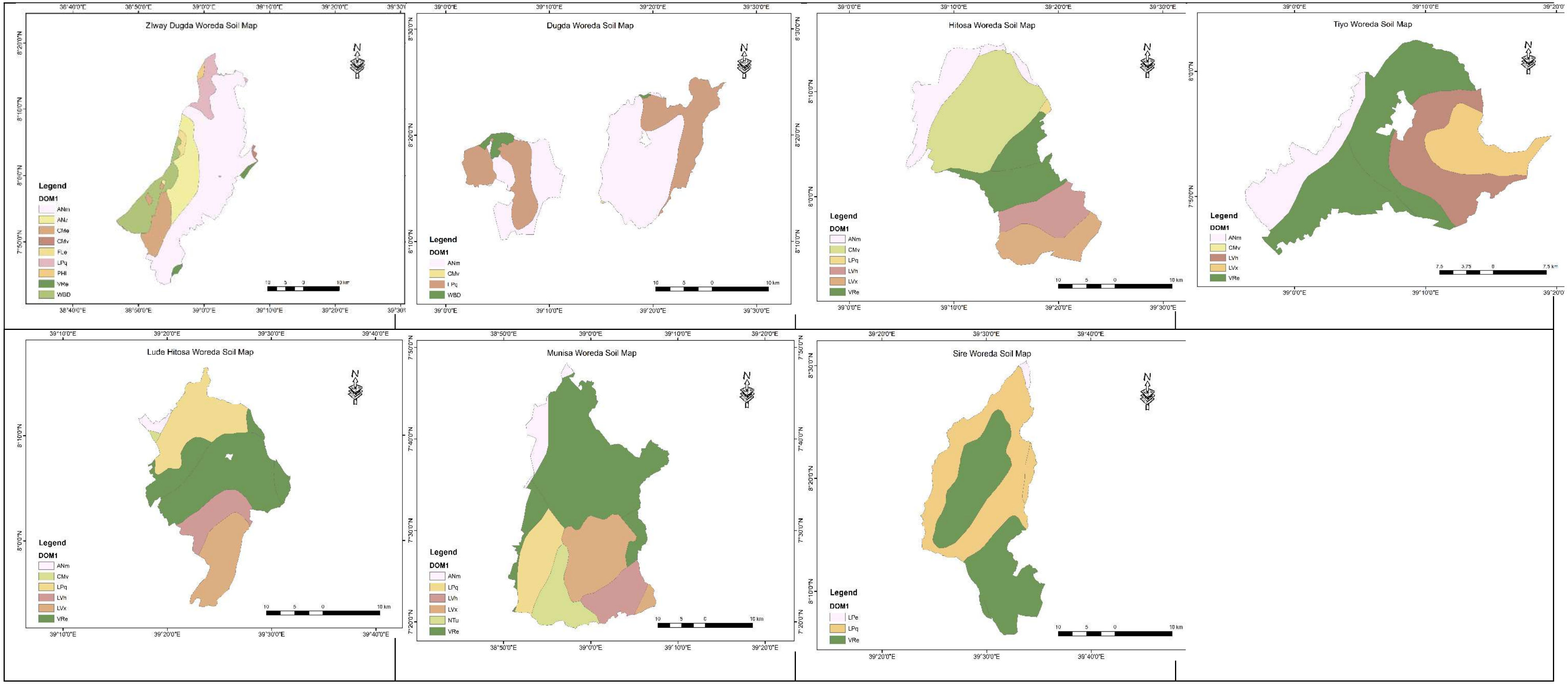


f) Munisa Elevation

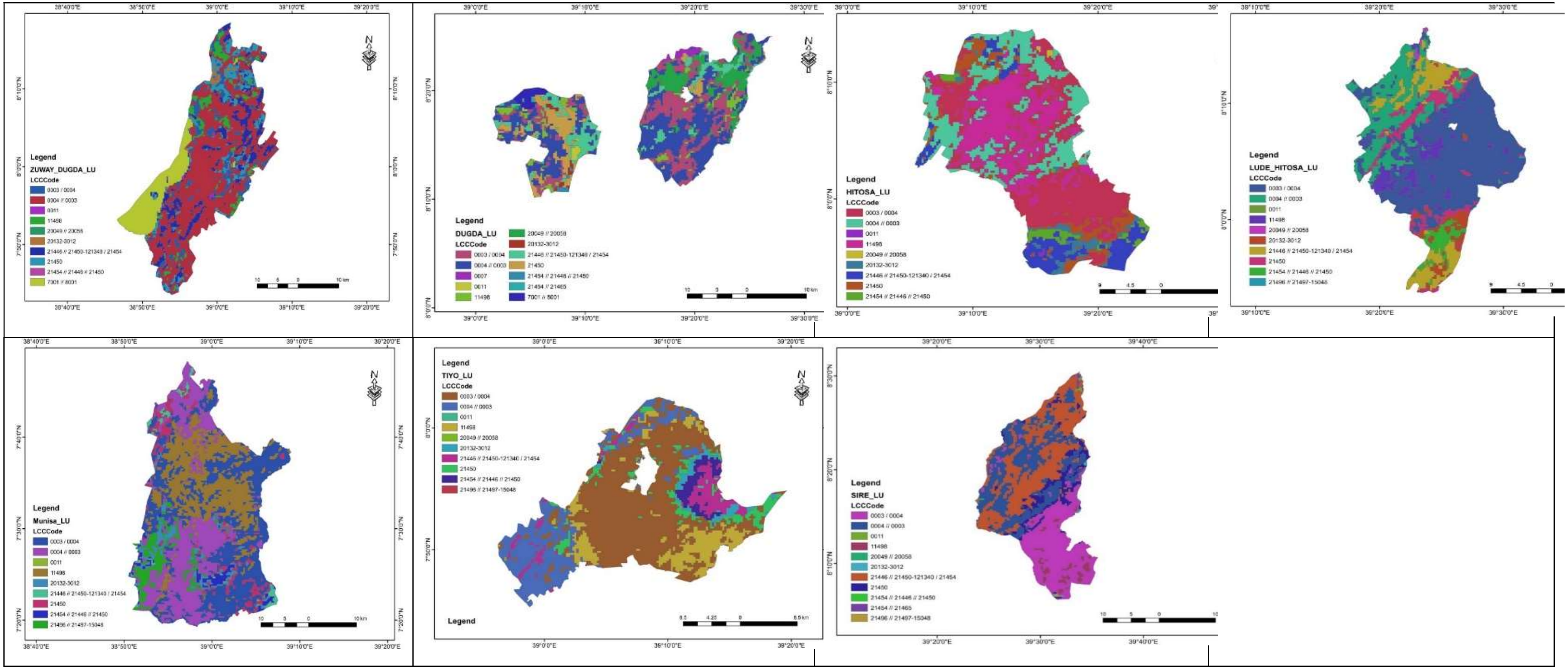


g) Sire Elevation

B. Soil Type


Zlway Dugda Woreda Soil Map
Legend
DOM1
ANm
ANz
CMe
CMv
FLe
LPq
PHI
VRe
WBD
Dugda Woreda Soil Map
Legend
DOM1
ANm
CMv
LPq
WBD
Hitosa Woreda Soil Map
Legend
DOM1
ANm
CMv
LPq
LVh
LVx
VRe
Tiyo Woreda Soil Map
Legend
DOM1
ANm
CMv
LVh
LVx
VRe
Lude Hitosa Woreda Soil Map
Legend
DOM1
ANm
CMv
LPq
LVh
LVx
VRe
Munisa Woreda Soil Map
Legend
DOM1
ANm
LPq
LVh
LVx
NTu
VRe
Sire Woreda Soil Map
Legend
DOM1
LPe
LPq
VRe

Land use Land cover Description



Appendixes 7. Calculated tractor variable cost

Calculated tractor variable cost per year in Ethiopia Birr

Tractor number	Machinery Age (year)	Year	Fuel/lt	fuel cost	Lubrication cost	R & M	Labor	operation cost
77	12	2012	19.1	2644.474	793.3422	26818.01	70650	100924.9282
		2013	21.8	12897	3869.1	281207.79	105300	223295.69
		2014	37.5	90532.61	27159.78	174099.9	111000	402829.7977
		2015	56.7	44000	13200	275000	106800	349156.6
		2016	82.5	251333.5	75400.04	450000	124577	901392.985
1524	6	2012	19.1	7007.856	2102.357	32181.61	69750	111060.9273
		2013	21.8	42321	12696.3	65432.2	99450	219921.3
		2014	37.5	176575	52972.5	461364.7	145500	836449.735
		2015	56,7	108470	32541	109372.5	147750	398133.45
		2016	79.1	523075.6	156922.7	461364.7	177024	1318466.128
76	12	2012	19.1	3173.369	952.0106	71067.73	93150	168362.2112
		2013	21.8	1500	450	294073.4	130050	426095.24
		2014	37.5	83568.57	25070.57	208919.9	119250	436846.5163
		2015	56.7	40000	12000	208919.9	120000	380976.58
		2016	79.1	271333.5	81400.04	445755.99	154576	953144.575

64	10	2012	19.1	2327.137	698.1411	123599.85	75150	201794.2288
		2013	21.8	53626	16087.8	162216.2	110700	342651.8234
		2014	37.5	171489.3	51446.8	73398.28	122250	418621.9278
		2015	56.7	35000	10500	353207.9	119250	618014.612
		2016	79.1	203103.4	60931.01	106631.7	147064	517809.168
63	10	2012	19.1	2565.14	769.5419	26013.47	74250	103617.2534
		2013	21.8	27051	8115.3	221203.9	105750	362142.041
		2014	37.5	205787.2	61736.16	80904.93	114750	463215.7993
		2015	56.7	28583	8574.9	168876.9	110250	316341.503
		2016	79.1	240125.3	72037.6	1996.145	121563	435801.1869
824	10	2012	19.1	4231.158	1269.348	42908.82	75600	124028.4251
		2013	21.8	42897	12869.1	147469.3	107100	310357.194
		2014	37.5	194354.6	58306.38	80904.93	116250	449853.3897
		2015	56.7	39500	11850	278559.8	108750	438716.54
		2016	79.1	166125.2	49837.56	71677.481	131324	425043.3405
823	10	2012	19.1	4495.606	1348.682	45590.62	70200	121654.0079
		2013	21.8	33311	9993.3	169589.7	105300	318215.7881
		2014	37.5	49921	14976.3	141792.1	113250	319976.938
		2015	56.7	45100	13530	295969.8	112500	467156.53
		2016	79.1	209224.6	62767.39	331989.5	143323	347383.6082