

Assessment of the Effect of Agricultural Machinery Trafficking on Soil
Compaction: A Case Study of Tamela Farm Site, Oromia Seed Enterprise



Abera Feyisa Bayisa

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

Presented in Partial Fulfillment of the Requirement for the Degree of Master's
in Agricultural Machinery Engineering

Office of Graduate Studies
Adama Science and Technology University

February, 2024
Adama, Ethiopia

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DECLARATION

First, I hereby declare that this thesis entitled “Assessment of the Effect of Agricultural Machinery trafficking on Soil Compaction: A Case Study of Tamela Farm Site, Oromia Seed Enterprise” is my work and has not been submitted to any university for a similar purpose. The references used in this proposal are duly recognized by proper citations.

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I, the major advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled “Assessment of the Effect of Agricultural Machinery trafficking on Soil Compaction: A Case Study of Tamela Farm Site, Oromia Seed Enterprise” prepared under my guidance by Abera Feyisa Bayisa and submitted in partial fulfillment of the requirements for the degree of Master of Science in Agricultural Machinery Engineering. Therefore, I recommend the submission of a revised version of the thesis to the department following the applicable procedures.

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I, the advisor of the thesis entitled “Assessment of the Effect of Agricultural Machinery trafficking on Soil Compaction: A Case Study of Tamela Farm Site, Oromia Seed Enterprise” prepared under my guidance by Abera Feyisa Bayisa, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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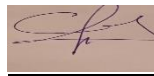
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TABLE OF CONTENT

DECLARATION.....	i
RECOMMENDATION OF ADVISOR.....	ii
APPROVAL PAGE OF M.SC. THESIS	iii
ACKNOWLEDGMENT	iv
TABLE OF CONTENT	v
LIST OF TABLES	viii
LIST OF FIGURES	x
ACRONYMS	xi
ABSTRACT	xii
CHAPTER ONE.....	1
1. INTRODUCTION	1
1.1. Background and Justification.....	1
1.2. Statement of the Problem.....	5
1.3. Objectives	6
1.3.1. General objective.....	6
1.3.2. The specific objectives	6
1.4. Significance of the Study.....	6
1.5. Scope of study.....	6
CHAPTER TWO.....	8
2. LITERATURE REVIEW.....	8
2.1. Soil Compaction	8
2.2. Soil Texture.....	9
2.3. Cause of Soil Compaction	9
2.3.1. Effect of soil type on soil compaction.....	11
2.4. Bulk Density	12
2.5. Types of Soil Compaction	13
2.6. Compression Stresses on the Topsoil	14
2.7. Factors Affecting Soil Compaction	14
2.7.1. Traffic over the Field and moisture content	16

2.8. Penetration Resistance and Root Elongation Rates	18
2.8.1. Effect of soil compaction on crop yield	19
2.9. Mitigation Measures of Soil Compaction	21
CHAPTER THREE	23
3. MATERIALS AND METHODS	23
3.1. Study Area Descriptions.	23
3.2. Materials	24
3.2.1. Tractor data	24
3.3. Methods	25
3.3.1. Experimental design.....	25
3.3.2. Layout of experimental plots.....	26
3.4. Soil Sampling Methods.....	27
3.4.1. Soil textural analysis	27
3.4.2. Determination soil maximum dry density and optimum moisture content.....	28
3.5. Field Experimental Procedure.....	29
3.5.1. Determination of soil bulk density by sand cone placement method.....	30
3.5.2. Determination penetration resistance by dynamic cone penetrometer.....	33
3.6. Data Analysis	34
3.7. Determination of Regression Coefficients for BD and PR	35
CHAPTER FOUR	36
4. RESULTS AND DISCUSSION.....	36
4.1. Determine Physical and Mechanical Properties Soil at Study Farm Site	36
4.1.1. Sieve analysis	36
4.1.2. Standard proctor test.....	36
4.1.3. Moisture content of soil.....	38
4.2. Effects of effect of farm machinery trafficking on soil parameters.....	39
4.2.1. Effect of the number of passes on BD for selected loads on a 0-15 cm soil layer...39	
4.2.2. Effect of the number of passes on bulk density for selected depths	48
4.2.3. Effect of loading on bulk density for selected number of passes.....	51
4.3. Effects of Loading and Number of Passes on Penetration Resistance.....	52
4.3.1. The 0-15 cm soil layer with varying loading level.....	52

4.3.2. Effects of the number of passes on PR for selected depths and various loading.	53
4.3.3. Effect of number of passes on PR on 0-15 cm soil layer with selected load	53
4.4. Analysis of variance for Bulk density.....	54
4.4.1. Bulk density regression equation	55
4.5. Analysis of variance for Penetration Resistance.....	56
4.5.1. Penetration resistance analysis regression equation.....	56
4.6. Bulk Density for 30-45cm with a Fitted Line.....	57
4.7. Penetration Resistance for 30-45cm with a Fitted Line.....	57
CHAPTER FIVE	59
5. CONCLUSION AND RECOMMENDATION	59
5.1. Conclusions.....	59
REFERENCE	61
Appendix I: Bulk Density Data	66
Appendix II: Penetration Resistance Data.....	68
Appendix III: Yield Data of Tamela Farm Site.....	71
Appendix IV: Soil Texture of Study Site	72

LIST OF TABLES

Table 1. Ideal and root-restricting bulk densities -----	12
Table 2. Maximum pressure generated by different tractors and animal -----	14
Table 3. Average yield in quintals per hectare for the last 4 years at the Temela farm site-----	21
Table 4. materials and function description-----	24
Table 5. Data table for documenting the two-factor factorial design testing-----	25
Table 6. ANOVA table for a two factor factorial -----	35
Table 7. Soil grading through sieve analysis-----	36
Table 8. Maximum dry density (MDD) and optimum moisture content (OMC) relationship--	37
Table 9. Evaluation of % change between numbers of passes for 30 KN at 0-15 cm depth----	40
Table 10. Evaluation of % change between numbers of passes for 33 KN at 0-15 cm depth --	41
Table 11. Evaluation of % change between numbers of passes for 36 KN at 0-15 cm depth --	41
Table 12. Evaluation of % change between numbers of passes for 30 KN at 15- 30cm depth-	42
Table 13. Evaluation of % change between numbers of passes for 33 KN at 15- 30cm depth-	43
Table 14. Evaluation of % change between numbers of passes for 36 KN at 15- 30cm depth-	43
Table 15. Evaluation of % change between numbers of passes for 30 KN at 30- 45cm depth-	44
Table 16. Evaluation of % change between numbers of passes for 33 KN at 30- 45cm depth-	45
Table 17. Evaluation of % change between numbers of passes for 36 KN at 30- 45cm depth-	45
Table 18. Evaluation of % change between numbers of passes for 30 KN at 45-60cm depth--	46
Table 19. Evaluation of % change between numbers of passes for 33 KN at 45-60cm depth--	47
Table 20. Evaluation of % change between numbers of passes for 36 KN at 45-60cm depth--	47
Table 21. Evaluation of % change between numbers of passes for 0-15cm depth -----	49
Table 22. Evaluation of % change between numbers of passes for 15-30cm depth -----	50
Table 23. Evaluation of % change between numbers of passes for 15-30cm depth -----	50
Table 24. Evaluation of % change between numbers of passes for 45-60cm depth -----	50
Table 25. Analysis of Variance (ANOVA) for bulk density -----	54
Table 26. Principal component analysis for bulk density -----	55
Table 27. Analysis of Variance (ANOVA) for penetration resistance -----	56
Table 28. Principal component analysis for penetration resistance-----	57
Table 29. BD kg/m ³ with changing normal load and number of passes in the 0-15cm depth--	66
Table 30. BD in kg/m ³ with changing NL and number of passes in -the 15-30 cm depth -----	66

Table 31. BD kg/m ³ with changing NL and number of passes in -the 30 -45cm depth-----	66
Table 32. BD in kg/m ³ with changing NL and number of passes in -the 45-60 cm depth-----	66
Table 33. Variation in BD in kg/m ³ with depth at number of passes at a NL of 30 KN -----	67
Table 34. Variation in BD kg/m ³ with depth at varying number of passes at a NL of 33 KN -	67
Table 35. Variation in BD kg/m ³ with depth at varying number of passes at a NL of 36 KN -	67
Table 36. Variation in PR J/cm with depth at varying number of passes at a NL of 36 KN----	69
Table 37. Variation in PR J/cm with NL at a Varying Number of Passes for the 0–15 cm-----	69
Table 38. Variation in PR in J/cm with NL at varying number of passes for the 15–30 cm----	69
Table 39. Variation in PR in J/cm with NL at varying number of passes for the 30-45 cm ----	70
Table 40. Variation in PR in J/cm with NL at varying number of passes for the 45–60 cm----	70
Table 41. Average yield in quintal per hectare for the last 4 years -----	71

LIST OF FIGURES

Figure 1. Soil textural triangle -----	9
Figure 2. Summary of factors inducing soil compaction-----	10
Figure 3. The effect of repeated passes on soil compaction beneath pneumatic tyre -----	15
Figure 4. Effect of soil moisture on load penetration under a tractor tire-----	17
Figure 5. Yield per hectare against years of Tamela 2019 up to 2022 annual report -----	21
Figure 6. Map of study area -----	23
Figure 7. Free body diagram of a tractor and a trailer -----	24
Figure 8. Experimental plots layout-----	26
Figure 9. Sampling points design-----	27
Figure 10. Standard proctor laboratory test -----	28
Figure 11. Tractor and loaded trailer used in the experiment -----	30
Figure 12. Preparation of the Test Hole and Sand Filling -----	32
Figure 13. Measure after oven dry soil sample at kulumsa agricultural research center -----	33
Figure 14. Tire mark's center is measured using a dynamic cone penetrometer. -----	34
Figure 15. A graph of moisture content % against dry density kg/m ³ -----	38
Figure 16. Effect of number of passes on Bulk density for selected loads for 0-15cm -----	40
Figure 17. Effect of number of passes on Bulk density for selected loads for 15- 30cm-----	42
Figure 18. Effect of number of passes on Bulk density for selected loads for 30- 45cm-----	44
Figure 19. Effect of number of passes on Bulk density for selected loads for 45-60cm -----	46
Figure 20. Effect of number of passes on BD for selected depths for a loading of 30 kN. -----	49
Figure 21. Effect of loading on BD for selected number of passes for 0-15 cm layer -----	51
Figure 22. Effect of loading on PR for selected number of passes for 0-15 cm depth-----	52
Figure 23. Effects of the Number of passes on PR for selected depth range at NL of 30 kN --	53
Figure 24. Effect of number of passes on PR for selected loads for 0-15 cm soil layer -----	54
Figure 25. Fitted lines to measured results of bulk density for 30 kN and 36 kN -----	57
Figure 26. Fitted lines measured results of Penetration resistance for 30 kN and 36 kN-----	58
Figure 27. USDA Soil Texture Triangle -----	72
Figure 28. High weight tractor trailed chemical sprayer in Tamela farm -----	72

ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ANOVA	Analysis of Variance
ASTM	American Society for Testing And Materials
BD	Bulk Density
DOF	Degree of Freedom
GHG	Greenhouse Gas
MDD	Maximum Dry Density
MS	Mean Square
MTA	Machine- Tractor Aggregates
NL	Normal Load
NT	No-Till
OMC	Optimum Moisture Content
OSE	Oromia Seed Enterprise
PR	Penetration Resistance
SC	Soil Compaction
SM	Sum Square
SPR	Soil Penetration Resistance
USDA	United States Department of Agriculture

ABSTRACT

Technology has increased agricultural productivity, but it also increases the weight of equipment and its use, potentially due to soil compaction. Soil compaction, a process that reduces air-filled soil pores, negatively impacts crop yield and reduces root growth and plant development, reducing agricultural output. According to the OSE annual report, average wheat and barley yields at the Tamela site have decreased by 3.3 quintals per hectare and 1.825 quintals per hectare per year, respectively, from 2019 to 2022. The study aims to evaluate the effect of agricultural machinery trafficking on soil compaction. The research experiment was done at Tamela Farm Site, Oromia Seed Enterprise. A four-wheeled 92.3 kN tractor was used in the experiments. The correlations between load, depth, and the number of passes for both bulk density and penetration resistance were described using multiple linear regressions. Three replications were performed for each of the three normal load levels used in the experiment, which were 30 kN, 33 kN, and 36 kN. The information gathered at depths of 0–15 cm, 15–30 cm, 30–45 cm, and 45–60 cm using the sand replacement technique and the dynamic cone penetrometer, respectively, the field bulk density and penetration resistance were assessed under various loading conditions and 1, 5, 10, and 15 numbers of passes. Using an analytical tool from a computer package (MS-Excel and Minitab), the data was examined. With a 95% confidence level and a p value of 0.05. The soil type was classified as sandy clay loam texture. According to the findings, the second soil layer's bulk density at 36 kN and 15 passes was 1494 kg/m³. The subsurface layer below 45–60 cm at 30 kN and one pass had the lowest bulk density of 1150 kg/m³. The maximum penetration resistance was discovered to be 153 J/cm at 36 kN and a depth below 45–60 cm. On the topsoil layer, the lowest penetration resistance measured was 9.52 J/cm at 30 kN. During the test period, the moisture content average was 24.084%. According to the results, the BD and SPR rose as the payload and number of passes increased. The coefficients of determination (R²) for bulk density and penetration resistance were found to be 0.8724 and 0.8674, respectively. Tamela farm sites are advised to minimize the number of passes and wheel loads; plant operators should be trained to reduce the number of runs on the same tire track. Deep tillage operations, often known as sub-soiling, should only be used on compacted soils. The use of appropriate field equipment, the absorption of organic matter into the soil, and the practice of crop rotation could all help to prevent soil compaction.

Key words: Bulky Density, Machinery, Penetration Resistance, Soil Compaction, and Traffic

CHAPTER ONE

1. INTRODUCTION

1.1. Background and Justification

Modern agriculture has been very successful in part because of mechanization, which has greatly increased food production potential thanks to the higher capacity of farm machinery. However, as vehicle weights have increased in tandem with capacity growth, there is an increased risk of subsoil compaction (Keller, 2022).

Mechanization in agriculture has greatly increased the productivity of agricultural field activities since the middle of the previous century. Agricultural equipment's weight has been steadily rising as a result of the increase in machinery capacity. Soil is literally put under more and more pressure as machinery weight increases (Parvin *et al.*, 2022).

Increased demand for food due to increasing population coupled with limited land has put a lot of pressure on land to increase output per unit area through mechanization. Soil compaction is an environmental problem. It is one of the causes of increased soil erosion and flooding. In addition, it also affects availability of nutrients and pesticide leaching to the groundwater (Weley & Ndiema, 2015).

The use of farm machinery that can replace both human and animal power in agricultural processes, or "farm mechanization," is the primary indicator of the modernization of agriculture. Driving in farmland in a mechanization system enables the use of farm machinery for the land preparation to the harvesting steps (Capello *et al.*, 2019).

Overall, the employment of more competent agricultural equipment and more timely field operations (planting, spraying, and harvesting) have resulted to a considerable boost in crop yield. However, this strategy has had the negative aspects of gradually increasing machinery power and weight (Botta *et al.*, 2020).

As machinery develops and soil is not adequately controlled, the soil becomes compacted, changing the soil's characteristics and structure (Keller *et al.*, 2019). Due to contact with the tractors' tires or tracks, the weight of the farming equipment compacts the soil during field work,

increasing and decreasing the bulk density and porosity of the soil, respectively. Trampling by livestock in addition to the use of farm equipment causes soil compaction (Capello *et al.*, 2019).

Analyzing the impacts of larger agricultural vehicles on soil stress and bulk density as well as the effects of increased compaction on root growth and soil hydraulic characteristics we demonstrate that the increased levels of subsurface compaction are a result of the machines' higher weight. We illustrate how this accelerated soil mechanical resistance and decreased root development rates (Keller *et al.*, 2019).

Heavy agricultural equipment generates soil compaction, which affects soil structure and reduces crop growth and development overall. To carry out different field activities including tillage, planting, chemical spraying, and harvesting, farm machinery must be able to handle a range of load demands. Wheel loads and the risk of soil compaction rise as a result of the increased gross weight of agricultural equipment. In many regions of the world, increasing soil compaction is facilitated by increasing the gross weight of the equipment and the number of passes (Shaheb *et al.*, 2021).

Agricultural machinery in the savanna ecosystems, especially the use of tractors for plowing leaves large tracts of land impacted due to their weights. Soil compaction increases soil strength and decreases soil physical fertility through decreasing storage of water and nutrients supply leading to additional fertilizer requirement and increasing production cost (Felix, 2021).

Today's agriculture employs highly efficient machinery, which enables fast and labor saving field operations. This machinery, however, has become bigger and heavier over time resulting in increased soil compaction risk during field traffic. Soil compaction is one of the main threats to the soil. As a common definition, soil compaction occurs when the soil stress exceeds the soil strength. Generally, soil strength depends on soil properties like soil texture, organic carbon, bulk density and water content, while soil stress depends on wheel load, inflation pressure, wheel size and wheel passes. Soil compaction can be differentiated in topsoil and subsoil compaction. While topsoil compaction may be lowered by soil tillage, subsoil compaction can last up to several decades or even be time persistent depending on soil conditions (Augustin *et al.*, 2020).

Cultivation of agricultural crops is associated with multiple passes of machine-tractor units over the field. Soil becomes compacted when movers pass on it. This leads to the deterioration of the basic physical and physical-mechanical properties of the sub- soil and topsoil layers, reducing crop yields and increasing energy consumption during agricultural operations. The level of soil compaction depends on the mass of the tractor, the type of mover used on the tractor, the type of soil and the technology of agricultural cultivation (Mударisov et al., 2020).

In modern agriculture, farm machinery is an integral part; however, it causes soil compaction. Soil compaction affects soil physical properties as it increases soil bulk density leading to reduction of soil water infiltration rate. Infiltration rate is influenced by agricultural traffic and its intensity and infiltration characteristic of the soil guides in the assessment of soil compaction. Traffic intensity increases soil bulk density negatively affecting soil infiltration parameters compared to no trafficked soil. Soil compaction caused by vehicular traffic negatively affects the important soil functions such as water flow and aeration, nutrient cycling, agricultural and forestry production, and habitats for soil organisms (Felix, 2021).

Stresses induced by heavy loads reach deep into the subsoil, thus increasing the risk of subsoil compaction. This is of particular concern because subsoil compaction is persistent due to the low recovery potential of subsoil. Crop development is directly affected by compaction by increased mechanical resistance in compacted soil, which slows down root growth resulting in reduced nutrient and water accessibility for roots. Compaction induced changes in pore volume and structure reduce water infiltration, water storage capacity, nutrient and water availability and soil aeration, which can result in reduced oxygen and increased carbon dioxide concentrations in soil that impair root growth. In addition to reducing crop yields, soil compaction results in a range of environmental disservices including increased risk of flooding and erosion and higher nutrient losses (Parvin *et al.*, 2022).

Agricultural soils provide a wide diversity of ecological services. Root growth, water movement, aeration, and heat transfer are directly influenced by the physical properties of soils. Therefore, food production, water storage, carbon sequestration, water quality and flood protection are all ecological services that depend on the structure of soils. One major threat to the quality of soil structure is compaction, especially in the soil layers beneath the usual primary tillage depth (Lamandé et al., 2018).

Soil compaction caused by vehicular traffic adversely affects key soil functions including water flow and aeration, nutrient cycling, agricultural and forestry production, and habitats for soil organisms. Soil compaction may lead to a cascade of physical feedbacks by increasing runoff and the risk of soil erosion by water and wind. We focus here on impacts of agricultural field traffic, however, soil compaction is of concern in the context of forest logging operations, recreational traffic and military operations on natural lands thus potentially jeopardizing ecosystem services for extended periods after the damage (Keller *et al.*, 2019).

In recent decades, the use of heavy machinery in agriculture has significantly increased, causing the compaction, which often remains for many years and may contribute to a decline in long-term site productivity. Severity of the damage depends on vehicle mass, weight of the carried loads, ground morphology, and soil properties, such as moisture (Keller *et al.*, 2019). Tillage operation consisted of primary tillage and secondary tillage, employed to increase the soil's structural macro porosity, while excessive tillage operations over these freshly tilled soils cause soil compaction (Shah *et al.*, 2017).

Agricultural machinery trafficking can be result in soil compaction. Specific causative agents are increases in the number of passages of machines through the same location, the high per axle loading of the machines and traffic on wet soil (Guimarães Jún yor *et al.*, 2019).

Tillage is only beneficial to the soil in the absence of machine traffic. This study piques interest in topics like how traffic affects subsurface runoff and how plow pans affect subsoil compaction, as well as how these factors affect water balance (water input) on a larger geographic scale than a single plot (Capello *et al.*, 2019).

The level of soil compaction depends on the mass of the tractor, the type of mover used on the tractor, the type of soil and the technology of agricultural cultivation (Hu *et al.*, 2020).

The two key parameters, soil BD and PR, are often used to determine and describe the levels of soil compaction throughout the soil profile. Soil cone penetrometer device with a 30° circular cone (ASABE S313.3) is used to characterize the PR of soils and standard protocol (ASABE Standards, 2013, 2018) for data recording and analysis has been followed in most of the published articles on soil compaction. However, it is important to address soil properties and

management data when soil PR is presented to describe and better understand the effect of compaction (Shaheb et al., 2021).

Soil compaction has detrimental effects on the physical, mechanical and hydraulic properties of soils, and affects important soil processes and function, and crop productivity (Botta *et al.*, 2020).

1.2. Statement of the Problem

It has been acknowledged that soil compaction, a process of soil particle rearrangement that decreases the percentage of soil pores that are air-filled, is a significant issue related to crop yield. The heavy use of agricultural equipment has increased soil compaction, creating an adverse environment for crop development and lowering the capacity of the soil for production (Guimares *et al.*, 2019). Soil compaction has become more common as a result of agricultural machinery crossing a field repeatedly. One of the most destructive deterioration mechanisms is soil compaction (SC). Crop yields are directly correlated with the impacts of compaction, and the stronger soil necessitates higher draught, which raises the fuel requirement for plowing (Zabrodskyi *et al.*, 2021). Other consequences of compacted soil are poor water percolation, increased surface runoff, increased soil erosion, and direct washing of herbicides into streams and rivers. This has impacted as the soil conditions are not favorable; it has a negative impact on the physical properties of the soil and is unfavorable for crop production yield. The increasing soil degradation due to soil compaction may be linked to the increase in weight of agricultural machinery, in the more intense use of machinery even under unfavorable soil conditions and in addition to poor crop rotation.

The consequences of soil compaction are decreased root growth and plant development, leading to a reduction in crop yield. The average wheat and barley yields at the Temela site declined by 3.3 quintals per hectare and 1.825 quintals per hectare per year, respectively, from 2019 to 2022, according to the OSE annual report. The purpose of this study is to evaluate the impact of agricultural machinery trafficking on soil compaction using a case study of Tamela Farm Site, Oromia Seed Enterprise. In order to create a database of information about how agricultural machinery trafficking affects soil characteristics impact on yields, In an effort to increase output and profitability, the findings will be utilized to advise the agricultural community about the main impacts of compacted soil and the steps they should take to prevent or minimize them.

1.3. Objectives

1.3.1. General objective

The overall objective of this study is to assess the effect of agricultural machinery trafficking on soil compaction.

1.3.2. The specific objectives

- To determine the physical and mechanical property of soil at the study farm site.
- To evaluate the effect of farm machinery traffic on soil parameters.
- To recommend appropriate mitigation measures in order to reduce soil compaction and an effort to increase productivity.

1.4. Significance of the Study

Soil compaction is a process in which soil is subjected to mechanical stress and densification. Soil comprises solid particles and spaces filled with water or/and air. Mechanization advances and the inadequate control of the soil induce its compaction which changes the soil structure and its characteristics. Excessive tillage operations over these freshly tilled soils cause soil compaction. Most agricultural operations required the use of heavy machinery during tillage and intercultural or fertilizer application. The continuous increases in the weight of farm machinery and the necessity to use heavy machines have a summary of factors inducing soil compaction. The effects of compaction are closely related to crop losses, and as a result of the stronger soil, higher drought is required, which means an increase in fuel consumption for tillage. The main significance of the study is to identify the compaction of soil by farm machinery through a case study of Tamela Farm Site, Oromia Seed Enterprise. In order to create a database of information about how agricultural machinery trafficking affects soil characteristics, it will be utilized to educate the agricultural community about the main impacts of compacted soil and to recommend appropriate Mitigation Measures in order to reduce soil compaction of the farm site in an effort to increase productivity and profitability.

1.5. Scope of study

Within the study region, this research was only assess the soil texture, maximum dry density, optimum moisture content, bulk density, relative compaction and penetration resistance of the soil. A maximum number of passes was allowed, with total loads ranging from metric tons three

levels. Other elements, such as weight transfer that might affect soil compaction was not be taken into account when this study is conducted at zero slopes.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Soil Compaction

The term "soil compaction" is used to describe the densification and distortion of soil that results in a reduction in total and air-filled porosity and the degradation or loss of one or more soil functions. The term "compaction" is occasionally used to describe the soil's density after compaction, despite the fact that the definition makes it clear that compaction is a process (Gratchev *et al.*, 2019).

A technique called soil compaction involves mechanically stressing and rises density of soil. Solid particles and voids filled with air or/and water make up soil. A more thorough understanding of soil's three-phase nature is provided by seeing it as a three-phase system. When under stress, soil particles were rearranged within the soil mass and the void volume shrunk, causing densification (Sutarno & Mohamad, 2023).

When the soil tension is greater than the soil strength, soil compaction results. In general, soil stress depends on wheel load, inflation pressure, wheel size, and wheel passes, whereas soil strength depends on soil parameters such soil texture, organic carbon, bulk density, and water content. Soil (Augustin *et al.*, 2020). Pore space, size, distribution, and soil strength all vary as a result of soil compaction. Measuring the bulk density is one approach to put a number on the change. The bulk density of a soil increases as the amount of pore space decreases. The bulk density of clay and silt-rich soils is lower than that of sandy soils because they naturally have greater pore space (Wesley & Ndiema, 2015).

Pore space is reduced by a process called soil compaction. It modifies the size, form, and spatial arrangement of clods and aggregates, as well as the pore spaces inside and between these units, which affects the structure of farmed soil. Natural occurrences like the freezing and thawing cycles in damp soil or human activities can both result in soil compaction. Climate, tillage practices, and cropping systems all affect how often and how intensely compaction episodes occur in cultivated plots. Rut development at the soil surface and a limited decrease in soil permeability in the area under the wheel are characteristics of soil compaction caused by wheeling (Defosseze & Richard, 2002).

2.2. Soil Texture

In order to determine the potentials and constraints of land use and management, soil texture which refers to the relative quantities of sand, silt, and clay particles in soils—is a crucial aspect of soil survey. A range of soil processes, including but not limited to structure formation, carbon sequestration, nutrient (e.g., N) retention, and water infiltration and storage, have been recognized as being significantly influenced by soil texture. But nothing is known about how it affects the variety and makeup of the soil microbial population (Xia *et al.*, 2020).

The physical characteristics of soil are crucial in deciding whether it is suitable for engineering, environmental, or agricultural applications. The physical characteristics of the soil have a direct impact on its capacity for supporting life, the movement, retention, and availability of water and nutrients to plants, the ease with which roots may penetrate the soil, and the passage of heat and air (Capello *et al.*, 2019).

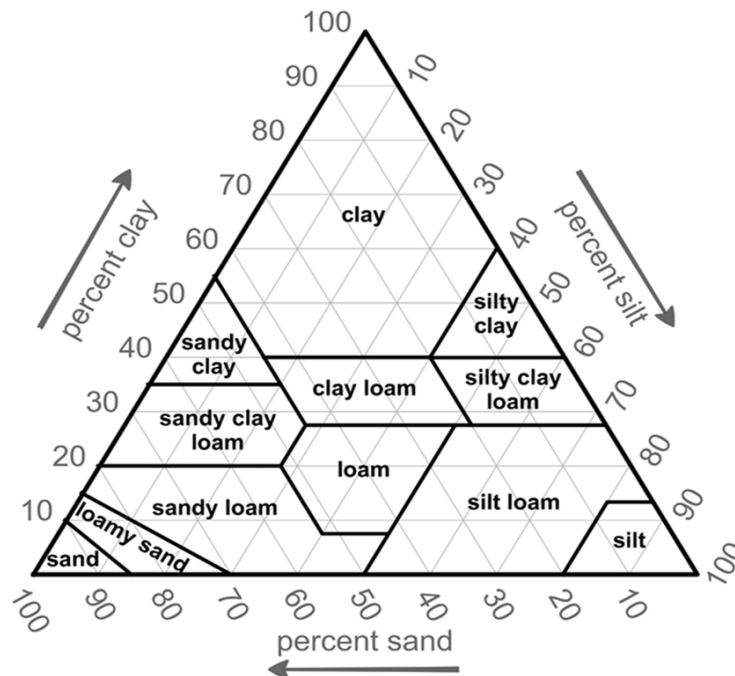


Figure 1. Soil textural triangle

(Source; Xia 2020)

2.3. Cause of Soil Compaction

Key components such as mechanical load, soil physical properties, agronomic operations, and crop rotation can influence soil compaction (Shah *et al.*, 2017). The effects of compaction on soil functions vary with soil type. The larger soil particles and larger pore size are less

susceptible to compaction, even when moist, compared to silt clay loam soils with smaller particles and smaller pore size with a weaker structure that are therefore more compatible, especially when moist. Soil compaction damage is becoming more common through the introduction of larger machinery (Sutarno & Mohamad, 2023).

An analysis of the geographical and temporal relationships between the extent of soil compaction and its causes has been done in order to quantify the impacts of soil compaction(Keller & Or, 2022)ⁱ.

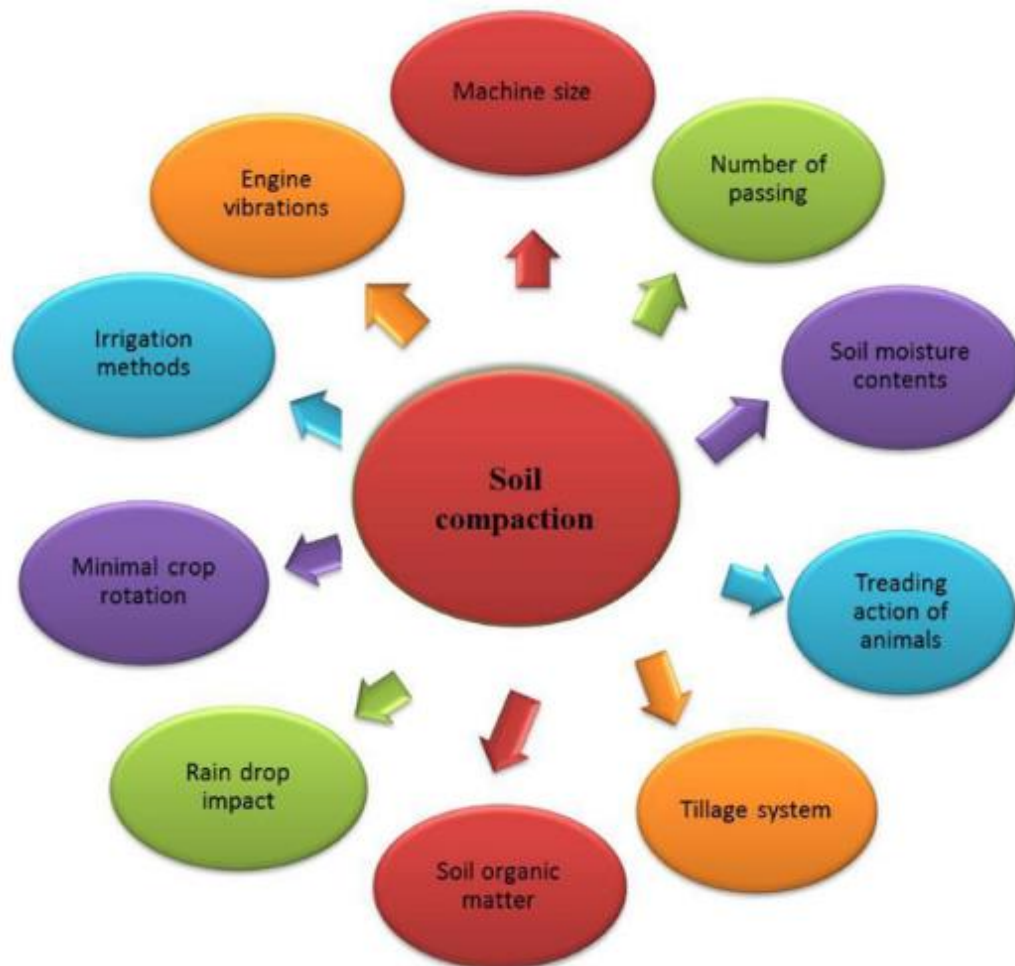


Figure 2.Summary of factors inducing soil compaction

The primary determinants of soil compaction include soil texture, soil moisture/wetness, soil strength, type and weight of agricultural equipment, tillage layer, and the volume of traffic. Other important variables are soil tillage layer and traffic volume. Multiple field passes with a

large tractor (wheel weights of 8 Mg) raise the possibility of serious soil structural damage that extends deep into the subsoil (Shaheb *et al.*, 2021).

Compaction of the soil has become more common as a result of the repetitive use of agricultural equipment in the field (Abich *et al.*, 2022). In order to boost the soil's structural macro porosity, tillage operations including primary tillage and secondary tillage were used; nevertheless, excessive tillage operations over these newly tilled soils result in soil compaction (Shah *et al.*, 2017). The level of soil compaction depends on the mass of the tractor, the type of mover used on the tractor, the type of soil and the technology of agricultural cultivation (Mударисов *et al.*, 2020). The amount of tractor runs through the field and large wheel loads are the major causes of soil compaction. The negative impacts of soil compaction are not limited to the layer that is used for agriculture. Also compacted are deeper soil layers, which might result in the production of plow pans that are exceedingly challenging to remove (Orzech *et al.*, 2021).

Topsoil compaction and motion resistance force are strongly related because, regardless of the soil mechanics where traffic is occurring, the heavier a tractor is, the more effort is needed to propel itself, which increases soil compaction. According to this concept, the subsoil's uppermost layer includes the pan layer that tractors have created. The pan layer sits below the layer that is regularly farmed (Botta *et al.*, 2012).

Wheel traffic's impact on the physical characteristics of soil The findings of this Research demonstrated that, independent of soil texture, soil b increased in the topsoil (0–30 cm depth) when soil compaction was related to axle load, number of wheel passes, compaction events, and/or tire inflation pressure (Zabrodskyi *et al.*, 2021).

2.3.1. Effect of soil type on soil compaction

Soil texture which refers to the relative amounts of sand, silt, and clay particles in soils—is an important feature of soil survey in determining the potentials and restrictions of land use and management. It is now recognized as an important predictor of soil processes. Along with the compacted dry density (degree of compaction), the micro-structure formed by compaction has a major impact on soil quality (Tatsuoka & Gomes Correia, 2018).

In the assessment of soil deterioration, soil compaction is a significant component. As a result, there is a decrease in soil volume and an increase in bulk density, which lowers soil porosity and affects the shape and size distribution of the soil pores (Edrriis *et al.*, 2020).

The most direct effect of soil compaction is an increase in the bulk density of soil. Optimum bulk densities for soils depend on the soil texture. Whenever the bulk density exceeds a certain level, root growth is restricted. No-till soils often have a higher bulk density than recently tilled soils. However, because of higher organic matter content in the topsoil and greater biological activity, the structure of a no-till soil may be more favorable for root growth than that of a cultivated soil, despite the higher bulk density. Penetration resistance is a better indicator of the effects of soil compaction on root growth than bulk density because results can be interpreted independent of soil texture (Wesley & Ndiema, 2015).

Table 1. Ideal and root-restricting bulk densities

Soil texture	Ideal bulk density(g/cm ³)	Bulk density restrict root growth
Sand, loam sand	<1.6	>1.8
Sandy loam, loam	<1.4	>1.8
Sand clay loam clay loam	<1.4	>1.75
Silt, silt loam	<1.3	>1.75
Silt clay loam	<1.4	>1.65
Sand clay silt clay	<1.1	>1.58
Clay	<1.1	>1.47

2.4. Bulk Density

Bulk density is defined as oven dry weight of soil per unit volume. Bulk density determines the extent of porosity in soil. Soils with good structure are characterized by increased soil macro aggregates and porosity. Increase in bulk density is reported with increase in soil compaction, as compacting forces squeeze the volume of soil via eliminating pore spaces. External stress (high axle load) reduces aggregate stability of soil, thus increasing bulk density of soil (Shah *et al.*, 2017). When harvester size rose, bulk density also did, and this was due to an increase in wheel loads (Parvin *et al.*, 2022).

Measuring soil ρ_b under different conditions provides useful information on the physical properties of soil. In recent studies, ρ_b has been measured using one of two groups of methods: well-established direct methods, or indirect methods. Direct methods for measuring soil ρ_b are often more practical and, thus, are generally used by agricultural soil scientists and civil engineers. They include measurements of the mass and volume of oven dried soil samples (Alshammary *et al.*, 2018).

Tractor wheel compaction had a substantial impact on bulk density, and because it was shown to rise with the number of tractor wheel passes, bulk density was considerably greater in soil that had been compacted. In contrast, soil that had not been compacted at all had lower bulk densities overall (Study *et al.*, 2015). We used two datasets to analyze the development of vehicle Weights: one for combine harvesters and one for tractors. (Parvin *et al.*, 2022).

The MDD or maximum dry density the highest density that may be achieved when compaction is applied to a material at different moisture levels is known as the maximum density of a material for a certain comp active effort. The moisture level at which the greatest density is attained is known as the optimal moisture content (OMC) for a certain comp active effort (Adeniji *et al.*, 2008).

2.5. Types of Soil Compaction

In general, three regions of compaction could be identified throughout the soil profile, namely topsoil or surface compaction, upper subsoil compaction, and subsoil or deep soil compaction, compaction beyond the normal tilled zone. The topsoil is the uppermost soil layer, generally comprising the top ~30 cm in depth (Obour & Ugarte, 2021).

Topsoil compaction is extremely hard to avoid, but it can be lessened by tillage and natural processes. The bottom soil layers become compacted due to subsoil. It is mostly brought on by the earth being overloaded from above. Compaction of the subsoil is significantly more enduring and challenging to remove (Wesley & Ndiema, 2015).

The motivation for much research is thus the negative impact of subsoil compaction on soil ecosystem services and the poor resilience to natural recovery. For the topsoil, in contrast, tillage, the effects from biota, and natural processes like frost-thaw and wet-drying are able to recover soil functions (Schjønnning, 2023).

2.6. Compression Stresses on the Topsoil

The highest risks of severe soil compaction are associated with the movements of loaded trailers, which apply the greatest compressive stresses to the soil. These stresses extend not only vertically but also horizontally, so that even if the traffic of the trailers is limited to defined lanes, the wagons may cause soil compaction at the sugarcane planting lines (Guimarães Júnnyor *et al.*, 2019).

External factors to the soil, such as type, intensity and frequency of applied load, as well as soil attributes such as moisture, texture, structure, carbon content and bulk density, may influence soil compaction levels (Pott *et al.*, 2020).

Table 2. Maximum pressure generated by different tractors and animal

Source	Stress (MPa)
Horses and cows	0.16 - 0.39
Sheep/humans	0.06 - 0.10
Small tractors < 2 tons	0.03 - 0.10
Large tractors (2-axle)	0.1 - 0.2

(source: Wesley & Ndiema, 2015)

2.7. Factors Affecting Soil Compaction

Soil compaction caused by vehicular traffic adversely affects key soil functions and ecosystem services that soils provide (Keller *et al.*, 2019). (Canillas & Salokhe, 2001) studied the effect of load and multiple passes on soil compaction. They concluded that the surface and the subsurface soil deformation characteristics, which were taken as indicative values of soil compatibility, strongly indicated that the maximum compaction occurred during the first three passes of a loaded wheel. When the axle load was increased it is caused by the greater pressure between the tire and soil surface at higher axle load. Statistical analysis revealed that the axle load had a significant influence on soil compaction.

The primary determinants of soil compaction include soil texture, soil moisture/wetness, soil strength, type and weight of agricultural equipment, tillage layer, tire type, inflation pressure, and the volume of traffic. Other important variables include the number of traffic passes. Multiple field passes with a large tractor (wheel weights of 8 Mg) raise the possibility of serious soil structural damage that extends deep into the subsoil (Shaheb *et al.*, 2021).

The axle load determines the depth to which the effect on the soil occurs. Heavier traffic or machinery has its effects going deeper into the soil more than lighter traffic on the same soil. When tyre pressure is increased, the surface area of the tyre lugs in contact with the soil decreases. The force will then be carried by a smaller surface area of the soil. The net effect on the soil will be deeper than when the pressure is lower. Low pressure means that the surface area in contact with the tire lugs also increases and hence less compaction of the soil. Soil compaction is also of growing concern in mechanized farms, mainly due to increasing production costs and economic pressure which leads to the use of heavier machinery and also to more contract machinery operation on smaller farms (Seehusen *et al.*, 2021).

The accuracy of forecasts of soil stresses is increased by the new model for the prediction of the contact stress distribution beneath agricultural tires because it considerably improves the input data for models of soil compaction. This is crucial for predicting soil compaction brought on by agricultural fields (Wesley & Ndiema, 2015).

Soil tension is not significantly influenced by tyre design, such as diagonal vs. radial tires. In a recent research, radial and diagonal ("old") tires evaluated at constant wheel load, diameter, and inflation pressure showed no change in soil stress (Keller *et al.*, 2019).

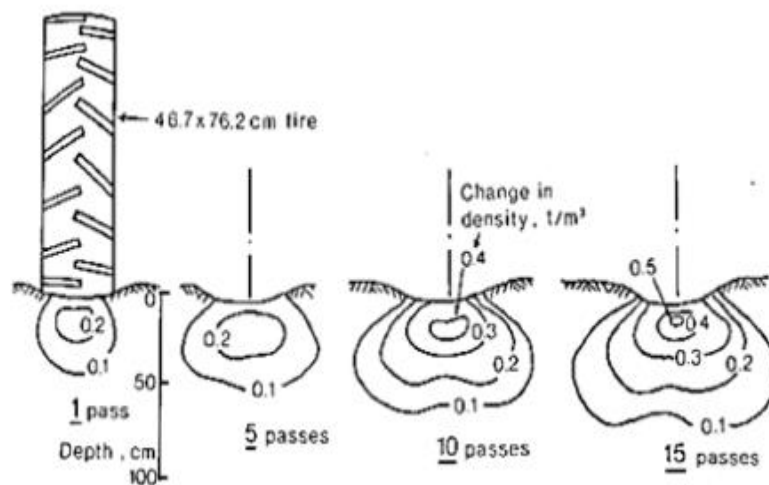


Figure 3. The effect of repeated passes on soil compaction beneath pneumatic tyre
(source: Wesley & Ndiema, 2015)

When the moisture content was low, the dry density kept increasing gradually during the whole compaction process. However, following an increase of moisture content, the specimen

achieved the majority of densification at the early stage, and showed only minor increases in dry density in the subsequent stages. The higher the water content, the fewer gyration numbers it takes to reach the stable dry density, indicating that less compaction efforts are needed (Hu *et al.*, 2020).

2.7.1. Traffic over the Field and moisture content

The pressure isobars or isobar contours represents the points with equal stress caused by the tire of a tractor under different soil conditions. These are normally referred to as pressure bulb lines since they resemble a bulb (Wesley & Ndiema, 2015). On the majority of the vineyard's surface, the repeated tractor traffic in the inter rows compacts the soil, and the risk of soil compaction increases when operations are carried out in wet soil conditions (Capello *et al.*, 2019). Soil compaction initially increases with increase in soil moisture up to a certain limit where the soil attains its maximum dry density (MDD). This limit is normally referred to optimum moisture content (OMC). Any further increase in moisture will result in the soil exhibiting its plastic properties. The optimum soil moisture varies depending on the composition of the soil (Wesley & Ndiema, 2015).

Soil water content is an important factor in making decisions about agricultural operation because of its effects on soil compaction by agricultural machines. Soil water content at wheeling, wheel characteristics, and machine loads are major factors that control compaction intensity in the field. For a given set of field equipment, the structure of the soil in the tilled layer results from the succession of water content conditions when cultural operations were carried out (Seehusen *et al.*, 2021).

Agricultural machinery places mechanical forces on the soil in the area where the tire (or track) meets the soil. The stress then spreads to deeper layers of the soil (Schjønning *et al.*, 2015). Wheel traffic applies vertical downward force on the surface of soil, which increases bulk density of soil. Shallow compaction caused due to heavy ground pressure (up to 5-10 inches) is usually eliminated with tillage practices. However, when axle load is high (>10 tons), deep compaction occurs. Amount of moisture also plays a greater role in the amount of compaction. In dry soil bearing strength of soil is increased so there is no significant compaction (Kumar *et al.*, 2018).

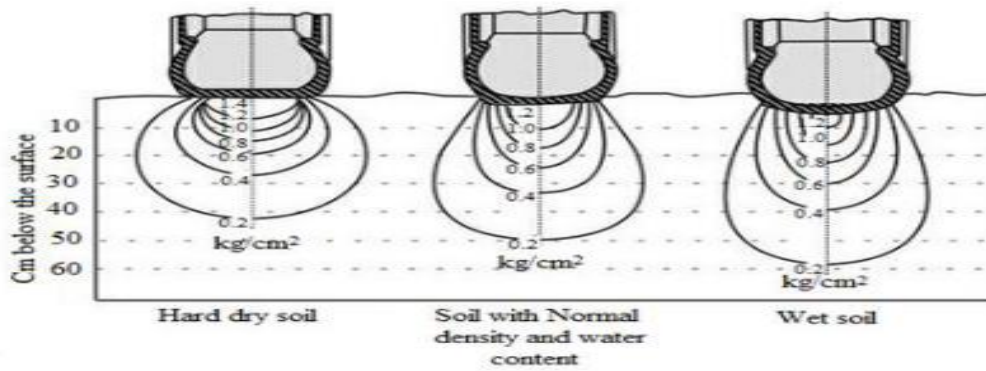


Figure 4. Effect of soil moisture on load penetration under a tractor tire
(source Gratchev 2019)

The isobars are calculated based on the Boussinesq equation (3.0) equation

$$\sigma_z = \frac{Q}{2\pi Z^2} \frac{1}{[1+(r/z)^2]^{5/2}} \dots\dots\dots (2.0)$$

$$\sigma_z = \frac{Q}{2Z^2} I_B \dots\dots\dots (2.1)$$

Where: I_B = Boussinesq stress coefficient and is given by equation (3.2) and illustrated in Figure 3.

$$I_B = \frac{3}{\pi} \frac{1}{[1+(r/z)^2]^{5/2}} \dots\dots\dots (2.2)$$

Where: Q is the vertical point load kilonewtons,

σ_z is vertical stress at that point P due to the load Q in kilonewtons,

Z is vertical depth of point P from the surface in meters,

r is the horizontal distance between point P below the surface and the vertical axis through the point load Q in meters.

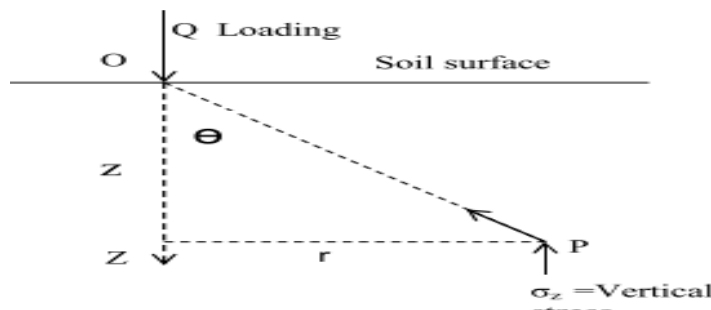


Figure 5. Vertical pressure within a soil mass

(Source; Defossez & Richard, 2002)

2.8. Penetration Resistance and Root Elongation Rates

The evaluation of soil penetration resistance has been a good indicator to check the condition of compaction that is, because it simulates the difficulty that the roots will grow and development. As the resistance to penetration of the soil is a dependent variable of numerous factors such as water content, texture and structure of the soil, it becomes difficult to obtain critical values the plants. The values of SPR have been considered limiting factors for the majority of plants when they are between 2 and 2.5 MPa (Bartzen *et al.*, 2019).

We used the bulk density profiles to estimate how soil penetration resistance and root elongation rates have changed due to the increase in vehicle weights. Root elongation in the soil is largely controlled by the soil mechanical resistance. The mechanical resistance is typically expressed as penetration resistance, and cone penetration resistance measurements can be used to quantify the mechanical energetics of bioturbation by plant roots. For a given soil texture, penetration resistance is a function of soil bulk density and hydration status or soil matric potential (Keller *et al.*, 2019).

Research has attempted to determine critical levels of soil physical properties for the proper development of the plants, using mainly the SPR. The value of 2.0 MPa, there are times adopted as limiting reference to the development of roots, but many studies show different results, which suggests the need for further studies in this area. Several authors have stated that the SPR values above 2.0 MPa are considered to be harmful to the development of roots (Bartzen *et al.*, 2019). Soil compaction (SC) is one of the most damaging degradation processes. The effects of compaction are closely related to crop losses and GHG emissions due to additional fuel use (Zabrodskyi *et al.*, 2021).

The extensive use of machinery in an agricultural setting can have detrimental impacts on the soil's quality, leading to compaction and alterations in the growth of the surrounding flora. High levels of compaction can harm plants by reducing ground flora, deforming roots, and causing delayed or diminished germination. Utilizing penetration resistance experiments, soil compaction is measured. Compared the impact of compaction between tractors with rubber tracks and those with standard wheels. By varying the number of tractors' passes, they examined

macro-porosity, pore shape and size distribution, bulk density, penetration resistance, and saturated hydraulic conductivity (Ben Hassen *et al.*, 2020).

Traffic-induced soil compaction occurs when mechanical stresses from machinery exceed the mechanical strength of the soil. During field traffic, significant stresses are transmitted to the subsoil. Soil mechanical strength is low at high water contents and high at drier conditions. The wheel load, the tyre pressure and traction from wheels are key drivers of soil compaction. When a wheel (or a track) is passing the surface of a soil, mechanical stresses are transmitted down in the soil profile. The stresses reduce with depth, but with modern (heavy) machinery significant stresses may reach deep soil layers, and soil deformation has been documented to at least 0.7 m (Gratchev *et al.*, 2019).

2.8.1. Effect of soil compaction on crop yield

Compacted soils typically show a degraded structure with low (macro) porosity, and low pore continuity and connectivity. The structural degradation, which can last for decades, adversely affects ecosystem services of arable soil including crop productivity. Low crop productivity on compacted soil results in interactions and feedback, soil penetration resistance, oxygen concentration in soil air, soil moisture, root growth and the accessibility of plants to water and nutrients (Colombi & Keller, 2019).

Several studies have shown that soil compaction affects (a) soil properties such as (i) changes soil structure, (ii) increases bulk density (BD), (iii) increases penetrometer resistance (PR), (iv) reduces soil aeration, (v) decreases water infiltration, and (vi) reduces hydraulic conductivity and (b) crop growth by (i) increasing mechanical impediment to root growth, (ii) hampering root architecture, and (iii) decreasing distribution and development of roots, A typical example of soil structural damage due to wheel traffic in the agricultural field. Besides the changes in soil structure, compaction reduces soil pore space and increases soil strength while decreasing root growth and root elongation rate, which results in reduced water and nutrient uptake by crops. The adverse effects of compaction on soil conditions further result in a decrease in plant emergence, plant establishment, and plant height. In severe cases, soil compaction substantially impacts crop growth, development, yield, and farm income (Macrì *et al.*, 2017).

The infiltration rate of soil was reduced significantly with the tractor wheel compaction reported that When a soil is tilled the infiltration rate will be increased because of the lower bulk density

but may be decreased because large pores continuity will be disrupted, and the importance of these two factors will depend on the level of compaction of the soil. Yield loss result from soil compaction which made the yield generated to depreciated in terms of market value compared to non-compacted soil (Study *et al.*, 2015).

Mechanically caused soil compaction is well accepted and documented, characterized by reduction of crop growth and deterioration in soil quality in many parts of the world. However, the vulnerability of soil to become compacted has been observed as an interaction of numerous factors, including soil physical properties, wheeling and number of passing (Shah *et al.*, 2017).

2.8.1.1. Average wheat and barley yield at Tamela farm site

The impacts of soil compaction attributed by machinery axle load, wheel passes and, compaction events on bulk density (ρ_b), penetration resistance (PR), and volume of pores at field capacity (θ_{Fc}), air permeability (k_a) at field capacity, saturated hydraulic conductivity (k_{sat}), and grain yield of corn, wheat, barley and soybean. Soil compaction, in general, adversely affected the soil physical properties investigated in coarse, medium, and fine textured soils, particularly in the topsoil. Overall, compaction decreased grain yield of corn, wheat, barley and soybean by 6–34% (Obour & Ugarte, 2021).

Compacted soil is detrimental to agriculture that is sustainable. By decreasing the amount of air-filled pore space, it lowers the volume of a given soil mass. Compaction of the soil alters the structure of the soil by raising bulk density, reducing total porosity, and increasing penetration resistance. Compaction of the soil can result from using heavy machinery for tillage activities, planting, applying crop protection agents pre- and post-emergence, and harvesting crops. Reduced crop growth and yield might result from these field operations using heavy-duty trucks and machinery because they gradually weaken the soil environment and soil structure, which are essential for sustainable crop production. Plant root anchoring and architecture are changed by compacted soil. Consequently, decreases in plant growth and nutrient uptake are seen, which lowers biomass and crop yield. (Shaheb *et al.*, 2021).

The farm has been growing mainly wheat and barley for 20 years but it is only recently that wheat production is decreasing in hectares and at the same time reducing hectares under barley and the reason is because wheat yields production has more impacted than barley (Table 3). A plant's capacity to absorb nutrients and water from the production stage may be hampered by

excessive soil compaction, which inhibits root development and hence restricts the quantity of soil that roots may investigate. Compared to plants produced under controlled conditions, plants grown in compacted soils have demonstrated a lower quantity of lateral roots. Plants growing in soil that was more compacted had lower fresh-to-dry mass ratios. Compacted soil can negatively impact crops by raising the mechanical barrier to root development (Ogbeche, 2019).

The farm has been growing mainly wheat for 20 years but it is only recently that wheat production increasing in hectares and at the same time reducing hectares under barley and The reason is because wheat production has better yields than barley (Table 3).The expected wheat production yields in the area is up to 40 quintals/ha.

Table 3.Average yield in quintals per hectare for the last 4 years at the Temela farm site

crop types	Year			
	2019	2020	2021	2022
Wheat (qu/ha)	31.30	22.63	19.26	18.07
Barley (qu/ha)	27.50	21.88	20.46	20.2

(Source: OSE Arsi branches annual reports, 2019-2022)

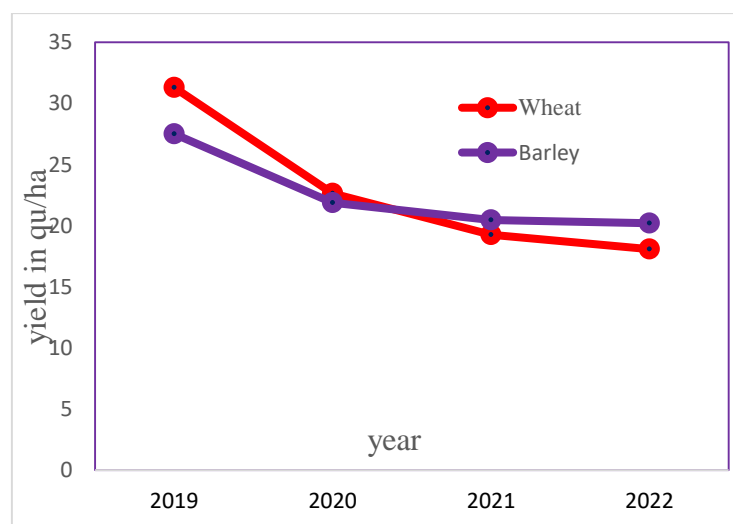


Figure 5. Yield per hectare against years of Tamela 2019 up to 2022 annual report

2.9. Mitigation Measures of Soil Compaction

Soil compaction is a major crop yield-limiting problem in no-till (NT) farming techniques. The selection of the appropriate de-compaction procedures for each yield environment may aid in

increasing productivity under NT and optimizing the utilization of time, labor, fuel, and other resources (Pott *et al.*, 2020). SPR in agricultural areas is a phenomenon that has a direct impact on root development and other pyrotechnical elements, which may jeopardize crop yield. Knowing the critical limits of SPR as well as the factors that can influence the increase of this property becomes necessary in order to develop a plan for soil management that is viable and more sustainable for the agricultural system and that promotes plant growth in order to maximize production and thus obtain gains in crop productivity (Bartzen *et al.*, 2019).

The problem of reducing soil compaction requires the search for new design and layout schemes of the tractor chassis, which will reduce soil compaction. One of the ways to improve the efficiency of the MTA (machine tractor aggregates) is to improve the geometry of the support part of the tracked tractor. To reduce the maximum pressure and the multiplicity of effects it is preferable to use a uniform distribution of pressure over the contact area of the support surface. Firstly, the uniform distribution does not create areas with extreme pressure, and secondly, the absence of areas with extreme pressure reduces the number of impacts to a minimum (to one). The pressure distribution can be significantly smoothed out by changing the geometry of the tractor support part (Mударisov *et al.*, 2020).

Opined that decomposition of crop residues promotes stable soil structure. This material acts as a glue to hold soil aggregates together. Incorporation of organic manure into the soil is done by retaining previous crop residues on the soil surface; growing small grains that have grass-like rooting systems; growing green manure crop in rotation; and applying animal manures, sludge, or other waste products. This strengthens soil structure, adds nutrients and organic carbon (Ogbeche, 2019).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Study Area Descriptions.

The study was carried out at the Oromia Seed Enterprise, which is managed by the Arsi branch. Tamela farm is one of the twelfth farms under OSE. It is located in West Arsi zone Gedeb-Asasa district, Oromia Regional State, Ethiopia. It covers an area of 3,224 hectares (2,953.5 ha cultivated and 270.5 ha non-cultivated). Mean annual rainfall and temperature is 475mm/year and 20°C respectively. Its altitude and slope 2400-2450 m above mean sea-level and 0-2% respectively. The main crops being cultivated in the farm are sunflower, teff, linseed and rapeseed. Moreover, the farm has the potential to cultivate wheat and barley; it is mechanized farming where human labor is used for some agronomic activities like weeding and loading-unloading of the grains. The farm operations are fully mechanized from land preparation to harvesting. The crop production is mainly mechanized and machinery sizes vary from 45 hp to 180 hp. The combine harvesters are large with grain tank capacity of up to 6 tons with a choice of wheat or corn harvesting heads.

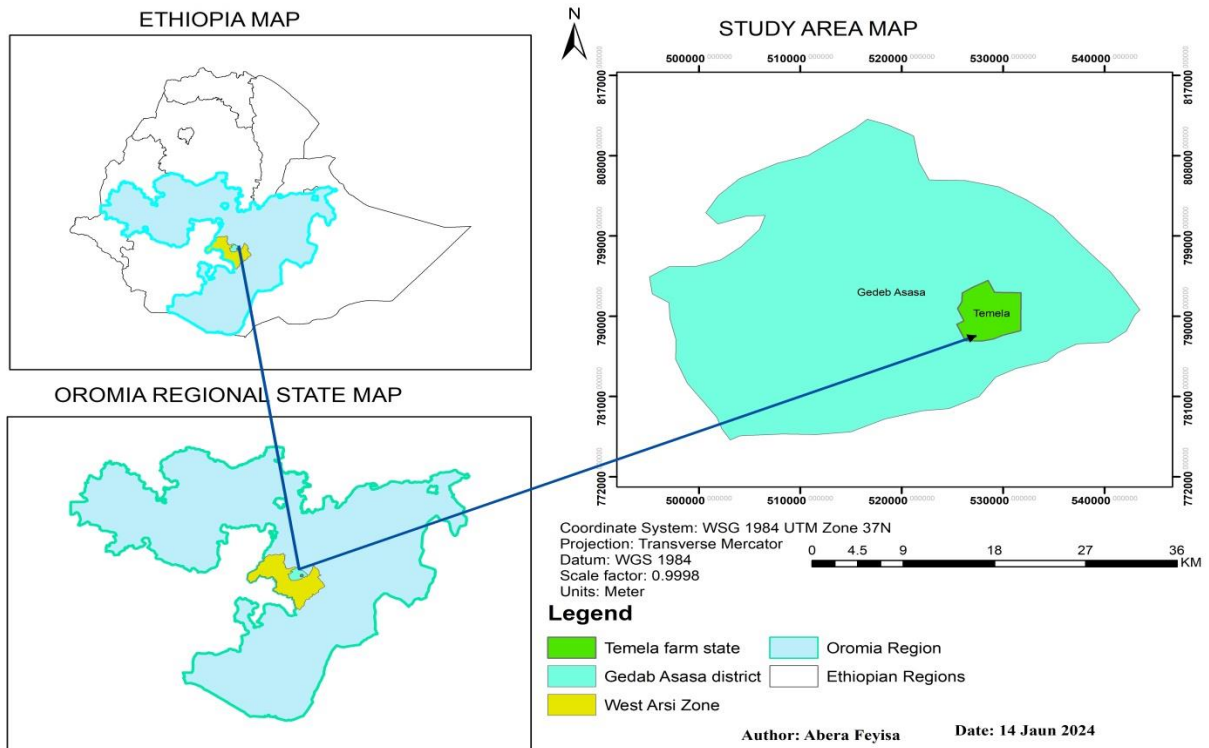


Figure 6. Map of study area

3.2. Materials

Table 4. materials and function description

no	materials	function
1	Tractor	For apply load
2	Dcp	To measure penetration resistance
3	Sand	For replacing soil
4	Jar	Sand filling
5	Plate	To allocate hole point
6	Hammer	For prepare test hole
7	Bags	For collecting soil sample
8	Electronic Balance	For weighting sand
9	Shovel	For soil excavation

3.2.1. Tractor data

During the field tests, 92.3 KN (net weight 9230 kg) and 170 hp four-wheel john Deere tractors tractor trailer was used. The total weight and the weight passed through each wheel or track of the machines were taken from the specifications provided by the manufacturers of the machines. Tire inflation pressures were measured in the field, while the machines were in use, with a digital tire pressure calibrator (Guimarães Júnnyor *et al.*, 2019). (The tyre pressure was kept at the recommended inflation of 124.2kPa. The weight on the big rear wheel of the tractor is 65% of the total weight of the tractor (W_{tractor}) the weight transfer from the trailer to the tractor rear wheel is 15% of the total weight of the trailer and the load (WTL) (Figure 7 and Figure 11). Therefore the normal force on the rear (F_r) tires is given by the total below (John Deere operator’s manual for 6135, 2021).

$$F_r = 0.5 \times [(65\% \times W_{\text{tractor}}) + (15\% \times W_{\text{TIL}})] \dots\dots\dots 3.0$$

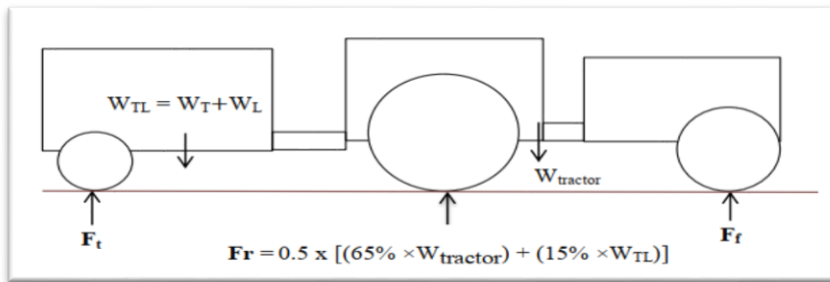


Figure 7. Free body diagram of a tractor and a trailer

3.3. Methods

3.3.1. Experimental design

The experimental design was a field experiment with two factors, loading (A), and number of passes (B), a=3 levels of loading b=4 levels of passes must also consider the frequency of machine passes (Macrì et al., 2017). Four treatments and one block were included in the randomized complete block design. There were three replications of each observation. With a = 4 levels of treatments per component and n = 4 repetitions, the trials were carried out in a totally randomized two factor factorial design. With three degrees of loading and 1, 5, 10, and 15 passes, the numbers of passes were chosen to correspond to the various farm operations (Wesley & Ndiema, 2015). Observations will be made at 0–15, 15–30, 30–45 and 45-60cm soil depths. The normal weight on a single rear tyre 30 kN, 33 kN and 36 kN were arrived at through chassis mechanics calculations (Figure 7) of the normal weight on the rear tyre as per field operations; planting,(net weight 2000kg) and chemical applicator towing a four ton trailer a fully (net weight 4000kg). The calculation to obtain these values is shown in Figure 7. The soil samples were collected and sent to the Kulumsa Agricultural Research and Adama Science and Technology University Civil Engineering Soil Mechanics Laboratory to determine moisture content, standard proctor tests, sieve and hydrometer analysis of the soil.

Table 5.Data table for documenting the two-factor factorial design testing

Treatments	No of passes				Totals	Averages
	1	5	10	15		
30kN	y111, y112, y113	y121, y122, y123	y131, y132, y133	y141, y142, y143	y1...	$\bar{y}_{1...}$
33kN	y211, y212, y213	y221, y222, y223	y231, y232, y233	y241, y242, y243	y2...	$\bar{y}_{2..}$
36kN	y311, y312, y313	y321, y322, y323	y331, y332, y333	y341, y342, y343	y3...	$\bar{y}_{3..}$
totals	y.1.	y.2.	y.3.	y.4.	Y...	$\bar{y} \dots$
Averages	$\bar{y}.1.$	$\bar{y}.2.$	$\bar{y}.3.$	$\bar{y}.4.$		

Where:

$$y_{.i} = \sum_{j=1}^b \sum_{k=1}^a y_{ijk} \quad \bar{y}_{i..} = \frac{y_{i..}}{an} \quad i = 1,2,3 \dots a \dots \dots \dots (3.1)$$

$$y_{.j} = \sum_{i=1}^a \sum_{k=1}^n y_{ijk} \quad \bar{y}_{.j.} = \frac{y_{.j.}}{bn} \quad j=1, 2, 3 \dots b \dots \dots \dots (3.2)$$

$$y_{ij.} = \sum_{k=1}^n y_{ijk} \quad \bar{y}_{ij.} = \frac{y_{ij.}}{n} \quad i = 1,2,3 \dots a, j = 1,2,3 \dots b \dots \dots \dots (3.3)$$

$$y_{...} = \sum_{i=1}^a \sum_{j=1}^b \sum_{k=1}^n y_{ijk} \quad \bar{y}_{...} = \frac{y_{...}}{abn} \dots \dots \dots (3.4)$$

3.3.2. Layout of experimental plots

Three equal pieces L1, L2, and L3 each measuring 300 m x 30 m will be cut out of the experimental plot. Three subplots, each 100 m x 10 m in size, were further split into each plot.

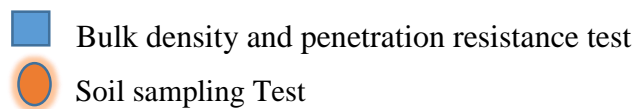
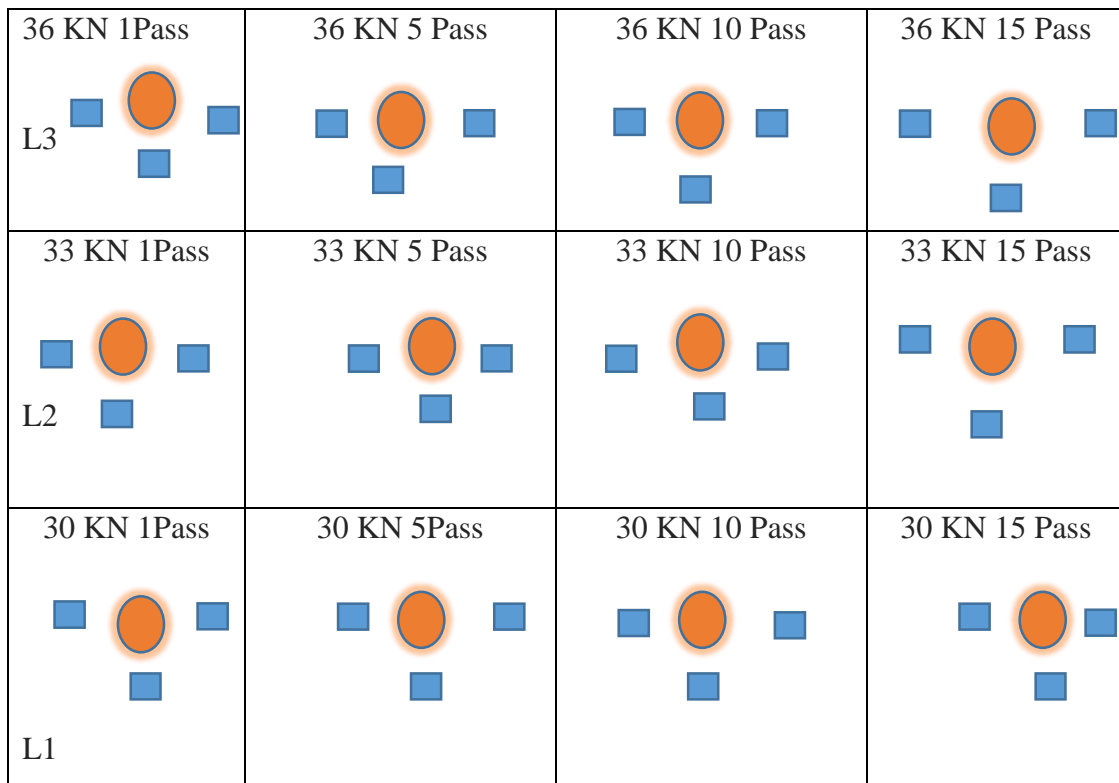


Figure 8. Experimental plots layout

3.4. Soil Sampling Methods

Random disturbed soil sampling was done for use in the standard Proctor test as per (ASTM D698 & AASHTO T99), and soil classification by using the standard (ASTM d422) from sampling points at the following depths 0-30 cm and 30-60 cm.

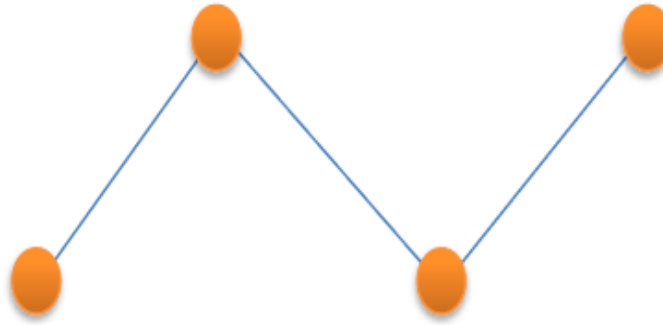


Figure 9. Sampling points design

3.4.1. Soil textural analysis

Grain size analysis is a typical laboratory test conducted in the soil mechanics field which is used to determine the particle size distribution of soils. The analysis is in Kulumsa Agricultural Research by laboratory technician conducted via two techniques which are through sieve analysis which is capable of determining the particle size ranging from 0.075mm to 100mm whereas distribution of particles smaller than 0.075mm can be determined using the hydrometer analysis Standard test method used for this test was ASTM d422.

i) **Sieve analysis:** is a method that is used to determine the grain size distribution of soils that are greater than 0.075mm in diameter. It is usually performed for sand and gravel but cannot be used as the method for determining the grain size distribution of finer soil. The sieves used in this method are made of woven wires with square openings. And also this test result gives hints about soil-water movement if permeability test is not available. Standard test method used for this test was ASTM d422.

ii) **Hydrometer analysis:** The hydrometer analysis of soil is based on Stokes law to calculate the size of soil particles from the speed at which they settle out of suspension in the water. For this study around 50g of dry soil passing 75 μ m sieve was taken and mixed with distilled water and dispersing agent like sodium hexa-meta-phosphate, (NaPO₃)₆ to form a gently mixed slurry. Then the prepared slurry was backfilled to a cylinder having 1000ml mark capacity and a 152H

hydrometer was immersed into the cylinder to record reading as per ASTM D7928 standard method.

3.4.2. Determination soil maximum dry density and optimum moisture content

A compaction test of soil is carried out using Proctor's test to understand compaction characteristics of different soils with change in moisture content. Compaction of soil is the optimal moisture content at which a given soil type becomes most dense and achieve its maximum dry density by removal of air voids.

Laboratory standard compaction tests were carried out on soil to determine the optimum moisture content and maximum dry density of materials. standard proctor compaction test were implemented with a 600 kN/m³ standard effort in the mold having a 4 inch (101.6mm) diameter and an internal effective height of 4.6 inches (117 mm), under which the material was compacted into three layers by applying 25 blows to each layer (ASTM D698, 2003).



figure(a).mixing soil sample with water for compaction



figure(b).compacting the soil



figure(c).determine the weight of compacted soil



figure(d).the soil sample was taken from layer of compacted soil for determining moisture content

Figure 10.Standard proctor laboratory test

Moisture was started at 8% (200 ml) for the initial sample, and the wet density was measured in each step until it reached its maximum and then decreased after increasing water content. After measuring wet mass for each soil sample and soil-additives mixtures for different water contents, a portion of each sample from the top, middle, and bottom was taken to the oven-dry machine to determine the moisture content that was available in the soil. Then the dry density of each sample at different moisture content was determined using the following equation.

$$\rho_{dry} = \frac{\rho_{wet}}{1+w} \dots\dots\dots (3.5)$$

Where: ρ_{dry} is dry density of sample in g/cm^3

ρ_{wet} is wet (bulk) density of sample in g/cm^3

W is moisture content in decimal

The degree of soil compaction is expressed in percentage (Donkoh *et al.*, 2012). The “degree of compaction” or “relative compaction” of the soil, DC, will be defined as:

$$DC = \frac{\rho_b}{\rho_{pd}} \times 100 \dots\dots\dots (3.6)$$

Where: ρ_b is the dry bulk density (from equ.3.9) and

ρ_{pd} is the maximum dry density of the same soil in a reference state obtained at laboratory (equ.3.2).

3.5. Field Experimental Procedure

The experimental plot was chosen such that it was fairly flat and by measuring 300 m long by 30 m wide. It was then divided into three strips of 100 m long by 10 m wide.

Step 1: The plot was harrowed using a disc plow, followed by a heavy disc harrow. Final harrowing and raking was completed in preparation for planting.

Step 2: Each strip was divided into three sections, each 100 m long and 10 m wide.

Step 3: Plot L1 was subjected to a 30 KN load by running the tractor at a forward speed 7.5km/hr once.

Step 4: The data were randomly taken at the center of the tire mark. A set of three replicates were taken at depths of 0–15, 15–30, 30–45 cm and 45-60 soil depths.

Step 5: Step 3 was repeated by operating the tractor through the same tyre mark with the same load of 30 KN four times to make the number of passes to five. Step 4 was then repeated. The same procedure was repeated for 10 and 15 passes on the same plot with the same load

Step 6: On the second plot 33 KN, steps 3, 4, and 5 were repeated but with a second load level.

Step 7: On the third plot 36 KN, steps 3, 4, and 5 were repeated but with the third load level.



Figure 11. Tractor and loaded trailer used in the experiment

3.5.1. Determination of soil bulk density by sand cone placement method

Soil samples were collected, along with compaction measurements recorded at the center of each axle load. Soil sampling was performed in the center of the inter row (exactly beneath the tire path) to represent the position at which stress propagation induced by the traffic is more intense. The sand mass in grams (g) was obtained by weighing and using the known volume of the calibrating container in cm^3 in the field the identified test point was leveled until the base plate is fitted flat on top. The base plate was then secured using hooks hammered to the ground. The cylinders were placed on the base plate. The sand in the 3000 g marked container was used to determine the mass of sand in the funnel and base. After removing the cylinder, the test hole was excavated up to a depth of 15 cm.

The field bulk density (in situ) was determined using sand cone replacement method (ASTM d1556) at the following depths 0-15 cm, 15-30 cm 30-45 cm and 45- 60 cm at random (Wesley & Ndiema, 2015). The American Society for Testing and Materials (ASTM) recommends Ottawa sand as the standard. According to (Yamamuro & Lade, 1997) The Ottawa sand was graded from its original gradation to sizes between the Nos. 50 and 200 sieve sizes of 300 μm and 75 μm, respectively, Was prepared in the Adama Science and Technology University geotechnical laboratory.

a) Determination of dry bulk density of sand to be used.

The sand mass in grams (g) was obtained by weighing and using the known volume of the calibrating container in cm³. The bulk density of sand was calculated as follows:-

$$\rho_1 = \frac{m_1}{v_1} \dots\dots\dots (3.7)$$

Where: ρ₁ is the dry density of sand in g/cm³,
M₁ is the mass of sand (g) and
V₁ is the volume of sand in cm³

The above calibration process was used to calibrate dry and clean sand to be used in the field.

b) Volume of the test hole (V)

In the field the identified test point was leveled until the base plate fitted flat on top (Figure 12). The base plate was then secured using hooks hammered to the ground.

After removing the cylinder, the test hole was excavated up to a depth of 15 cm (Figure 12). The soil from the test holes was scooped, packed into a polythene bag, sealed and labeled.

The remaining sand in the cylinder was carefully returned to their specific container. The container was then weighed with the remaining sand. M₆ and M₇ were obtained by subtracting the remaining weights from their respective initial weights of the calibrated clean sand The volume of the test hole where soil had been scooped was then determined using the equation

$$V = \frac{m_6 - m_7}{\rho_1} \dots\dots\dots (3.8)$$

Where: ρ₁ is the dry density of sand in g/cm³,
M₆ is the mass of sand (g) used to fill the test hole and
M₇ is the mass of sand remaining in the jar (g)

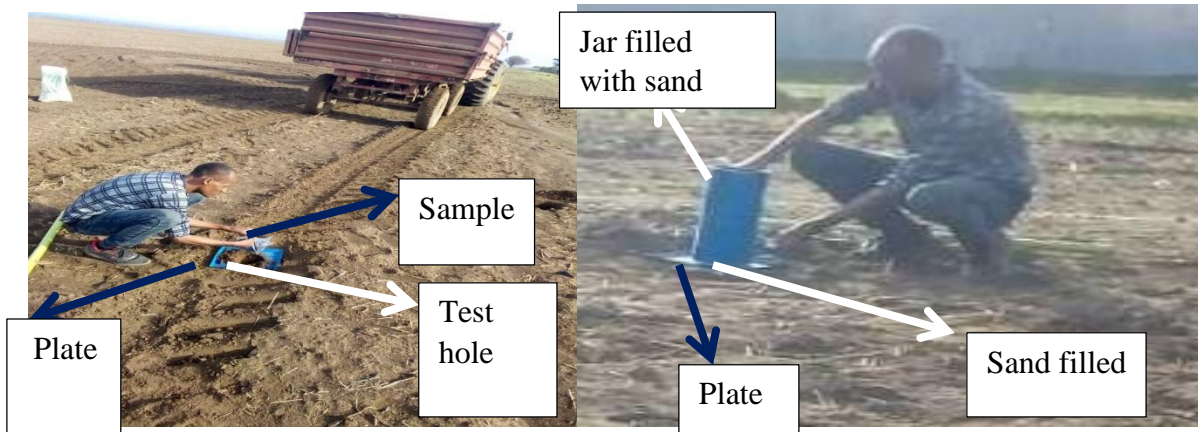


Figure 12. Preparation of the Test Hole and Sand Filling

c) Moisture content determination of the scoped material (ASTM d2216).

Soil moisture is an important parameter, which has a fundamental influence on the transfer of stress into the soil (Hu *et al.*, 2020). The soil moisture was determined by the oven dry method. Three samples were collected randomly from the test plots. The samples were kept in the oven for 24 hours at a temperature of 105°C. The samples were weighed before and after drying. The moisture content (Dry basis) was determined by the following formula (Gebrekidan, 2022).

$$\text{Moisture Content (\%)} = \frac{Ww - Wd}{Wd} \dots\dots\dots (3.9)$$

Where: Ww is Weight of wet soil sample,

Wd is Weight of dry soil sample

The scooped material from the test hole was packed in a sealed polythene sampling bag and taken to the lab for oven drying. The moist mass M4 was determined. After which two samples were scooped into moisture drying cans per sample. The moisture cans with moist soil samples were each weighed M2 in grams. After oven drying for 24 hours, at 105°C temperature weight M3 in grams was taken. The percentage moisture content w was calculated using equation 3.7. The average percentage moisture content of the two samples was taken.

$$w = \frac{m2 - m3}{m3} \times 100 \dots\dots\dots (4.0)$$

Where: w is the moisture content of the material from the test hole in %,

M2 is the mass of the moisture sample and the can in (g) and

M3 is the dry mass of moisture sample in (g)



Figure 13. Measure after oven dry soil sample at kulumsa agricultural research center

d) Calculation of the dry mass of the material from test hole

$$m5 = \frac{m4}{(0.01)(w+100)} \dots\dots\dots (4.0)$$

Where: w is the moisture content of the material from the test hole in percentage,

M4 is the moist mass of the materials from the test hole in g and

M5 is the dry mass of the materials from the test hole in g

e) Calculation of the bulk density of the materials from the test hole

$$\rho2 = \frac{m5}{V} \dots\dots\dots (3.1)$$

Where: $\rho2$ is the bulk density of the material from the test hole in g/cm³,

M5 is the dry mass of the materials from the test hole in g and

V volume of the test hole in cm³

3.5.2. Determination penetration resistance by dynamic cone penetrometer

The DCP was positioned vertically and in the middle of the tire mark. It was then allowed to fall freely after being lifted vertically to its effective height of 575 mm. 60° cone, anvil with driving rod, metal plate coupling for ruler, lower extension rod, upper extension rod, spanners, 13 mm and 17mm, a bottle of adhesive, steel ruler, all contained in a wooden carrying case Up until the cone was at least 65 to 70 cm below the surface of the earth, the reading on the scale rule was noted after each hammer stroke (Wesley & Ndiema, 2015) is given by:-

For every fall of the 8 kg hammer the energy released to move the cone into the soil is given by:

Kinetic energy= *potential energy*

$$\frac{1}{2}mv^2=mgh$$

$$v = \sqrt{2gh} = \sqrt{2} \times 10 \times 0.575 = 3.39 \text{ m/s}$$

$$\text{Kinetic energy} = \frac{1}{2}mv^2 = \frac{1}{2} \times 8 \times 3.39^2 = 46 \text{ joules}$$

The Penetration resistance is therefore calculated using the following equation

$$(\text{PR}) = \frac{N \times 46}{D \text{ in cm}} \dots\dots\dots (4.2)$$

Where: PR is Penetration resistance in j/cm

N is number of blows of the hammer

D is depth moved in cm



Figure 14. Tire mark's center is measured using a dynamic cone penetrometer.

3.6. Data Analysis

The data collected from field experiments was analyzed using an analysis tool from a computer package (MS-Excel and Minitab). A two-way analysis of variance (ANOVA) This analysis was used to test the hypotheses of the main effect of loading (factor A), the number of passes (factor B), and the loading and number of passes interaction effect (AB interaction). The results were evaluated and displayed in an ANOVA table and graph for a two-factor factorial.

Table 6. ANOVA table for a two factor factorial

Source of variations	Degrees of Freedom	Sum of squares	Mean Square	F0
A treatments	a-1	SSA	$\frac{SSA}{a-1}$	$\frac{SSA}{SSE}$
B blocks	b-1	SSB	$\frac{SSB}{b-1}$	$\frac{SSB}{SSE}$
E Error	(a-1)(b-1)	SSE	$\frac{SSE}{(a-1)(b-1)}$	
Total	abn-1			

F- Distribution was used to test significance in the null hypotheses. Other tests like the 95% confidence interval. The above process was analyzed using Minitab software

3.7. Determination of Regression Coefficients for BD and PR

This was determined using multiple linear regression models since the experiment has more than one variable that is loading (L), depth (D) and number of passes (P) based on the multiple linear regression model equation (Montgomery & Runger,2012).

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \varepsilon \dots\dots\dots (4.3)$$

Where: y is the bulk density in g/cm³, or soil penetration resistance (Joule per centimeter)

X₁ is depth in meters,

X₂ number of passes,

X₃ is the loading in KN,

ε is the expected error

β₀ is the intercept and β₁, β₂ and β₃ are partial regression coefficients.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. Determine Physical and Mechanical Properties Soil at Study Farm Site

4.1.1. Sieve analysis

The results of soil sieve analysis using British Standard (BS) sieves and samples passing through a 5-mm sieve yielded 21.8125% clay, 17.1875% silt, and 61% sand was determined by kulumsa agricultural research soil laboratory technicians (Table7). The soil texture based on the USDA textural soil triangle (Figure 27) was found to be sand clay loam. Generally, sand clay loam has a bulk density between 1100 kg/m³ and 1400 kg/m³.

Table 7. Soil grading through sieve analysis

soil	Test point (TP)					
	TP1	TP2	TP3	TP4	TP5	TP6
Clay %	21.5625	21.8125	22.8125	21.8125	21.0625	21.8125
Silt %	17.1875	17.1875	17.1875	17.1875	17.1875	17.1875
Sand %	61.25	61	60	61	61.75	61
Texture	sand clay loam	sand clay loam	sand clay loam	sand clay loam	sand clay loam	sand clay loam

4.1.2. Standard proctor test

Soil compaction initially increases with increase in soil moisture up to a certain limit where the soil attains its maximum dry density (MDD). This limit is normally referred to optimum moisture content (OMC). Any further increase in moisture will result in the soil exhibiting its plastic properties. The optimum soil moisture varies depending on the composition of the soil (Wesley & Ndiema, 2015).

Moisture was started at 8% (200 ml) for the initial sample, and the wet density was measured in each step until it reached its maximum and then decreased after increasing water content. After measuring wet mass for each soil sample and soil-additives mixtures for different water contents, a portion of each sample from the top, middle, and bottom was taken to the oven-dry machine to determine the moisture content that was available in the soil.

Compaction is the process of raising soil density or unit weight by reducing air volume; water content is often left unchanged. Compaction level is also determined by the dry density of the soil, which is often based on water content and comp-active effort (number of blows, hammer weight, height of free fall, and number of layers). The ideal moisture content is reached at maximum dry density. (Hassan *et al.*, n.d.).

Availability of data on MDD and OMC was help in selecting tractor and machinery sizes to be used on agricultural farms to guard against over compacting agricultural soils to avert the losses in crop yields (Adeniji *et al.*, 2018).

On the ISC soil, the proctor conducted a typical proctor compaction test in accordance with ASTM standard D698. The average maximum dry density (MDD) of the soil was determined to be 1589.3 kg/m³ at an average optimal moisture content (OMC) of 24.65% (Table 8), and the predicted optimum water content for compaction is (OMC) of 24.65% (Table 8). Up until the optimum moisture content of about 24.65% for the sandy clay loam soil under study, increasing the moisture content causes an increase in bulk density with compaction. Thereafter, any additional moisture content causes a decrease in bulk density from the maximum of 1589.3 kg/m³ at the optimum moisture content.

Soil compaction initially increases with increase in soil moisture up to a certain limit where the soil attains its maximum dry density (MDD). This limit is normally referred to optimum moisture content (OMC). Any further increase in moisture will result in the soil exhibiting its plastic properties. The optimum soil moisture varies depending on the composition of the soil (Wesley & Ndiema, 2015). It was found that bulk density increased gradually as moisture content increased, up until a point where bulk density did not rise as moisture content increased (Adeniji *et al.*, 2008).

Table 8. Maximum dry density (MDD) and optimum moisture content (OMC) relationship

Test Pits (TP)						
Test No.	TP1		TP2		TP3	
No.	OMC %	MDD kg/m ³	OMC %	MDD kg/m ³	OMC %	MDD kg/m ³
1	11.43	1338	10.34	1196	12.5	1266
2	15.4	1525	15.91	1406	15.33	1465

3	24.4	1648	24.64	1535	24.91	1585
4	30.2	1508	31.51	1407	30.08	1462
Average	20.36	1505	20.6	1386	20.7	1445
MDD kg/m ³			1589.3			
OMC %			24.65			

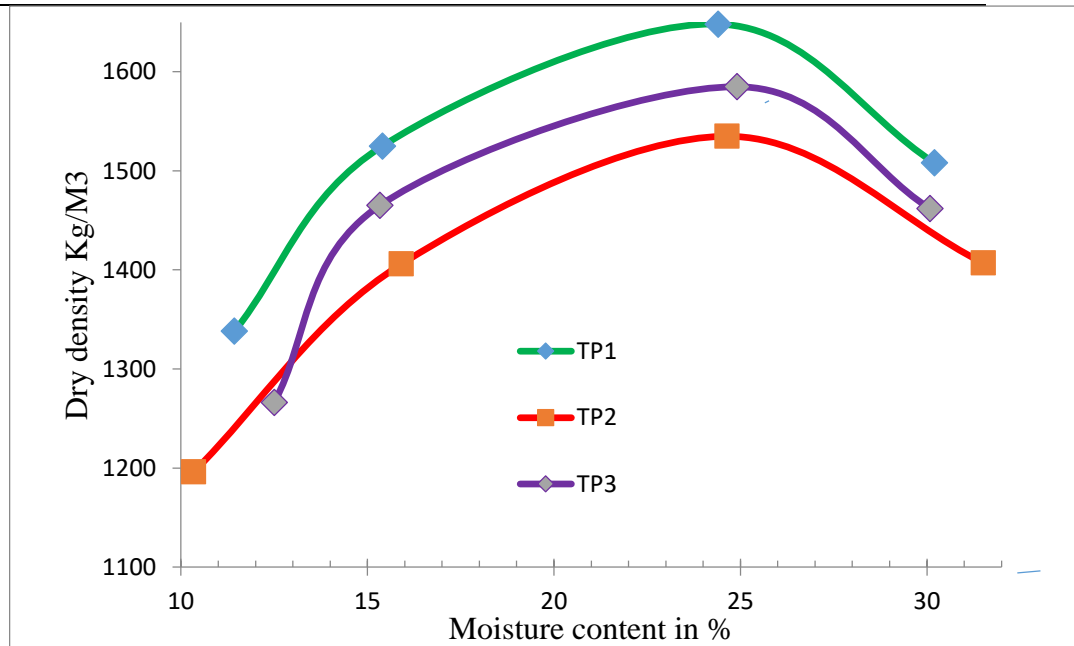


Figure 15. A graph of moisture content % against dry density kg/m³

4.1.3. Moisture content of soil

Due to its impact on soil compaction by agricultural machine loads, soil water content is a crucial consideration when making judgments concerning agricultural operations. Major variables that affect compaction intensity in the field include wheel parameters, machine loads, and soil water content at wheeling. The sequence of water content circumstances experienced throughout the course of cultural activities determines the structure of the soil in the tilled layer for a certain set of field tools (Seehusen *et al.*, 2021).

Moisture content on dry basis of soil was measured by oven dry method. The scooped material from the test hole was packed in a sealed polythene sampling bag and was taken to the Kulumsa Agricultural Mechanization Center soil laboratory for oven drying. The average moisture content of the experimental field was 24.084%.

4.2. Effects of effect of farm machinery trafficking on soil parameters

4.2.1. Effect of the number of passes on BD for selected loads on a 0-15 cm soil layer.

The results of the different number of passes for the selected loadings of 30 KN, 33 KN, and 36 KN were plotted against their respective bulk densities for each soil layer. The displayed data in figure 16 shows that loading affects both the bulk density and the number of passes. According to (Study et al., 2015), bulk density was found to be significantly affected by the number of tractor wheel passes, and bulk density was generally higher in soil that had been compacted. In contrast, bulk density was generally found to be lower in soil that had not been compacted at all.

The increase in bulk density between a single pass and 5 passes is 6.92% (Table 10) for the medium loading of 33 KN the highest increase in bulk density is between the first and 5 passes for all the three levels of loading of 30 KN, 33 KN and 36 kN. The results show that there is an increase in bulk density with the increase in the number of passes (Table 9, 10 & 11). The change in bulk density between the first pass and 5 passes with the change in loading levels of 30, 33 and 36 KN is 5.83, 6.92 and 5.44 % respectively. The impact of number passes is felt between the first pass and five passes in all the treatments. This clearly confirms that bulk density is affected by change in loading as well as the change in the number of passes.

According to (Ben Hassen *et al.*, 2020) There is a direct correlation between the tractor weight and the number of passes and the bulk density node, which is linked to penetration resistance. In a study (Ogbeche, 2019) applied weight or mechanical stress leading to a coarsening or loss of soil structural units, decrease in soil volume, increase in bulk density, decrease in porosity and reduction in hydraulic conductivity of the soil. Compacted soils have reduced available water capacity. The change in pore space restricts root growth, and the gas exchange necessary for plant growth. Compaction restricts infiltration of water, increasing runoff and erosion, leading to the loss of valuable nutrients. The increase in the gross weight of the equipment and an increase in the number of passes play significant roles in enhancing soil compaction in many parts of the world (Shaheb *et al.*, 2021).

According to (Obour & Ugarte, 2021) Soil compaction, in general, adversely affected the soil physical properties investigated in coarse, medium, and fine textured soils, particularly in the topsoil. Overall, compaction decreased grain yield of corn, wheat, barley and soybean by 6–

34%. According to (Orzech *et al.*, 2021) There are differences in the impacts of soil compaction and simplified tillage on crop yields, soil moisture content, and bulk density of soil. Soil horizons, plant growth phases, and crop species all have different variations in soil bulk density and moisture content.

In a study (Botta *et al.*, 2020) the yield penalties are proportional to the traffic intensity applied to the soil. Traffic intensity is determined by the combined effect of the number of passes with a given farm vehicle over a given area and its overall load. According to (Shaheb *et al.*, 2021) yield of crops decreased significantly in compacted soils due to heavy machinery, higher axle load, and repeated field trafficking as compared to light equipment, lower axle load.

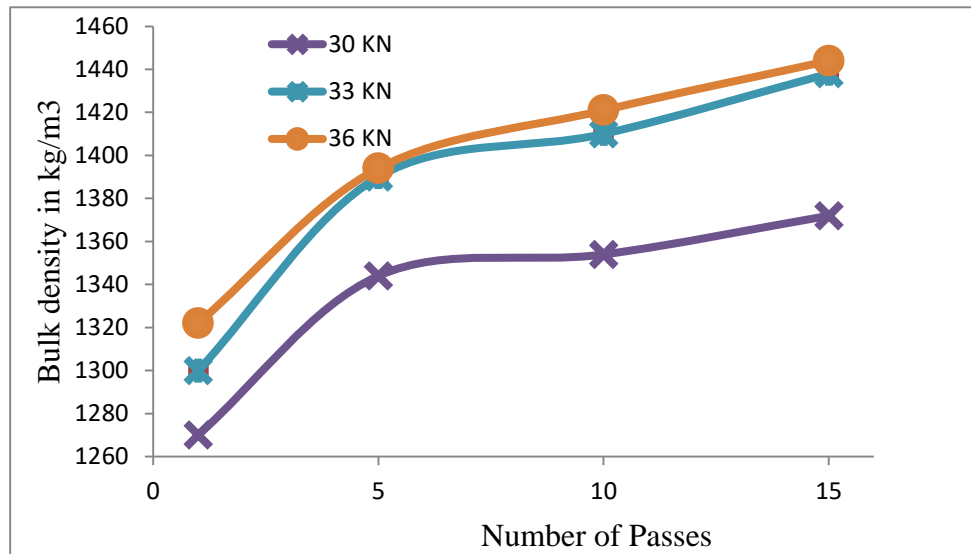


Figure 16. Effect of number of passes on Bulk density for selected loads for 0-15cm

Table 9. Evaluation of % change between numbers of passes for 30 KN at 0-15 cm depth

Load in KN	Number of Passes				Percentage change in Bulk density
	1	5	10	15	
30	1270	1344			$\frac{(1344 - 1270)}{1270} \times 100 = 5.83\%$

30	1344	1354	$\frac{(1354 - 1344)}{1344} \times 100 = 0.88\%$	
30		1354	1372	$\frac{(1372 - 1354)}{1354} \times 100 = 1.33\%$

Table 10. Evaluation of % change between numbers of passes for 33 KN at 0-15 cm depth

Load in KN	Number of Passes				Percentage change in Bulk density
	1	5	10	15	
33	1300	1390			$\left\{ \frac{1390 - 1300}{1300} \right\} \times 100 = 6.92\%$
33		1390	1410		$\left\{ \frac{1410 - 1390}{1390} \right\} \times 100 = 1.44\%$
33			1410	1438	$\left\{ \frac{1438 - 1410}{1410} \right\} \times 100 = 1.98\%$

Table 11. Evaluation of % change between numbers of passes for 36 KN at 0-15 cm depth

Load in KN	Number of Passes				Percentage change in Bulk density
	1	5	10	15	
36	1322	1394			$\left\{ \frac{1394 - 1322}{1322} \right\} \times 100 = 5.446\%$
36		1394	1421		$\left\{ \frac{1421 - 1394}{1394} \right\} \times 100 = 1.94\%$
36			1421	1444	$\left\{ \frac{1444 - 1421}{1421} \right\} \times 100 = 1.62\%$

4.2.1.1. Effect of the number of passes on bulk density for selected loads on a 15- 30cm soil layer

The results of the varying number of passes for the selected loadings of 30 KN, 33 KN, and 36 KN were plotted against their respective bulk densities for every soil layer. In figure 17, The plotted results indicate that loading has an effect on the bulk density as well as the number of passes. The percentage change in bulk density increases with load and the number of passes. The percentage change in bulk density from single pass to five passes for 30KN, 33KN, and 36KN is 4.47%, 4.58%, and 5.51%, respectively, as shown in Tables 12, 13, and 14.

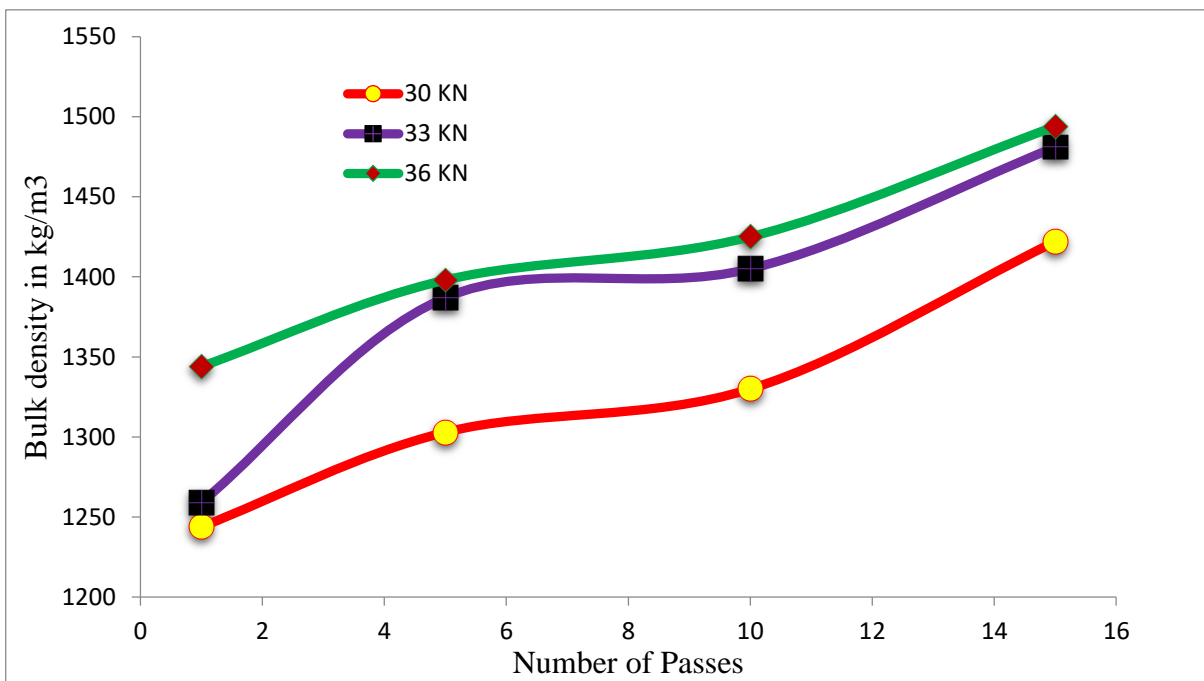


Figure 17. Effect of number of passes on Bulk density for selected loads for 15- 30cm

Table 12. Evaluation of % change between numbers of passes for 30 KN at 15- 30cm depth

Load in KN	Number of Passes				Percentage change in Bulk density
	1	5	10	15	
30	1,244	1290	1303	1420	$\left\{ \frac{1303 - 1244}{1244} \right\} \times 100 = 4.74\%$

$$30 \qquad 1290 \quad 1330 \qquad \left\{ \frac{1330 - 1303}{1303} \right\} \times 100 = 2.07\%$$

$$30 \qquad \qquad 1330 \quad 1380 \qquad \left\{ \frac{1380 - 1330}{1330} \right\} \times 100 = 3.76\%$$

Table 13.Evaluation of % change between numbers of passes for 33 KN at 15- 30cm depth

Load in KN	Number of Passes				Percentage change in Bulk density
	1	5	10	15	
33	1309	1,369			$\left\{ \frac{1309 - 1369}{1309} \right\} \times 100 = 4.58\%$
33		1,369	1405		$\left\{ \frac{1405 - 1369}{1369} \right\} \times 100 = 2.63\%$
33		1405	1481		$\left\{ \frac{1481 - 1405}{1481} \right\} \times 100 = 5.13\%$

Table 14.Evaluation of % change between numbers of passes for 36 KN at 15- 30cm depth

Load in KN	Number of Passes				Percentage change in Bulk density
	1	5	10	15	
36	1344	1418			$\left\{ \frac{1418 - 1344}{1344} \right\} \times 100 = 5.51\%$
36		1418	1455		$\left\{ \frac{1455 - 1418}{1418} \right\} \times 100 = 2.61\%$
36			1455	1520	$\left\{ \frac{1520 - 1455}{1455} \right\} \times 100 = 4.47\%$

4.2.1.2. Effect of the number of passes on bulk density for selected loads on a 30- 45cm soil layer

The results of the varying number of passes for the selected loading of 30 KN, 33kN and 36 KN were plotted against their respective bulk density for every soil layer. In figure 18

the plotted results indicate that loading has an effect on the bulk density as well as the number of passes. The percentage change bulk density is increased with load and number of passes. The lower level of load 30KN has less impact on percentage of bulk density increment when compared to medium load level 33KN and higher load level 36KN. The change in from single pass to for 30KN, 33KN, and 36KN is 3.5%, 6.44% and 7% respectively.

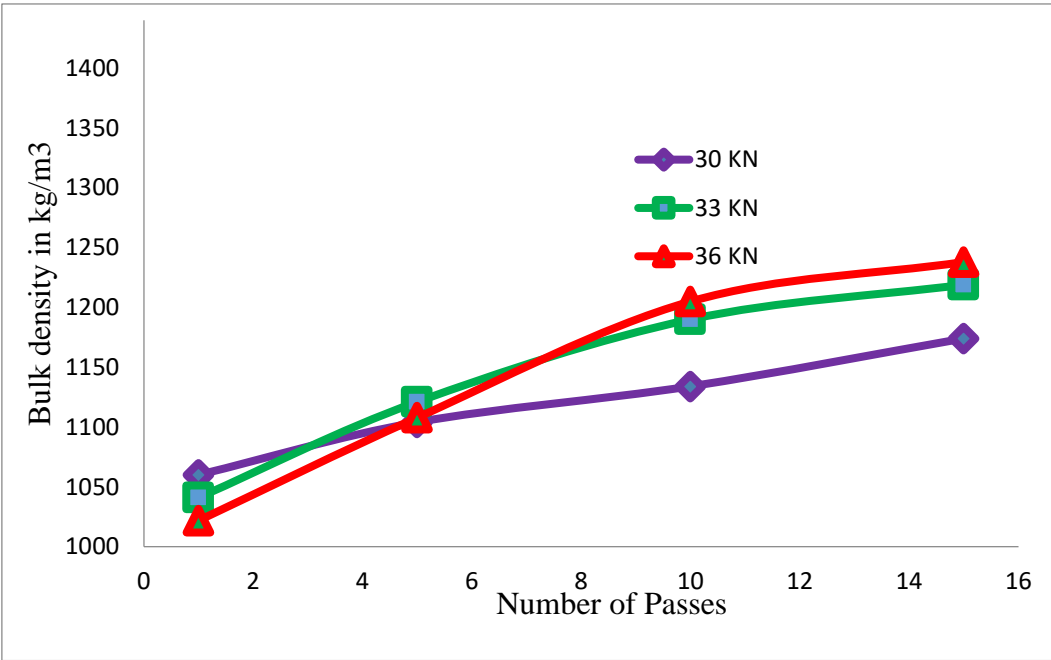


Figure 18.Effect of number of passes on Bulk density for selected loads for 30- 45cm

Table 15.Evaluation of % change between numbers of passes for 30 KN at 30- 45cm depth

Load in KN	Number of Passes				Percentage change in Bulk density
	1	5	10	15	
30	1260	1304			$\left\{ \frac{1304 - 1260}{1260} \right\} \times 100 = 3.5\%$
30		1304	1334		$\left\{ \frac{1334 - 1304}{1304} \right\} \times 100 = 2.3\%$

30	1334	1374	$\left\{ \frac{1374 - 1334}{1334} \right\} \times 100 = 3\%$
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Table 16. Evaluation of % change between numbers of passes for 33 KN at 30- 45cm depth

Load in KN	Number of Passes				Percentage change in Bulk density
	1	5	10	15	
33	1241	1321			$\left\{ \frac{1321 - 1241}{1241} \right\} \times 100 = 6.44\%$
33		1321	1390		$\left\{ \frac{1390 - 1321}{1321} \right\} \times 100 = 5.22\%$
33			1390	1419	$\left\{ \frac{1419 - 1390}{1390} \right\} \times 100 = 2.1\%$

Table 17. Evaluation of % change between numbers of passes for 36 KN at 30- 45cm depth

Load in KN	Number of Passes				Percentage change in Bulk density
	1	5	10	15	
36	1222	1308			$\left\{ \frac{1308 - 1222}{1222} \right\} \times 100 = 7\%$
36		1308	1370		$\left\{ \frac{1370 - 1308}{1308} \right\} \times 100 = 4.74\%$
36			1370	1438	$\left\{ \frac{1438 - 1370}{1370} \right\} \times 100 = 4.96\%$

4.2.1.3. Effect of the number of passes on bulk density for selected loads on a 45-60 cm soil layer

The results of the varying number of passes for the selected loading of 30 KN, 33kN and 36 KN were plotted against their respective bulk density for every soil layer. In figure 19 the plotted results indicate that loading has an effect on the bulk density as well as the number of passes. The percentage change bulk density is increased with load and number of passes. The lower level of load 30KN and medium load level 33 KN has less impact on percentage of bulk density increment when compared to higher load level 36 KN. The change in bulk density increment from single pass to five pass for 30KN, 33KN, and 36 KN is 1.6%, 5.65% and 16% respectively.

According to (Shaheb *et al.*, 2021) multiple passes in the field with a heavy tractor (wheel loads) increase the risk of severe soil structural damage deep into the sub-soil. The same trend happens to this higher load level has a higher impact than lower and medium load level.

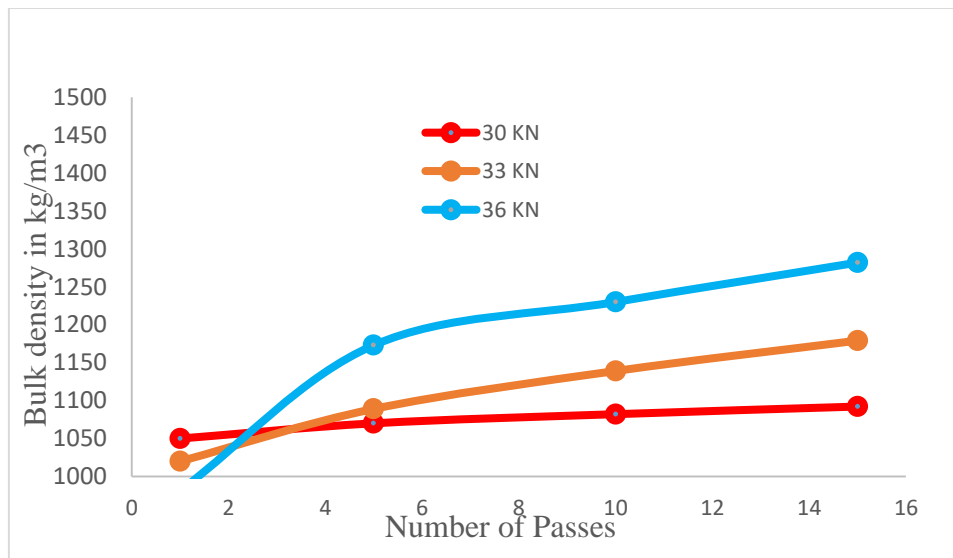


Figure 19. Effect of number of passes on Bulk density for selected loads for 45-60cm

Table 18. Evaluation of % change between numbers of passes for 30 KN at 45-60cm depth

Load in KN	Number of Passes				Percentage change in Bulk density
	1	5	10	15	
30					

30	1250	1270			$\left\{ \frac{1270 - 1250}{1250} \right\} \times 100 = 1.6\%$
30		1270	1282		$\left\{ \frac{1282 - 1270}{1270} \right\} \times 100 = 0.94\%$
30			1282	1292	$\left\{ \frac{1292 - 1282}{1282} \right\} \times 100 = 0.75\%$

Table 19.Evaluation of % change between numbers of passes for 33 KN at 45-60cm depth

Load in KN	Number of Passes				Percentage change in Bulk density
	1	5	10	15	
33	1220	1289			$\left\{ \frac{1289 - 1220}{1220} \right\} \times 100 = 5.65\%$
33		1289	1339		$\left\{ \frac{1339 - 1289}{1289} \right\} \times 100 = 3.87\%$
33			1339	1379	$\left\{ \frac{1379 - 1339}{1339} \right\} \times 100 = 2.98\%$

Table 20.Evaluation of % change between numbers of passes for 36 KN at 45-60cm depth

Load in KN	Number of Passes				Percentage change in Bulk density
	1	5	10	15	
36	1181	1373			$\left\{ \frac{1373 - 1181}{1181} \right\} \times 100 = 16.25\%$
36		1373	1430		$\left\{ \frac{1430 - 1373}{1373} \right\} \times 100 = 4.88\%$
36			1430	1482	$\left\{ \frac{1482 - 1430}{1430} \right\} \times 100 = 3.63\%$

4.2.2. Effect of the number of passes on bulk density for selected depths

The top soil layer has the highest bulk density and increases with increasing number of passes. In study of (Seifu *et al.*, 2022) Top layer of agricultural soil compaction by heavy agricultural machinery is one of the main negative factors which limits plant growth and crop yield.

The increase in bulk density between a single pass and 15 passes in the top layer is 7.72% (Table 21, 22 and 23). The second soil layer is less affected as the decrease in bulk density between first and the second layers for 1,5,10 and 15 passes are 4.74%, 2.07%, and 5.41% respectively. From this result the top layer has the lowest bulk density of 1270 kg/m³ and the highest is 1372 kg/m³. The 15-30 cm, 30-45cm and 45-60 cm are less affected though there is an increase in bulk density with corresponding change in the number of passes (Figure 20).

Tractor wheel compaction had a substantial impact on bulk density, and because it was found to rise with the number of tractor wheel passes, bulk density was generally higher in compacted soil. Conversely, zero compaction was associated with lower bulk density(Study *etal.*, 2015).

According to (Wesley & Ndiema, 2015) studied the impacts of compaction on a soil aggregate's pore size distribution at zero, three, and five passes. He came to the conclusion that as the number of passes rise, the pore diameters of the soil decrease. This suggests that the soil's volume has decreased but its bulk density has increased. Despite higher bulk density, the same pattern was seen with loading levels of 33 KN and 36 KN. Additionally, with the chosen amounts of loading, there is a general reduction in bulk density with increasing depth.

Low (macro) porosity, low pore continuity, and low pore connectivity are common features of damaged soil structures found in compacted soils. The crop production and other ecosystem services provided by arable soil are negatively impacted by the structural degradation, which can endure for decades. The interactions and feedbacks, soil penetration resistance, oxygen concentration in soil air, soil moisture, root growth, and the plants' accessibility to water and nutrients are all affected by low crop productivity on compacted soil (Colombi & Keller, 2019). Because of the increase in bulk density, the soil cannot allow for water penetration and roots cannot continue to grow. The high bulk density will cause greater surface drainage, which will lead to poor yields. His study established a link between soil compaction and crop root length and agricultural productivity.

According to (Castioni *et al.*, 2021) Every equipment activity resulted in a constant increase in BD and SPR, yet the size and significance of the changes varied depending on the soil layers. BD, for instance, increased significantly by 8% at 2.5 cm (from 1.60 to 1.74 Mg m⁻³), but no significant changes were seen at deeper levels.

According to (Shaheb *et al.*, 2021) Conversely, increases in vehicle/wheel load, at a given ground pressure, induce considerable increases in compaction at deeper depths. High ground pressure significantly increases soil BD of topsoil, but has little influence at greater depths.

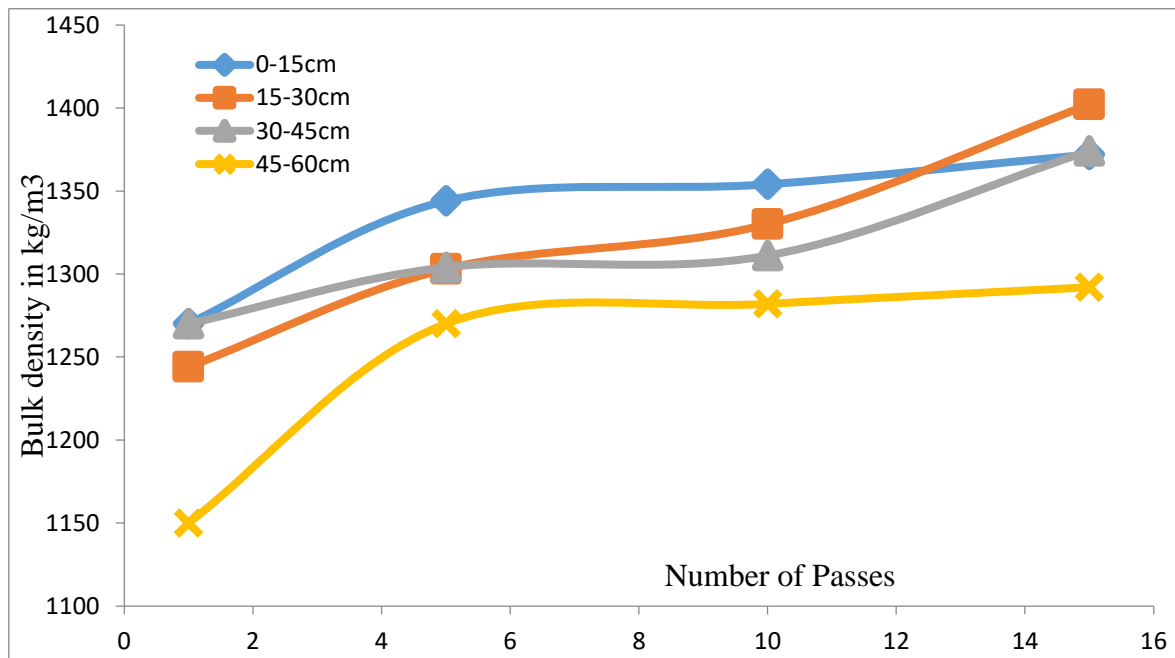


Figure 20. Effect of number of passes on BD for selected depths for a loading of 30 kN.

Table 21. Evaluation of % change between numbers of passes for 0-15cm depth

Depth in cm	Number of passes				Percentage change in Bulk density
	1	5	10	15	
0-15 cm	1270	1344			$\left\{ \frac{1344 - 1270}{1270} \right\} \times 100 = 5.83\%$
0-15 cm		1344	1354		$\left\{ \frac{1354 - 1344}{1344} \right\} \times 100 = 0.744\%$

$$0-15 \text{ cm} \quad 1354 \quad 1372 \quad \left\{ \frac{1372-1354}{1354} \right\} \times 100 = 1.33\%$$

Table 22. Evaluation of % change between numbers of passes for 15-30cm depth

Depth in cm	Number of passes				Percentage change in Bulk density
	1	5	10	15	
15-30 cm	1244	1303			$\left\{ \frac{1303 - 1244}{1244} \right\} \times 100 = 4.74\%$
15-30 cm		1303	1330		$\left\{ \frac{1330 - 1303}{1303} \right\} \times 100 = 2.07\%$
15-30 cm			1330	1402	$\left\{ \frac{1422 - 1330}{1330} \right\} \times 100 = 5.41\%$

Table 23. Evaluation of % change between numbers of passes for 15-30cm depth

Depth in cm	Number of passes				Percentage change in Bulk density
	1	5	10	15	
30-45 cm	1270	1304			$\left\{ \frac{1304 - 1270}{1270} \right\} \times 100 = 2.67\%$
30-45 cm		1304	1311		$\left\{ \frac{1311 - 1304}{1304} \right\} \times 100 = 0.54\%$
30-45 cm			1311	1374	$\left\{ \frac{1374 - 1311}{1311} \right\} \times 100 = 4.8\%$

Table 24. Evaluation of % change between numbers of passes for 45-60cm depth

Depth in cm	Number of passes				Percentage change in Bulk density
	1	5	10	15	
45-60 cm	1250	1270			$\left\{ \frac{1270 - 1250}{1250} \right\} \times 100 = 1.6\%$
45-60 cm		1270	1282		$\left\{ \frac{1282 - 1270}{1270} \right\} \times 100 = 0.944\%$

45-60 cm	1282	1292	$\left\{ \frac{1292 - 1282}{1282} \right\} \times 100 = 0.78\%$
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4.2.3. Effect of loading on bulk density for selected number of passes

The bulk density for a single pass shows a linear relationship (Figure 21) and ranges from 1270 kg/m³ to 1322 kg/m³, with the lowest bulk density since it had just been plowed and harrowed in anticipation of planting and had no effects from previous farm operations. The aforementioned relationships show how loading affects bulk density, which grows with increasing loading. According to Table 21, the difference in bulk density between one pass and five passes at a loading level of 30kN is 5.83%.

in a study (Keller & Or, 2022) A repeated run over the same area of ground could result in serious soil compaction. Assessed how many tractor passes had an effect on soil density. The results unmistakably demonstrate that, compared to several repeated runs, a single pass had a substantially lower influence on or compaction of the soil. In a study (Šimečková *et al.*, 2021) At both of the investigated tire pressures, the tractor's passage increased bulk density while decreasing total porosity and minimum air capacity. According to (Felix, 2021) Compaction caused a somewhat reduced infiltration in the tractor tire passage area. The adverse impact of soil compaction on soil water infiltration was verified by the measurements of unsaturated hydraulic conductivity.

According to (Study *et al.*, 2015) studied infiltration rate of the soil reduces with an increase in the numbers of passes. The bulk density increases with an increase in the number of passes and both reduce the yield and growth of the crop.

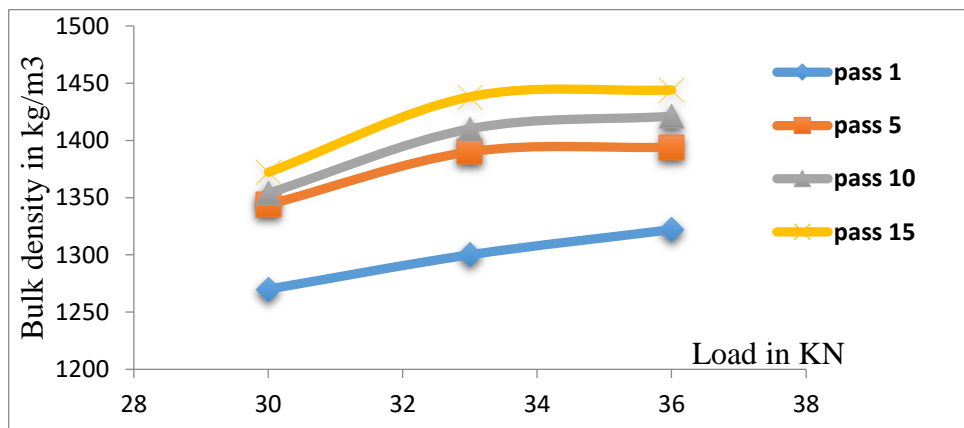


Figure 21. Effect of loading on BD for selected number of passes for 0-15 cm layer

4.3. Effects of Loading and Number of Passes on Penetration Resistance

4.3.1. The 0-15 cm soil layer with varying loading level

The least impacted soil layer is the top layer, which is often influenced by all farming activities (Figure 22).according to (Tonui & Mutuli, 2016) studied As the loading increases, the penetration resistance rises. Additionally, it rises as the quantity of passes rises. The resistance increased by 70% with a loading intensity of 30kN from initial penetration resistance of 9.2 J/cm for one pass to 15.64 J/cm after 15 passes. The penetration resistance increases when the burden is raised. Additionally, it increases as more passes are made. The highest penetration resistance for this layer is 29.84 J/cm for the heaviest loading and most passes.

According to (Canillas & Salokhe, 2021) study that when performing machinery operations in the field, soil compaction is greatly influenced by the axle load and the number of tire passes. By varying the number of tractors' passes, they examined macro-porosity, pore shape and size distribution, bulk density, penetration resistance, and saturated hydraulic conductivity.

Wheat crops suffer from the harmful effects of compacted soil. Due to heavy compaction, wheat's root and shoot are shorter overall . Wheat is a shallow-rooted plant, therefore its short roots cause the plant to pick up less moisture. Due to the delay in development processes brought on by soil compaction, wheat plants' fresh and dry weights also decreased. Also noted were fewer tillers. All of these outcomes ultimately result in a low yield of wheat (Kumar et al., 2018).

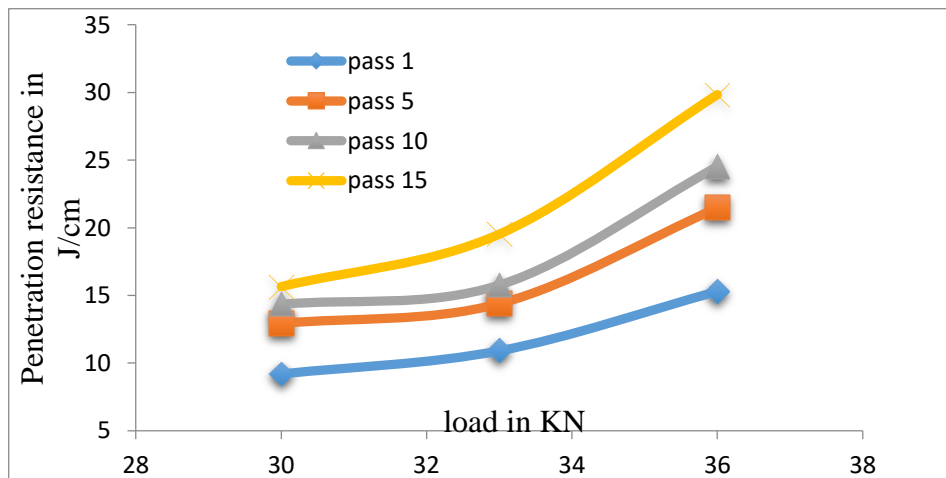


Figure 22. Effect of loading on PR for selected number of passes for 0-15 cm depth

4.3.2. Effects of the number of passes on PR for selected depths and various loading.

The influence of pass number is shown in Figure 23 in a way that makes it obvious that more passes have a bigger impact on penetration resistance than a single pass does. 15.86 J/cm for a single pass and 42.2 J/cm for fifteen passes were the penetration resistance values for the 45-60 cm layer. The most passes influence every one of the selected soil layers. Because of this, as the number of passes rises, the impact on the soil penetrates deeper into the soil.

According to (Tonui & Mutuli, 2016) The highest number of passes affects all the selected soil layers. This means that as you increase the number of passes the impact on the soil goes deeper into the soil. The same trend applies to all the other loading levels of 33 kN and 36 kN

According to (Botta *et al.*, 2020) studied soil penetration resistance (strength) increased and water infiltration into soil decreased as traffic intensities.

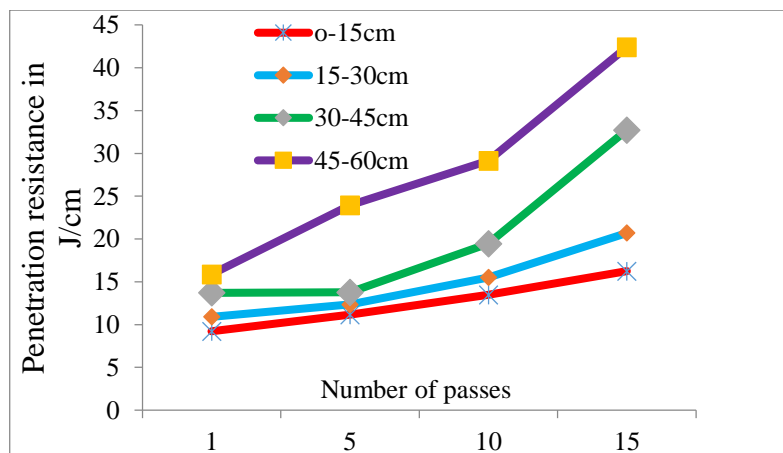


Figure 23. Effects of the Number of passes on PR for selected depth range at NL of 30 kN

4.3.3. Effect of number of passes on PR on 0-15 cm soil layer with selected load

The number of passes and the chosen loads indicate that the penetrating resistance increases as the number of passes rises. In addition, the increased loading causes a vertical increase in penetration resistance (Figure 24c). The increase is 70.6% when the numbers of passes are compared for one pass and 15 passes at 30 kN, and it is the same for a loading level of 33 kN.

According to Colombia & Keller (2019), high soil penetration resistance, oxygen content in soil air, soil wetness, root growth, and the plants' accessibility to water and nutrients interact and feed back to cause low yields on compacted soil.

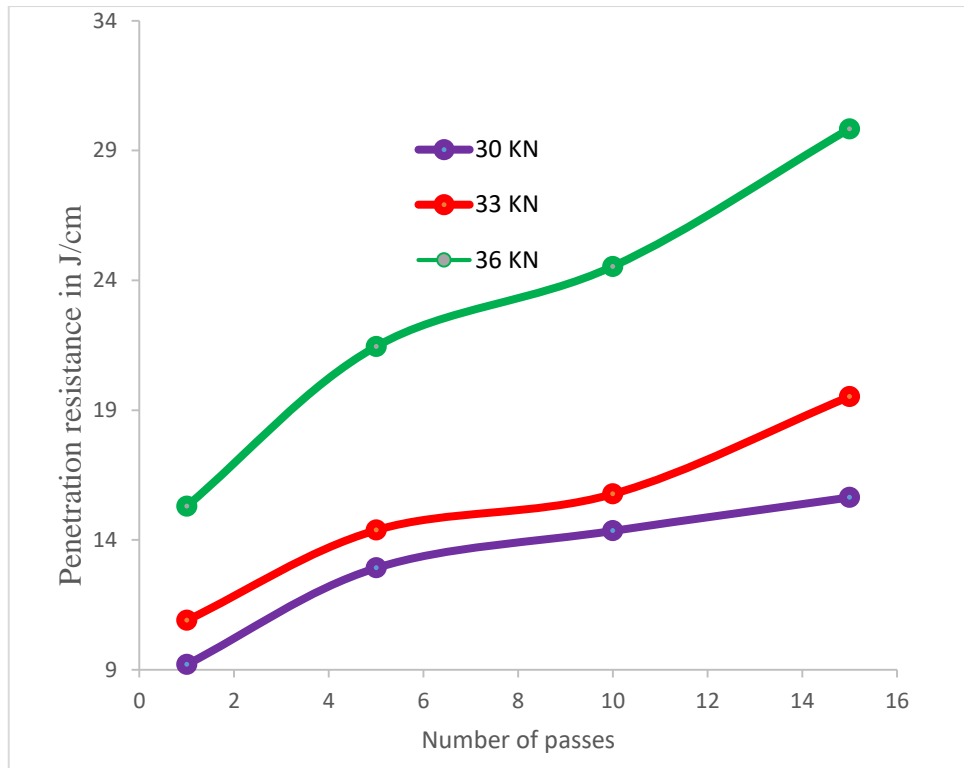


Figure 24. Effect of number of passes on PR for selected loads for 0-15 cm soil layer

4.4. Analysis of variance for Bulk density

Using the stepwise technique in Minitab software, a multiple regression analysis of variance for bulk density was performed with a 95% confidence interval and a P-value of = 0.05. The ANOVA table (Table 25) shows the results. At the 95% confidence level, and P-value of = 0.00 for the load, number of passes and depth are all significant.

Table 25. Analysis of Variance (ANOVA) for bulk density

Source	DF	SS	MS	F-Value	P-Value
D	3	68874	22958	19.06	0.000
P	3	195930	65310	54.23	0.000
L	2	56370	28185	23.40	0.000
Error	39	46965	1204		
Total	47	368139			

Coefficient of determination (R^2) = 0.8724

- Where: BD is Bulk density (kg/m³),
- D is Depth (cm),
- L is Load (kN)
- P is Passes

4.4.1. Bulk density regression equation

Regression Equation for predicting the bulk density at a given depth, loads and number of passes was developed using Minitab software by stepwise method and the final equation is given by equation 4.1. The regression equation is

$$BD = 846 - 2.02D + 14.0L + 11.9P \dots\dots\dots 4.1$$

- Where: BD is Bulk density (kg/m³),
- D is Depth (cm),
- L is Load (kN)
- P is Passes

It was determined using Minitab's principal component analysis (PCA) method that the final bulk density in equation 4.1 is made up of 0.475 percentage of loading, 0.25 proportions of passes, and finally 0.25 proportion of depth (Table 26). The findings indicate that the loading has the greatest influence on bulk density and is responsible for 47.5% of soil compaction, while the depth and number of passes are each responsible for 25%. This demonstrates that compared to the quantity of passes, axle load is the dominant factor contributing to subsurface compaction. According to (Shah *et al.*, 2017) It has been noted that a variety of elements, including soil physical characteristics, wheeling load, and number of passing, interact to cause soil to become susceptible to compacting.

Table 26.Principal component analysis for bulk density

	L	D	P	BD
Variance	1.9003	1.0000	1.0000	0.0997
Proportion	0.475	0.250	0.250	0.025
Cum.Proportion	47.5%	72..5%	97.5%	100%

4.5. Analysis of variance for Penetration Resistance

Utilizing the stepwise technique, a 95% confidence interval, and a P-value of 0.05, the multiple regression analyses of variance for penetration resistance was completed. On the ANOVA table (Table 27), the results are shown. Results analysis indicates that, at a 95% confidence level, the P-value = 0.00 for the load, and depth, as well as the P-value of = 0.002 for numbers of passes are all significant.

Table 27. Analysis of Variance (ANOVA) for penetration resistance

Source	DF	SS	MS	F-Value	P-Value
D	3	14502.3	4834.1	14.41	0.000
P	3	6008.1	2002.7	5.97	0.002
L	2	20010.7	10005.3	29.82	0.000
Error	39	13086.4	335.5		
Total	47	53607.5			

Coefficient of determination (R^2) = 0.8674

4.5.1. Penetration resistance analysis regression equation.

The penetration resistance regression equation was developed based on the loading, number of passes and depth. The proposed regression equation for the prediction of penetration resistance at any given depth, load and number of passes is given by Equation 4.2

$$PR = - 278 + 8.32L + 1.01D + 2.11P \dots\dots\dots 4.2$$

Where: PR is Penetration resistance (J/cm),

D is Depth (Cm),

L is Load (kN)

P is Passes.

Using Principal component analysis (PCA) method it was established in Minitab that in equation 4.2 the final penetration resistance consist of 0.465 proportion of loading, 0.25 proportion numbers of passes and finally 0.25 proportion of depth (Table 28).according to (Tonui & Mutuli, 2016) studied the loading has the highest impact on the penetration resistance and contributes 46% to soil compaction while the number of passes and depth contribute 25% each the same trend happened the loading has the highest impact on the penetration resistance and contributes 46.5% to soil compaction while the number of passes and depth contribute 25% each.

Table 28. Principal component analysis for penetration resistance

	L	D	P	PR
Variance	1.8603	1.00	1.00	0.1397
Proportion	0.465	0.25	0.25	0.035
Cum. Proportion	46.5%	71.5%	96.5%	100%

4.6. Bulk Density for 30-45cm with a Fitted Line

The results of soil layer 30-45cm displayed graphically displays a second degree polynomial relationship with the coefficient of determination of 0.939 and 0.9512 for 30 kN and 36 kN test results (Figure 25)

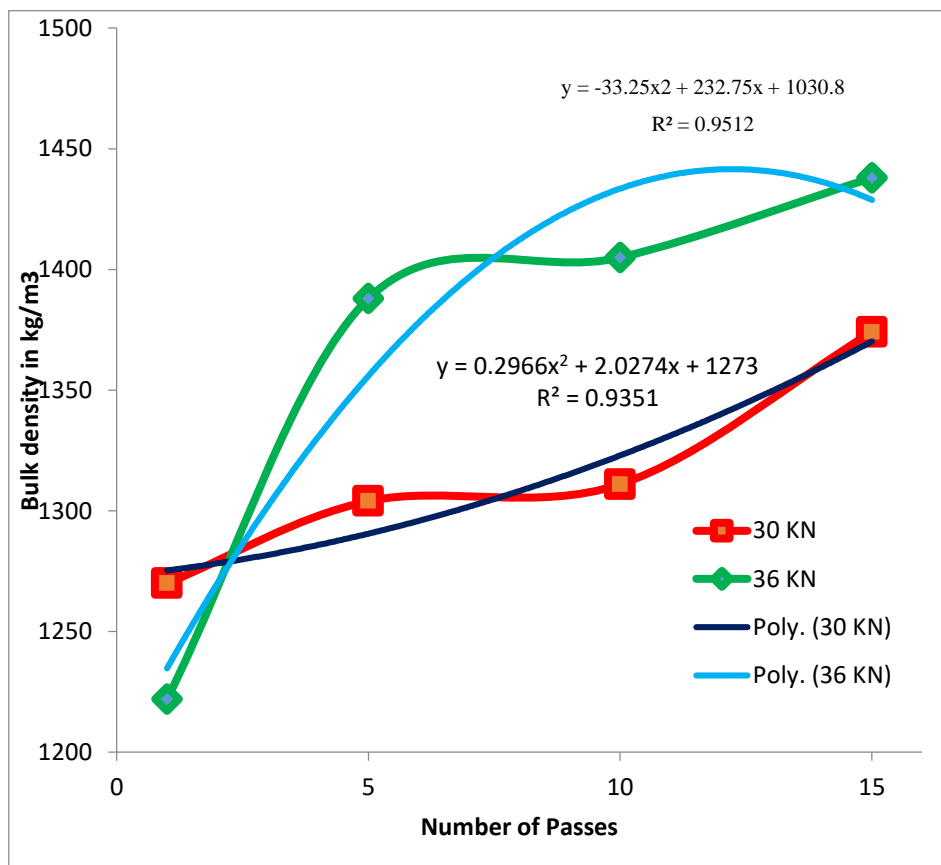


Figure 25. Fitted lines to measured results of bulk density for 30 kN and 36 kN

4.7. Penetration Resistance for 30-45cm with a Fitted Line

The results of soil layer 30-45cm displayed graphically displays a second-degree polynomial relationship with the coefficient of determination of 0.9992 and 0.9817 for 30kN and 36kN test results (Figure 26)

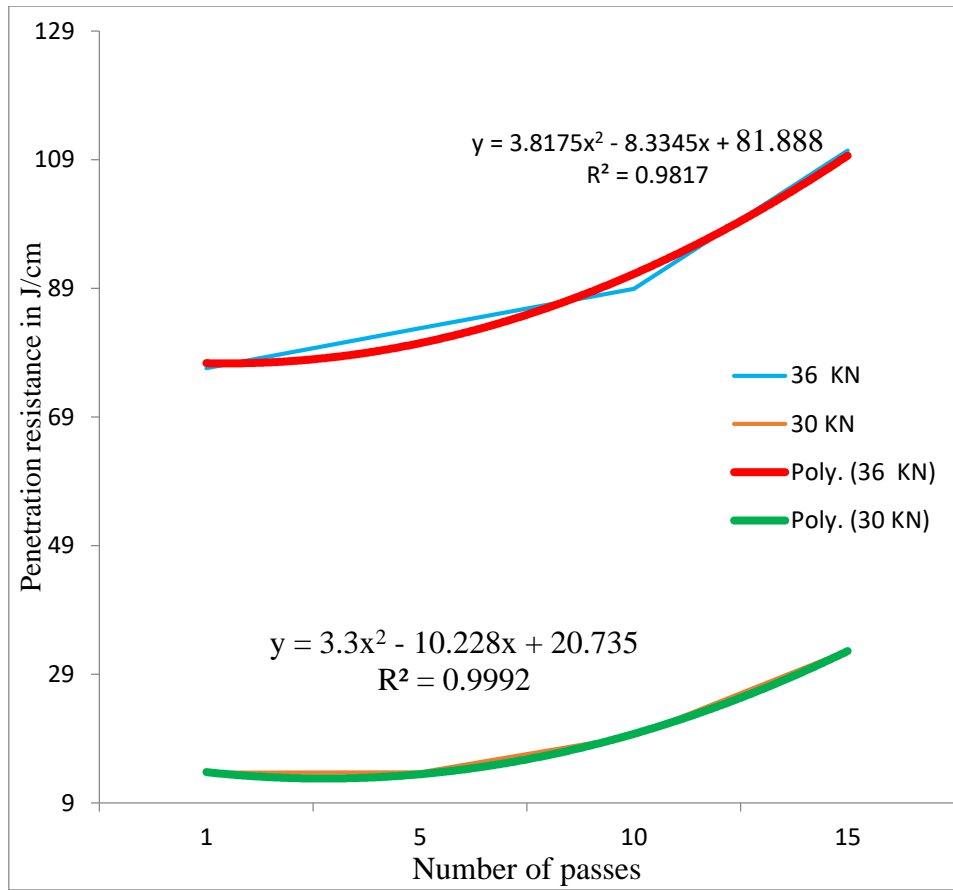


Figure 26. Fitted lines measured results of Penetration resistance for 30 kN and 36 kN

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusions

The soil texture based on USDA textural soil triangle was classified as sand clay loam by Kulumsa Agricultural Research center. The maximum dry density (MDD) and the optimum moisture content (OMC) was 1589.3 kg/m^3 and 24.65% respectively. Observed bulk density 1150 to 1494 kg/m^3 and the Relative compaction was 72.35% to 94% the moisture content during the experiment was 24.084%. Observed penetration resistance was 9.2 to 153 J/cm.

- The topsoil layer was highly affected by loads, and bulk density dropped as depth rose. With increasing depth, a lower load level has less of an effect.
- The bulk density of the topsoil layer is the highest and rises with the number of passes and load.
- The effects of the number of passes are felt in all treatments between the first pass and five passes. This demonstrates clearly how changes in loading and the number of passes have an impact on bulk density.
- Bulk density increased with the increase in the number of passes.
- Of the three factors that contribute to soil compaction, loading has the greatest effect on bulk density and accounts for 47.5% of it, while the depth and number of passes each make up 25%.
- Increased soil compaction is largely a function of increasing the gross weight of the machinery and the quantity of passes.
- Penetration resistance was shown to be significantly impacted by loading and the number of passes.
- With an increase in loading and passes, the penetration resistance rises.
- The number of passes and depth both contribute 25%, but loading has the greatest effect on the penetration resistance and is responsible for 46.5% of soil compaction.
- Compared to the number of passes, the increase in loading has a greater impact on the soil's lower layers.
- The coefficients of determination (R^2) for bulk density and penetration resistance were found to be of 0.8724 and 0.8674, respectively.

5.2. Recommendation

- It is required to make an effort to minimize the wheel load and the number of passes performed by agricultural machinery during the cropping seasons in order to manage soil compaction sustainably;
- Throughout agricultural operations, the plant operators should receive training to reduce the number of runs on the same tire track.
- The study also showed that increasing the axle load on the machinery has the most negative effects on the soil and can even influence the subsurface. As a result, wherever feasible, the axle load should not be increased unnecessarily.
- To address the extra load on the axle, the machine setting can be adjusted.
- Deep tillage practices, normally referred to as sub soiling should be carried out on soils confirmed to be compacted. This is aimed at restoring the lost soil properties and involves loosening compacted soil layers below the ploughing depth, without inverting them. Sub soiling leads to improved root growth and water and nutrient infiltration.
- Use of the proper equipment for field activities could reduce soil compaction.
- A way to reduce soil compaction. Healthy farming techniques including crop rotation with legume crops, tilling soil at various depths with the right amount of moisture, using equipment in top operating conditions, and lowering machine vertical pressure on the ground helps prevent potential compaction.
- The development of lightweight farm equipment should be the main focus of future studies.
- The current study concentrated on the impact of load, number of passes, and depth on soil compaction at constant speed and standard tire pressure. In addition to the previously mentioned elements, it will be required to investigate in future studies how tire inflation pressure and forward speed impact soil compaction.

REFERENCE

- Abich, S. O., Gitau, A. N., & Nyaanga, D. M. (2022). Effect of soil compaction on physico-mechanical properties of silt loam soils of Njoro, Kenya. *Agricultural Engineering International: CIGR Journal*, 24(4), 20–29.
- Adeniji, F., Umara, B., Dibal, J., Adv, K. O.-I. J. E. T., & 2013, undefined. (2008). Determination of Compaction Characteristics of Maiduguri Soil. *Citeseer*, 9001(9), 478–482.
- Al-Shammari, A. A. G., Kouzani, A. Z., Kaynak, A., Khoo, S. Y., Norton, M., & Gates, W. (2018). Soil Bulk Density Estimation Methods: A Review. *Pedosphere*, 28(4), 581–596.
- Augustin, K., Kuhwald, M., Brunotte, J., & Duttmann, R. (2020). Wheel load and wheel pass frequency as indicators for soil compaction risk: A four-year analysis of traffic intensity at field scale. *Geosciences (Switzerland)*, 10(8), 1–15.
- Bartzen, B. T., Hoelscher, G. L., Ribeiro, L. L. O., & Seidel, E. P. (2019). How the Soil Resistance to Penetration Affects the Development of Agricultural Crops? *Journal of Experimental Agriculture International*, 30(5), 1–17.
- Ben Hassen, H., Elaoud, A., & Masmoudi, K. (2020). Modeling of agricultural soil compaction using discrete Bayesian networks. *International Journal of Environmental Science and Technology*, 17(5), 2571–2582.
- Botta, G. F., Antille, D. L., Bienvenido, F., Rivero, D., Avila-Pedraza, E. A., Contessotto, E. E., Ghelfi, D. G., Nistal, A. I., Pelizzari, F. M., Rocha-Meneses, L., & Ezquerria Canalejo, A. (2020). Effect of cattle trampling and farm machinery traffic on soil compaction of an entic haplustoll in a Semiarid region of Argentina. *Agronomy Research*, 18(Special Issue 2), 1163–1176. <https://doi.org/10.15159/AR.20.063>
- Botta, G. F., Tolon-Becerra, A., Tourn, M., Lastra-Bravo, X., & Rivero, D. (2012). Agricultural traffic: Motion resistance and soil compaction in relation to tractor design and different soil conditions. *Soil and Tillage Research*, 120, 92–98.
- Canillas, E. C., & Salokhe, V. M. (2001). Regression analysis of some factors influencing soil compaction. *Soil and Tillage Research*, 61(3–4), 167–178.
- Capello, G., Biddoccu, M., Ferraris, S., & Cavallo, E. (2019). Effects of tractor passes on hydrological and soil erosion processes in tilled and grassed vineyards. *Water (Switzerland)*, 11(10).

- Castioni, G. A. F., de Lima, R. P., Cherubin, M. R., Bordonal, R. O., Rolim, M. M., & Carvalho, J. L. N. (2021). Machinery traffic in sugarcane straw removal operation: Stress transmitted and soil compaction. *Soil and Tillage Research*, 213(November 2020).
- Colombi, T., & Keller, T. (2019). Developing strategies to recover crop productivity after soil compaction—A plant eco-physiological perspective. *Soil and Tillage Research*, 191(December 2018), 156–161.
- Defosse, P., & Richard, G. (2002). Models of soil compaction due to traffic and their evaluation. *Soil and Tillage Research*, 67(1), 41–64.
- Donkoh, E., Degenstein, J., & Ji, Y. (2012). Process integration and economics evaluation of sugar beet pulp conversion into ethanol. *International Journal of Agricultural and Biological Engineering*, 5(2), 1–8.
- Edrri, M. K., Al-Gaadi, K. A., Hassaballa, A. A., Tola, E., & Ahmed, K. A. M. (2020). Impact of soil compaction on the engineering properties of potato tubers. *International Journal of Agricultural and Biological Engineering*, 13(2), 163–167.
- Felix, K. A. (2021). Effect of agricultural machinery on physical and hydraulic properties of agricultural soils. *Journal of Soil Science and Environmental Management*, 12(2), 58–66.
- Gebrekidan, B. Z. (2022). *Optimization of Machine Tractor Out t : - Case of Disc Plough*. 0–23.
- Gratchev, I., Jeng, D.-S., & Oh, E. (2019). Soil compaction. In *Soil Mechanics Through Project-Based Learning* (Number 155).
- Guimarães Júnnyor, W. da S., Diserens, E., De Maria, I. C., Araujo-Junior, C. F., Farhate, C. V. V., & de Souza, Z. M. (2019). Prediction of soil stresses and compaction due to agricultural machines in sugarcane cultivation systems with and without crop rotation. *Science of the Total Environment*, 681, 424–434.
- Hassan, W., Ahmad, M., Farooq, A., Ajwad, A., Ali, H. Q., & Ilyas, Y. (n.d.). *Correlation of Maximum Laboratory Dry Density and Optimum Moisture Content of Soil with Soil Parameters*. 1–6.
- Hu, W., Jia, X., Zhu, X., Su, A., Du, Y., & Huang, B. (2020). Influence of moisture content on intelligent soil compaction. *Automation in Construction*, 113(November 2018), 103141.
- Keller, T. (2022). *Farm vehicles approaching weights of sauropods exceed safe mechanical limits for soil functioning*. 1–6.

- Keller, T., & Or, D. (2022). Farm vehicles approaching weights of sauropods exceed safe mechanical limits for soil functioning. *Proceedings of the National Academy of Sciences of the United States of America*, 119(21), 1–6.
- Keller, T., Sandin, M., Colombi, T., Horn, R., & Or, D. (2019). Historical increase in agricultural machinery weights enhanced soil stress levels and adversely affected soil functioning. *Soil and Tillage Research*, 194(May), 104293.
- Kumar, V., Jain, M., Rani, V., Kumar, A., Kumar, S., & Naresh. (2018). A Review of Soil Compaction- Concerns, Causes and Alleviation. *International Journal of Plant & Soil Science*, 22(4), 1–9.
- Lamandé, M., Greve, M. H., & Schjønning, P. (2018). Risk assessment of soil compaction in Europe – Rubber tracks or wheels on machinery. *Catena*, 167(January), 353–362.
- Macrì, G., De Rossi, A., Papandrea, S., Micalizzi, F., Russo, D., & Settineri, G. (2017). Evaluation of soil compaction caused by passages of farm tractor in a forest in southern Italy. *Agronomy Research*, 15(2), 478–489.
- Mudarisov, S., Gainullin, I., Gabitov, I., Hasanov, E., & Farhutdinov, I. (2020). Soil compaction management: Reduce soil compaction using a chain-track tractor. *Journal of Terramechanics*, 89, 1–12.
- Obour, P. B., & Ugarte, C. M. (2021). A meta-analysis of the impact of traffic-induced compaction on soil physical properties and grain yield. *Soil and Tillage Research*, 211(August 2020), 105019.
- Ogbeche, S. (2019). *Overview of Engineering Problems of Soil Compaction and Their Effects on Growth and Yields of Crops Overview of Engineering Problems of Soil Compaction and Their Effects on Growth and Yields of Crops*. July.
- Orzech, K., Wanic, M., & Załuski, D. (2021). The effects of soil compaction and different tillage systems on the bulk density and moisture content of soil and the yields of winter oilseed rape and cereals. *Agriculture (Switzerland)*, 11(7), 1–17.
- Parvin, N., Coucheney, E., Gren, I.-M., Andersson, H., Elofsson, K., Jarvis, N., & Keller, T. (2022). On the relationships between the size of agricultural machinery, soil quality and net revenues for farmers and society. *Soil Security*, 6, 100044.
- Pott, L. P., Amado, T. J. C., Leal, O. A., & Ciampitti, I. A. (2020). Mitigation of soil compaction for boosting crop productivity at varying yield environments in southern

- Brazil. *European Journal of Soil Science*, 71(6), 1157–1172.
- Schjøning, P. (2023). An empirical model for prediction of topsoil deformation in field traffic. *Soil and Tillage Research*, 227(November 2022).
- Schjøning, P., van den Akker, J. J. H., Keller, T., Greve, M. H., Lamandé, M., Simojoki, A., Stettler, M., Arvidsson, J., & Breuning-Madsen, H. (2015). Driver-Pressure-State-Impact-Response (DPSIR) analysis and risk assessment for soil compaction-A European perspective. In *Advances in Agronomy* (Vol 133). Elsevier Ltd.
- Seehusen, T., Mordhorst, A., Riggert, R., Fleige, H., Horn, R., & Riley, H. (2021). Subsoil compaction of a clay soil in South-East Norway and its amelioration after 5 years. *International Agrophysics*, 35(2), 145–157.
- Seifu, Y., Hiremath, S. S., Tola, S., & Wako, A. (2022). Modelling and Simulation of Hydraulic System to Measure Soil Compaction for Agricultural Field. *Ethiopian Journal of Science and Sustainable Development*, 9(1), 2022.
- Shah, A. N., Tanveer, M., Shahzad, B., Yang, G., Fahad, S., Ali, S., Bukhari, M. A., Tung, S. A., Hafeez, A., & Souliyanonh, B. (2017). Soil compaction effects on soil health and cropproductivity: an overview. *Environmental Science and Pollution Research*, 24(11), 10056–10067.
- Shaheb, M. R., Venkatesh, R., & Shearer, S. A. (2021). A Review on the Effect of Soil Compaction and its Management for Sustainable Crop Production. *Journal of Biosystems Engineering*, 46(4), 417–439.
- Šimečková, J., Polcar, A., Hammerová, A., Votava, J., & Kumbár, V. (2021). *Changes to the physical properties of the soil after the passage of an agricultural tractor ***. 97–105.
- Study, A. C., Lower, O. F., & Farm, B. (2015). *Effect of tractor wheel compaction on soil for crop yield (a case study of lower niger river basin farm)*. 5(1), 8–14.
- Sutarno, M. S., & Mohamad, H. M. (2023). *Peat Soil Compaction Characteristic and Physicochemical Changes Treated with Eco-Processed Pozzolan (EPP (. January.*
- Tonui, W., & Mutuli, D. (2016). *Determination of Soil Compaction Cultivated Fields Using Dynamic Cone*. August.
- Wesley, E. T., & Ndiema, P. C. (2015). *Assessment of Soil Compaction Levels by Farm Machinery in Cultivated Fields of Elfam Farm*. 6, 95–100.
- Xia, Q., Ruffy, T., & Shi, W. (2020). Soil microbial diversity and composition: Links to soil

- texture and associated properties. *Soil Biology and Biochemistry*, 149, 107953.
- Yamamuro, J. A., & Lade, P. V. (1997). Static liquefaction of very loose sands. *Canadian Geotechnical Journal*, 34(6), 905–917. <https://doi.org/10.1139/cgj-34-6-905>
- Zabrodskyi, A., Šarauskis, E., Kukharets, S., Juostas, A., Vasiliauskas, G., & Andriušis, A. (2021). Analysis of the impact of soil compaction on the environment and agricultural economic losses in Lithuania and Ukraine. *Sustainability (Switzerland)*, 13(14).

Appendix I: Bulk Density Data

Table 29. BD kg/m³ with changing normal load and number of passes in the 0-15cm depth

Number of Passes				
Load(KN)	1	5	10	15
30	1270	1344	1354	1372
33	1300	1390	1410	1438
36	1322	1394	1421	1444

Table 30. BD in kg/m³ with changing NL and number of passes in -the 15-30 cm *depth*

Number of Passes				
Load(KN)	1	5	10	15
30	1244	1303	1330	1402
33	1259	1387	1405	1481
36	1344	1398	1425	1494

Table 31. BD kg/m³ with changing NL and number of passes in -the 30 -45cm *depth*

Number of Passes				
Load(KN)	1	5	10	15
30	1170	1304	1311	1374
33	1181	1321	1390	1419
36	1222	1388	1405	1438

Table 32. BD in kg/m³ with changing NL and number of passes in -the 45-60 cm *depth*

Number of Passes				
Load(KN)	1	5	10	15
30	1250	1270	1282	1292
33	1220	1289	1339	1379
36	1181	1373	1430	1482

Table 33. Variation in BD in kg/m³ with depth at number of passes at a NL of 30 KN

Number of Passes				
Depth (cm)	1	5	10	15
7.5	1270	1344	1354	1372
22.5	1244	1303	1330	1422
37.5	1270	1304	1311	1374
52.5	1150	1170	1282	1292

Table 34. Variation in BD kg/m³ with depth at varying number of passes at a NL of 33 KN

Number of Passes				
Depth (cm)	1	5	10	15
7.5	1300	1390	1410	1438
22.5	1259	1387	1405	1481
37.5	1181	1321	1390	1419
52.5	1165	1189	1339	1379

Table 35. Variation in BD kg/m³ with depth at varying number of passes at a NL of 36 KN

Number of Passes				
Depth (cm)	1	5	10	15
7.5	1322	1394	1421	1444
22.5	1344	1398	1425	1494
37.5	1222	1388	1405	1438
52.5	1181	1373	1391	1419

Appendix II: Penetration Resistance Data

Table 36. Variation in PR (J/cm with Depth at a Various Number of Passes at a NL of 30 KN)

Number of passes				
Depth (cm)	1	5	10	15
7.5	9.2	11.15	13.47	16.24
22.5	10.91	12.35	15.50	20.70
37.5	13.71	13.77	19.46	32.72
52.5	15.86	23.94	29.14	42.4

Table 37. Variation in PR J/cm with depth at varying number of passes at a NL of 33 KN

Number of passes				
Depth (cm)	1	5	10	15
7.5	10.91	21.46	30.67	33.73
22.5	15.3	39.87	39.46	52.13
37.5	36.8	42.92	55.2	82.8
52.5	46	53.13	58.27	85.86

Table 36. Variation in PR J/cm with depth at varying number of passes at a NL of 36 KN

Number of passes				
Depth (cm)	1	5	10	15
7.5	15.3	21.46	24.53	29.84
22.5	27.6	36.8	39.46	42.92
37.5	76.6	82.8	88.93	110.4
52.5	82.8	92	138	153

Table 37. Variation in PR J/cm with NL at a Varying Number of Passes for the 0–15 cm

Number of passes				
Load(KN)	1	5	10	15
30	9.2	12.92	14.35	15.64
33	10.91	14.38	15.77	19.52
36	15.3	21.46	24.53	29.84

Table 38. Variation in PR in J/cm with NL at varying number of passes for the 15–30 cm

Number of passes				
Load(KN)	1	5	10	15
30	10.91	12.35	15.50	20.70
33	15.3	39.87	39.46	52.13
36	27.6	36.8	39.46	42.92

Table 39. Variation in PR in J/cm with NL at varying number of passes for the 30-45 cm

Number of passes				
Load(KN)	1	5	10	15
30	13.71	13.77	19.46	32.72
33	36.8	42.92	55.2	82.8
36	76.6	82.8	88.93	110.4

Table 40. Variation in PR in J/cm with NL at varying number of passes for the 45-60 cm

Number of passes				
Load(KN)	1	5	10	15
30	15.86	23.94	29.14	42.4
33	46	53.13	58.27	85.86
36	82.8	92	138	153

Appendix III: Yield Data of Tamela Farm Site

Table 41. Average yield in quintal per hectare for the last 4 years

Year	Crop types	Area cultivated	Total yield	<i>yeild</i> / <i>ha</i>
2019/20	Wheat	2074.59	64932	31.30
	Barley	520.9	14326.8	27.50
	Total/average	2594.49	79258.8	30.5
2020/21	Wheat	1758.65	39799.45	22.63
	Barley	586.74	12764.60	21.88
	Total	2345.39	50644.45	21.59
2021/22	Wheat	1810.53	34875.33	19.26
	Barley	534.86	10934.23	20.46
	Total	2345.39	45809.56	19.34
2022/23	Wheat	1758.65	31754.645	18.07
	Barley	437.78	8843.15	20.2
	Total	2196.43	40597.795	18.48

Appendix IV: Soil Texture of Study Site

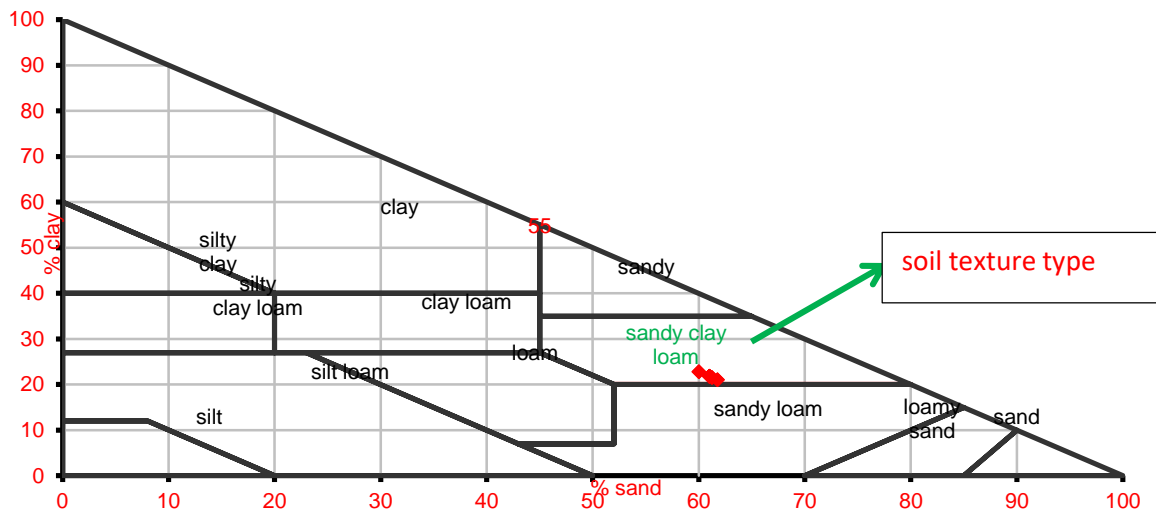


Figure 27. USDA Soil Texture Triangle



Figure 28. high weight tractor trailed chemical sprayer in tamela farm
