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NOMINATION SUMMARY

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Name of course studied: BSc(Hons) Agriculture with Mechanisation		
Period studied	**From:** 2021	**To:** 2025
Qualification to be gained: BSc(Hons) Agriculture with Mechanisation		
Project Title: An investigation into the technological practices and innovations for protecting soil and water resources on agricultural land		
Details of material submitted with nomination: (Project/Exec Summary/videos etc) Dissertation project report.		
SIGNED BY PROPOSER: Graham Higginson		**DATE SUBMITTED:** 30th September 2025

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An investigation into the technological practices and innovations for protecting soil and water resources on agricultural land

by

William Luke Mayer

Being an Honours Research Project submitted
in partial fulfilment of the requirements for the
BSc (Honours) Degree in
Agriculture and Mechanisation

2025

Student Declaration Form for Submission with Major Projects

Section 1

This form must be completed by the student and included at the beginning of the Honours Research Project.

Candidate’s Name	William Mayer
Candidate’s Number	21149000
Degree Programme	BSc (Hons) Agriculture with Mechanisation
Supervisor	Graham Higginson
Major Project Title	An investigation into the technological practices and innovations for protecting soil and water resources on agricultural land
Word Count	9,075
Confidential?	No

In submitting this Major Project I acknowledge that I understand the definition of, and penalties for, cheating, collusion and plagiarism set out in the assessment regulations. I also confirm that this work has not previously been submitted for assessment for an academic award, unless otherwise indicated

(Electronic) Signature of student: William Mayer

Date: 4/05/2025

Table of Contents

Table of Tables

Table of Figures

Acknowledgements

I would like to say thank you to my supervisor Dr. Graham Higginson for his continuous support and guidance throughout the completion of this honours research project.

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I would like to thank my family for their support throughout my final year at Harper Adams University.

Summary

An investigation into the technological practices and innovations for protecting soil and water resources on agricultural land

W.L. Mayer and Dr. G. Higginson

BSc (Hons) Agriculture with Mechanisation

Introduction Soil compaction is a major challenge in agriculture, which impacts the soil structure, water infiltration, root development, and ultimately, crop productivity. Despite there being widespread recognition of compaction and its negative consequences, there is still uncertainty about how routinely and accurately farmers test for compaction prior to making cultivation decisions. Without testing, cultivation decisions may be made on assumption rather than diagnosis, potentially worsening the problem. This study aimed to evaluate the extent of compaction testing among farmers and to identify the key factors influencing their decision making.

Materials and Methods A survey was distributed online and received 94 responses from farmers and farm managers across arable and mixed farming systems. The survey was designed to capture both quantitative and qualitative data, including whether compaction testing is carried out, what tools are used, and what factors influence decisions regarding cultivation strategies. Farmers were asked to comment on perceived barriers to testing, gave their views on alternative soil management strategies, and their familiarity with relevant guidance or policy.

Results While 63% of respondents acknowledged being familiar with compaction being an issue, only 43% reported routinely testing for it. Of those, 12% used a penetrometer, 59% relied on visual indicators (waterlogging, stunted crops), which can give a good indication of compaction, although not the extent of the problem. The 26% of respondents who observed signs of poor root growth in crops support the findings of Lipiec *et al. (*2012) study on root growth in compacted soils. More formal methods such as digging soil pits or bulk density were rarely employed.

Ploughing was the most common cultivation response, used by 60% of farmers regardless of whether compaction had been confirmed and may help to explain the high levels of compaction on certain farms. These findings support those of Hamza and Anderson (2005), who argue that conventional tillage may worsen long-term soil structure.

Barriers to testing included time constraints (35%), lack of training (44%). Smaller farms were less likely to invest in compaction diagnosis, often relying on field history and observation. Adoption of conservation tillage and minimum tillage was low (3% and 16% respectively). Many respondents recognised the value of structured soil assessment but lacked the resources, time, or technical support to implement these practices consistently.

Conclusion Although most farmers and farm managers are aware of the risk of soil compaction, fewer than half actively assess it before cultivation. Of those who do, the majority relies on instinct or visual assessment, which may fail to identify sub-surface issues or variation within a field. A significant proportion of cultivation is still carried out without evidence-based guidance, often defaulting to blanket conservation tillage or at worst, traditional ploughing.

Improving the uptake of compaction testing and alternative soil management strategies will require targeted education, equipment subsidies, and practical demonstration.

References

Hamza, M.A. and Anderson, W.K. (2005) 'Soil compaction in cropping systems: A review of the nature, causes and possible solutions', *Soil and Tillage Research,* 82(2), pp. 121–145 Available at: https://doi.org/10.1016/j.still.2004.08.009.

Lipiec, J., Horn, R., Pietrusiewicz, J. and Siczek, A. (2012) 'Effects of soil compaction on root elongation and anatomy of different cereal plant species', *Soil and Tillage Research,* 121, pp. 74–81 Available at: https://doi.org/10.1016/j.still.2012.01.013.

Chapter One – Introduction

Soil compaction remains a significant challenge in modern agriculture, affecting soil structure, water infiltration, root development, and overall crop productivity. Although the effects of compaction are well understood, there is a lack of certainty over levels or types of compaction before cultivation. Without compaction testing, soil management decisions may be based on visual assessment and assumption rather than the use of accurate data, increasing the risk of ineffective tillage. This could lead to greater soil degradation and compaction. Identifying the current options that are available to evaluate soil compaction, and understanding the barriers to testing are key to making informed soil management decisions towards reducing compaction and increasing productivity and sustainability.

Agricultural mechanisation has improved efficiency on farm but has increased the level of soil compaction as well, particularly in arable systems where heavy machinery is frequently used. Previous research has highlighted the effects of repeated machinery traffic, improper tillage and livestock movement on soil structure and water movement and farmers are aware of the effects of soil compaction. However, despite the various technological testing methods available (penetrometer testing, bulk density, controlled traffic farming) many farmers still rely heavily on visual indicators like waterlogging or stunted crop growth to assess compaction. While these methods are practical, the observations do not show what is going on beneath the surface, which could lead to the incorrect tillage method being used.

This study investigates whether farmers routinely test for soil compaction ahead of cultivation, identifies what they use to reduce compaction on farms, and evaluates the methods used. It looks at the current, relevant literature surrounding agriculture and soils, as well as the advancements in tillage methods. It describes what compaction is and what current compaction testing methods are available.

This research highlights the current gaps in soil assessment practices among farmers and the need to move from a vague awareness of compaction towards the implementation of precise testing strategies if there is to be improved soil management and a more sustainable agricultural industry.

The study evaluates the barriers that prevent the adoption of structured compaction testing and identifies a research gap as being the lack of evidence surrounding whether farmers carry out compaction testing before tillage or not. The methods and methodology section demonstrates how the experiment was carried out using a questionnaire that gathered both quantitative and qualitative data. The results are discussed and recommendations for future studies made.

Chapter Two - Literature Review

Agriculture is a critical driver for global development. Despite many technological advancements in the agricultural industry, it still poses a considerable amount of pressure on natural resources especially on soil and water. Due to environmental, population and climate concerns, farmers are having to improve their methods of growing crops to better conserve the limited resources that they have, forcing them to adopt more sustainable and conservational methods.

This literature review examines recent technological advancements and their application in sustainable farming practices aimed at soil and water conservation. It discusses the critical role of soil compaction testing to optimise these technologies and focuses on whether farmers are testing for compaction or not.

2.1 Agriculture in the United Kingdom

Agriculture is the practice of growing crops and producing livestock to produce food, materials and other products to sustain human life. It has developed from being a subsistence method of producing food to becoming more mechanised over time (Ofstehage, 2020). Agriculture plays an important part in the global economy and its development (Dethier and Effenberger, 2012). According to Alston and Pardey (2014) agricultural production takes up a significant amount of the global land, equating to approximately 40 percent of the world's total land area. Agriculture can be broken down into the arable sector, which involves the production of food such as cereals and fresh produce, and the livestock sector involving the rearing of animals to produce meat, dairy, and other products.

In the United Kingdom (UK), according to the Department of Environment, Food and Rural Affairs (DEFRA) (DEFRA, 2022) agricultural land takes up 17 million hectares or 69 percent of the total land in the UK. The arable sector in the UK uses the largest area of land at 6.1 million hectares (DEFRA, 2024). This means that the rural landscape is mostly used for agricultural practices and the sector plays an important role in rural communities, directly employing around 471,000 people (DEFRA, 2022). It is acknowledged that farms play an important role in maintaining and managing the countryside in the UK. Therefore, they must be environmentally friendly and practice sustainable farming.

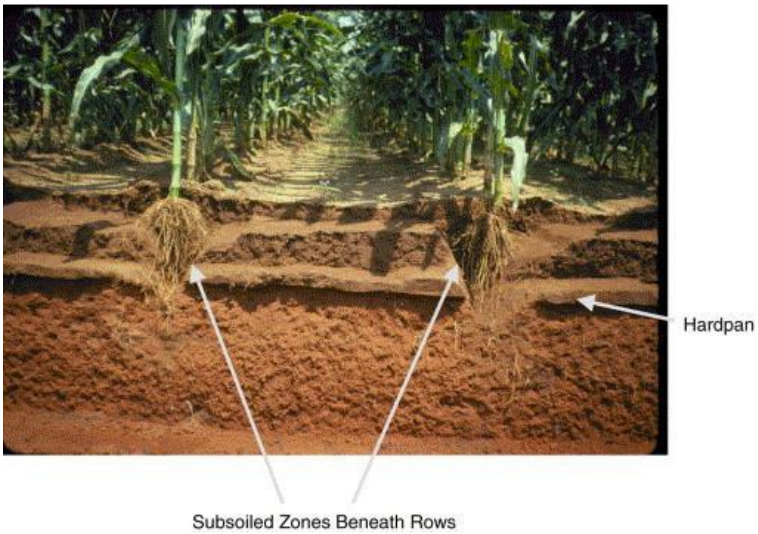
Initiatives introduced by the government such as the Environmental Land Management Scheme (ELMS), devised by DEFRA (2022), have incentivised farmers to move in the direction of sustainable agriculture with the addition of subsidies and grants for better practices. In recent years, agriculture has been seen increasingly as an industry that causes environmental damage, impacting consumer opinion and influencing policy changes. This has forced a shift towards greater sustainability. ELMS aimed to get at least 70 percent of UK farmers to take up sustainable farming methods. As a result, farmers have started to use methods such as conservation tillage and precision agriculture to address soil degradation and compaction, towards sustainability.

2.2 Compaction

Soil compaction is a major issue in agriculture that affects soil structure, water retention and crop productivity. Research has demonstrated that compaction decreases the soil's porosity, thereby limiting water infiltration, air exchange, and root penetration (Hamza and Anderson, 2005). According to Van Orsouw *et al.* (2022) soil compaction can lead to yield loss of between 5% to 40% and is one of the most serious problems facing modern agriculture.

Soil compaction is a result of the densification of soil particles which leads to a decrease in pore space. Soil compaction typically occurs when there is repeated pressure on soil and is usually caused by large machinery that is used on farm, and grazing animals. Compaction occurs naturally when soil is repeatedly wet and dried, causing expansion and contraction of pore spaces as Goldberg-Yehuda *et al.* (2024) suggested in their study. Greenwood and McKenzie (2001) suggested that grazing livestock on agricultural land exerts the same amount of pressure to the ground as arable machinery making the soil susceptible to compaction in all farming activities. Schlotzhauer and Price (1999) found that natural compaction was limited to the top five centimetres, for example through rainfall, whereas livestock trampling the soil increased compaction to 20 centimetres. Machinery compaction can be up to 60 centimetres below the soil surface, making it difficult for farmers to assess without formal testing.

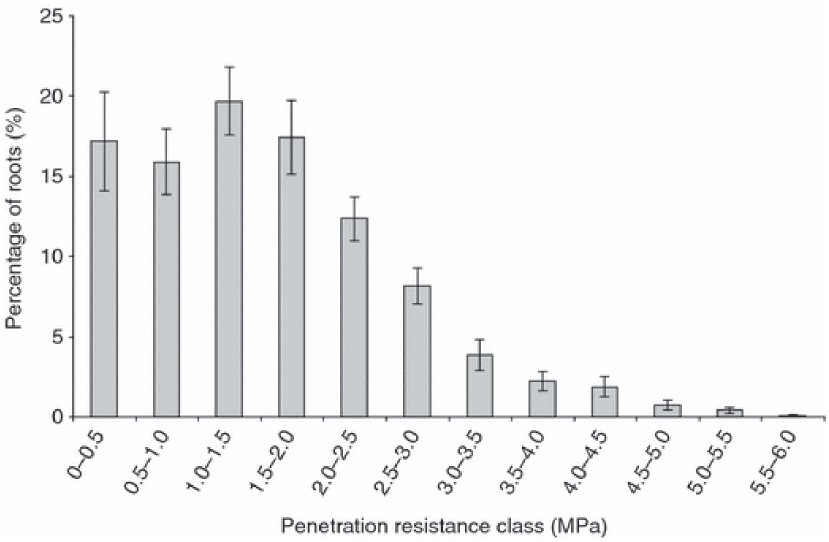
Understanding the causes and consequences of compaction is vital as it allows farmers to implement mitigation strategies. Studies have shown that conducting field operations in the wrong conditions, particularly when wet, is a significant cause for soil compaction (Lipiec, J. *et al.,* 2003). The depth and severity of soil compaction depends on the soil type, soil texture, moisture content and the weight of the equipment or animal that moved on that location. Long term effects may occur such as the formation of a hard pan, as seen in Figure 1, which can make the soil unproductive for use unless it is corrected (Raper, 2005).



(Raper, 2005)

Figure 1, In-row Subsoiling

Soil compaction limits root growth and access to nutrients as well as soil microbial activity (Rakkar and Blanco-Canqui, 2018). This restricts overall plant health and decreases crop yields (Lipiec et al., 2012). In Sinnett *et al's.* (2008) forestry study, their findings suggested that the higher the level of compaction seen on a soil penetrometer reading, the weaker the root growth found in the soil (as seen in Figure 2). These results are similar to those in a soil compaction test by Yu *et al.* (2024) where sandy clay loam and a sandy loam were used. Their findings suggested that with higher levels of compaction, there were fewer and shorter roots in the wheat crop. However, this study is limited as it only looked at two soil types and it was carried out in a laboratory where external factors were not taken into consideration.



(Sinnett *et al.,* 2008)

Figure 2, Root growth compared to penetrometer resistance. Where when the resistance increases there was a clear decrease in root percentage

Barraclough and Weir (1988) conducted a field study with similar findings to the previous study. They saw that roots which did not have a compacted pan in the soil grew to a much deeper root depth than those that were growing with a shallow pan.

A review carried out by Cárceles Rodríguez *et al.* (2022) suggested that conventional methods of farming increase soil compaction and deterioration of soil as well as increasing the chance of soil erosion caused by surface runoff, and a decrease in soil organic matter. This study did not carry out any field studies to back up their findings. However, field studies from the 1970s which were drawn on by Raghavan, Alvo and McKyes (1990), alongside their own laboratory modelling, reflected the contribution that heavy farm machinery makes to compaction.

2.2.1 Environmental impact of compaction

Soil compaction reduces the porosity of soils, which negatively impacts water infiltration rates. This increases the likely hood of surface runoff, where topsoil, nutrients and agrochemicals flow into nearby water bodies, contributing to water pollution and increasing the likelihood of eutrophication (Lal, 2003). Reduced infiltration rates can increase the risk of flooding occurring as the soil is unable to store adequate amounts of water during heavy rainfall, causing it to continue to flow. Furthermore, studies such as da Silva, Kay and Perfect (1997) have shown that reduced permeability in compacted soils may reduce the water available for plant roots, which could increase the drought stress on the plant in a drier season.

Soil biodiversity is affected by compaction as it alters the conditions for organisms that live within the soil such as earthworms, arthropods and other soil microbes. In compacted soils there is less space between soil particles, preventing movement of oxygen and nutrients that are critical for the survival of the living organisms within the soil (Capowiez *et al.,* 2009). Research indicates that earthworm populations and diversity decrease in compacted soils as they are unable to burrow through the soil, this restriction limits food availability (Bertrand *et al.,* 2015). As earthworms are involved in the degradation of organic matter, the decrease in population could lead to a slower rate of decomposition thus reducing nutrient cycling within the soil (Blouin *et al.,* 2013). Earthworms play an important role in water infiltration within the soil as their burrows allow for water to drain more quickly in than in soils where there are no channels.

Overall, soil compaction creates less resilient soil, making farming more susceptible to the impact of weather conditions and climate change. Effective soil and water conservation is vital for the sustainability of farming. There is the need for farmers to incorporate mitigation strategies into their farming systems that reduce compaction caused by carrying out agricultural processes.

2.2.2 The impact of compaction on water management

Sustainable water management in agriculture is the ability to balance the supply of water with the demand from crops or other operations carried out on farm. Effective water management practises are essential as they address challenges such as water scarcity, climate change and allow for agriculture to intensively produce food (Iglesias and Garrote, 2015).

Irrigation is a method that is traditionally used in dry or semi-arid places, and in the production of high-quality horticultural crops. It provides the required water for the crops where there is unpredictable rainfall which could limit the crop growth. According to Sauer *et al.* (2010) irrigation has the potential to increase crop yields as the plant never has water deficit. However, irrigation in agriculture makes the highest demand on fresh water in the world, where according to Frimpong *et al.* (2023) 70 percent of freshwater withdrawal is for agriculture. As so much water is used, there is a need for efficient irrigation methods to reduce the potential for loss as it is crucial for ensuring food security globally and preserving the environment.

One of the key barriers to efficient irrigation methods is knowing and understanding the level of soil compaction and the way it relates to soil types and crop types. For example, a study in northern Quebec on potatoes grown under irrigation in sandy soil showed that there were different levels of irrigation needed for different levels of compaction (Mbarki *et al.,* 2023). The report concluded that optimal efficiency in irrigation on the potatoes was when there was a medium level of compaction in sandy soils. A study in Punjab, India reported the need to know and understand compaction levels for growing moongbean in loamy sandy soils. While the study showed the benefit of a certain level of compaction in increasing water retention in this soil type, the overall result showed a decrease in infiltration of water in the soil by 38% with high compaction levels which negatively impacted yields (Kahlon, Singh and Dhingra, 2020).

The used of effective irrigation allows for crops to receive adequate quantities of water while reducing the quantity of water lost by evaporation and run off (Marcinkowski, Piniewski and Okruszko, 2024). Other methods such as soil moisture conservation practices, including mulching, cover cropping, and conservation tillage enhance water retention in the soil by addressing soil compaction which improves infiltration and retention, reducing evaporation from the soil and improving overall soil health (Frimpong *et al.,* 2023).

Effective irrigation and water management practices are key for sustainable agriculture, ensuring that crops receive sufficient water while minimizing losses and preserving environmental resources.

2.2.3 Methods for reducing compaction

As compaction has the potential to lower crop yields and impair soil health over time, farmers have developed various methods to mitigate the negative effects of compaction. There are mechanical approaches as well as biological methods that are used throughout the world. Mechanical methods such as subsoiling and deep tillage physically break up the compacted layers of soil to enhance water drainage and root penetration. Batey (2009) suggested that reducing tyre pressure to widen the size of the tyre or putting dual wheels on equipment, as well as the use of tracks further lowers compaction (Keller and Arvidsson, 2016). Molari *et al.* (2012), like Keller and Arvidsson (2016), found the use of rubber tracks reduced compaction. As there is such a high reliance on machinery in agriculture there has been increasing interest on the use of controlled traffic farming, whereby machinery is restricted to defined traffic lanes throughout the field (Baker *et al.,* 2006). Controlled traffic farming has been shown to reduce soil compaction over the whole field and result in a slight increase in crop yield. The field study carried out in Tasmania by McPhee *et al.* (2015) got similar findings to Hefner *et al.* (2019) showing that controlled traffic farming, a precision farming method, is a way to reduce the level of compaction on farms. The findings in the in-depth study carried out by Nawaz, Bourrié and Trolard (2013), found that using precision farming methods such as controlled traffic farming, along with the use of subsoiling, hastened the reduction of compaction across the whole field compared to natural remedies such as cover crops which can take between ‘5 and 18 years’.

2.2.4 Precision Agriculture

As the global population is predicted to reach 9.7 billion by 2050 (United Nations, 2022) there is a need for more efficient methods of farming to produce more food on less land. Azadi, Ho and Hasfiati (2011) carried out a study into land conversion drivers, finding that there was a decrease in agricultural land and an increase in industrialization, meaning that more efficient farming methods would be needed to keep up with the increasing population.

Precision agriculture is a method that can be used for more efficient farming. Precision agriculture has been driven by the improvements in technologies, data collection and analysis on farm which allows for more accurate predictions to be made (Bhakta, Phadikar and Majumder, 2019). For example, GNSS guidance on farm machinery which allows for controlled traffic farming, enables more accurate data collection, and gives farmers more control over existing products (Petrović *et al.,* 2024). Yield maps of fields from harvest can be used to determine variable rate application of fertilisers, chemicals and seeds, minimising costs of production throughout the year, as well as possibly reducing the environmental impact. As chemical resistance is increasing, there has been a drive in the direction of alternative weed control techniques to reduce the reliance on herbicides, such as weed detection (Hu *et al.,* 2024) and precision agriculture offers methods that can be used to reduce this.

Barbosa Júnior *et al.* (2024) carried out a meta review study in which they mentioned that precision agriculture has allowed for more sustainable farming methods to be carried out, with conservation tillage methods and cover cropping becoming more prominent. It is now possible to generate compaction maps which allow for selective cultivation methods for certain areas of the field instead of blanket cultivation method. This is a form of conservation tillage (Shamal, Alhwaimel and Mouazen, 2016). However, Bahmutsky *et al.* (2024) findings suggested that these technologies would not be accessible to smaller farms due to the high implementation costs.

2.2.5 Conservation Tillage and Soil Health

Conservation tillage is any method of tillage that retains at least 30 percent of crop residue (Bergtold and Sailus, 2020). It incorporates systems such as no-till, min-till and strip tillage all of which minimize soil disturbance, reduce compaction, preserve crop residue and enhance the overall soil health.

The importance of soil health as a major component of sustainable agriculture cannot be over-emphasised. It provides the essential nutrients, water and support for plants (M. Tahat *et al.,* 2020). Soil health can be defined as the ability for soil to function as a living system within the ecosystem (Doran and Zeiss, 2000) whilst soil diversity is an important part of maintaining agricultural biodiversity (Costantini and Mocali, 2022). Over time with incorrect farming practices, soil health can deteriorate, reducing its ability to grow healthy crops without heavy reliance on chemicals and additional fertiliser, as the soil organic matter begins to depreciate. However, Turmel *et al.* (2015) state that with the return of crop residue to the soil, and use of conservation agriculture, such as conservation tillage, over time this can be reversed.

Conservation tillage improves soil structure by promoting aggregation, reducing soil erosion, and increasing water retention. However, there are limitations to the benefits of blanket conservation tillage on farms. Alaoui and Diserens (2018) highlight the importance of mapping compaction to determine the difference in timescales of topsoil compaction and subsoil compaction, and the need to select appropriate tillage to suit either. This is supported by Shamal, Alhwaimel and Mouazen (2016) whose study into using online sensors to determine soil compaction levels revealed that the largest part of the field of study needed no tillage, and only 4.8% needed aggressive tillage which had a significant cost-reduction element. More radically, in a five-year study by Cooper *et al.* (2020) it was found that the use of conservation tillage did not alter the soils biological or physical properties after the five years. Whereas in the review by Stevens and

Quinton, (2009) it was suggested that there were advantages to using a no-till system as it decreased the surface run off from the fields in their study.

When carrying out conservation tillage it is important to note that often there is an increase in compaction below the topsoil (Martínez *et al.,* 2008) as there is no subsoiling carried out. This can be determined through compaction testing or soil mapping.

2.2.6 Cover crops

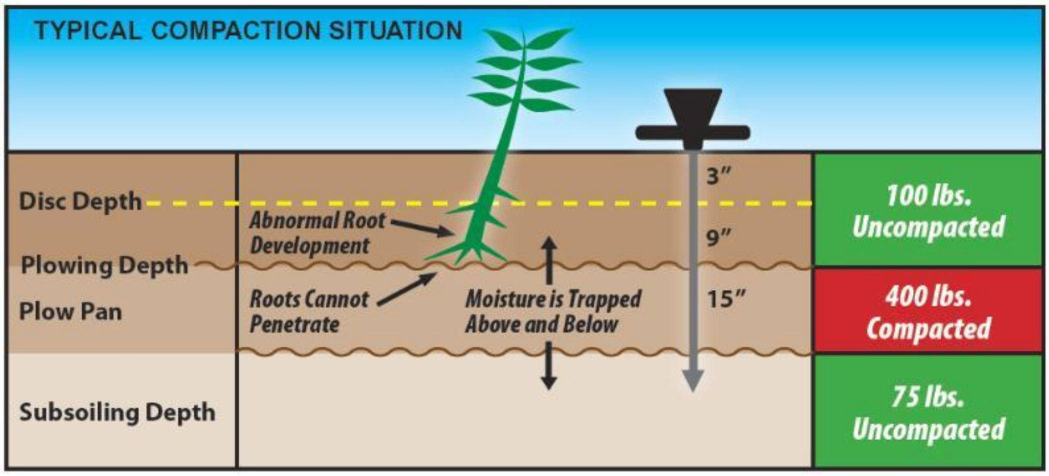
Cover crops are increasingly being recognised globally for their ability to improve soil water retention and infiltration rate. Using deep rooting cover crops, a reduction in soil compaction and an improvement in soil health can be seen, as there is more aeration (Chen, Weil and Hill, 2014) into the soil, which allows for better water infiltration. Research shows that cover crops enhance soil structure by reducing its bulk density, increasing the soil organic matter. Nichols *et al.* (2022) carried out a long-term trial on the use of cover crops to improve the water retention in soils, their findings suggested that the use of cover crops in a rotation allowed for certain soil types to drain slightly faster after they had been saturated with rain. Similarly, Chalise *et al.* (2019) saw an increased soil water infiltration of 1.8 percent in cover crop field compared to 1.3 percent in no cover crop fields. These reports suggest that the use of cover crops allow for a better water infiltration rate. In Chalise *et al.* (2019) experiment there were improvements to the yield of soybean by 14 percent showing that the use of cover crops is beneficial to farmers due to the improvement in the soil structure, reduction in compaction and aeration of the soil.

Cover cropping is often used in conservation agriculture and sustainable agriculture as it is recognised to improve soil health, reduce erosion and enhance nutrient cycling. There has been a global increase in the use of cover crops which has been driven by the need to reduce environmental degradation while allowing for productive agriculture to continue.

2.3 Testing and monitoring soil compaction

Soil compaction testing has been adopted by farmers all over the world as a method for ensuring effective soil management techniques as it allows them to make decisions about tillage methods and other plans for the upcoming growing season. There are various methods of carrying out soil compaction testing which range from handheld tools to more advanced technology, both of which have advantages and limitations.

One of the most common methods used for measuring soil compaction is a cone penetrometer (Figure 3), which is used to measure the resistance of soil penetration in a specific location, giving the user a quantitative estimate of compaction levels of their soil (Wang *et al.,* 2024). Sun *et al.* (2012) mentioned in their study that a penetrometer is a useful tool, but it is limited to measuring shallow depths of soil as there is more room for error as the depth increases. Soil penetrometers can be used to assess root growth which is a useful way of determining the impact of soil compaction. While penetrometers are a useful tool, they require careful calibration and are labour intensive on a large scale (Kotrocz, Mouazen and Kerényi, 2016). Sudduth *et al.* (2008) mentioned that the output of the penetrometer is its cone index. This value will change depending on the soil type, compaction level, moisture content of the soil and the particle size, meaning the higher the cone index the greater the level of compaction.



(International, 2021)

Figure 3, Soil penetrometer The Green areas are where root growth would continue at its optimal level

Bulk density is another method of soil testing which is widely used in agriculture. This method involves the collection of soil samples and then calculating their mass per unit volume. Bulk density or porosity for optimal crop growth will vary greatly between soil type and crop type (Håkansson and Lipiec, 2000). Bulk density is the soil's ability to function as structural support, and it reflects the soil's ability to move water as well as its aeration (Meng *et al.,* 2023). A study in Canada carried out by Pathirana *et al.* (2024) determined that soils which have been compacted had an increased bulk density which is the same as Meng *et al.* (2023) found in their experiment.

Another method of soil testing is conducting a visual assessment.
This technique entails excavating shallow pits for observing the soil profile and evaluating the layers for root penetration, compaction, and the existence of structural problems such as plough pans and structural quality (Mutuku *et al.,* 2021). This method is the most used by farmers as it is very easy to carry out and has a low cost. However, this method is subjective and depends on the experience and expertise of the observer. The visual assessment is usually carried out first and then followed up by a lab-based assessment (Warrick, 2001). A comparative analysis of these methods suggests that combining multiple testing approaches would yield the most reliable assessments.

Soil testing can be used to identify soil nutrient such as phosphorus where the optimum parts per million is between 5.1-8.0 (Micha *et al.,* 2023) and organic matter. Both nutrient and organic matter are very important to know as farmers are able to make more accurate application plans for fertilizer and seeds depending on the results that are received from soil analysis.

The choice of a compaction or soil analysis method depends on various factors, including farm size, available resources, and the level of accuracy required. As there is a drive towards more sustainable farming practices, effective soil compaction testing is becoming a more recognised step for tillage decisions for improving soil health.

2.3 Research gap

Compacted soil is widely known in agriculture as a major issue that affects soil health, water infiltration, root penetration and crop productivity. There are various methods that exist for farmers to test soil compaction on farm such as soil penetrometers, bulk density testing or visual assessments. While there is much research into the effectiveness of these methods for testing compaction, there is limited research into whether farmers are actively carrying out their own compaction test before carrying out tillage for the next crop. Existing studies primarily look at the causes and consequences of soil compaction, as well as the potential strategies to mitigate compaction. However, there is a gap in understanding of whether farmers have adopted compaction testing practices. Specifically, there is little known about how many farmers carry out their own tests before tillage, or the reason why they would not.

This study seeks to obtain data which will aid the research gaps that have been discussed throughout this literature review, by carrying out a survey to gather the reasons why farmers do or do not carry out their own compaction testing prior to carrying out tillage. It looks at what methods are available to carry out compaction testing on a farm and methods for reducing the impact of compaction through the literature review.

Chapter Three - Methodology

This study was carried out in accordance with the Harper Adams University research policy as well as the MRS conduct code.

Aim:

To Investigate whether farmers/farm managers are testing soil compaction before carrying out cultivation.

Objectives:

1. Are farmers measuring soil consolidation ahead of cultivation?
2. What are the methods used to measure soil consolidation by farmers and farm managers?
3. What methods can be used to reduce compaction?

3.1 Research design

This study adopted a qualitative research design using a questionnaire. This allowed for the best collection of data, as this study aimed to find out whether farmers are carrying out compaction testing prior to carrying out tillage on farm. A qualitative approach was appropriate as it allows for an in-depth understanding of farmer experiences, practices and decision-making processes about their soil assessments. Qualitative research was particularly useful for exploring real world agricultural practices, where multiple factors influence farmers methods of measuring and responding to soil compaction (Creswell and Poth, 2016). As most studies that investigated compaction were technical or laboratory-based, the use of a questionnaire provided a different set of results as the responses given were based on the respondents' experiences and insight into their knowledge of the subject.

3.1.1 Participants and sampling strategy

The targeted participants for the study were farmers and farm managers who were actively working on farm with soil and carrying out soil management and agricultural production. As they had experience managing soil compaction and, soil structure in all field conditions it made them a valuable source of information regarding the methods that are used on farm to assess what the appropriate method of tillage was.

3.1.2 Purposive sampling method

As the participants of this qualitative research were selected by specific criteria rather than being completely random, a purposive sampling method or judgement sampling, was used to find participants for the research. As the data that is being collected was specific to the agricultural industry where knowledge about compaction testing in agriculture is present, other sampling methods such as random sampling would not work. The criteria that the participants were selected on was:

1. Active involvement in farming or farm management.
2. Experience in monitoring soil conditions and managing soil health.

This study aimed to gather 65 responses from participants as that was enough to provide a diverse perspective, and the experience of the farmers was represented. After a three-week period 94 responses were collected which equated to one percent of the total population of farmers in the United Kingdom (Statista, 2019). The selected sample size provided sufficient depth for analysis while being feasible in the given time and resource constraints.

3.2 Data collection: online questionnaire

This study used an online questionnaire as the collection method to gather an insight into what methods farmers and farm managers use to measure compaction and consolidation prior to carrying out tillage. The questionnaire was designed to collect both qualitative and quantitative forms of data and, provided a structured approach to understand how soil assessments were carried out in real-world agriculture. The questionnaire was built on JISC online surveys as it allowed for easy distribution and collection of data. It allowed for the creation of a survey that had a range of questions allowing for different types of analysis. The responses from the questionnaire were anonymous. The questionnaire was released via Facebook on to farmer forums which ensured it reached the correct audience, where there were ongoing discussions which related to the topics that were being researched.

3.2.1 Questionnaire structure

The questionnaire consisted of 19 questions including multiple choice questions, Likert scale and open-ended questions. A copy of the questionnaire can be found in Appendix 1.

The responses from the questionnaire were anonymous, however some questions were asked to gather demographic information, to collect background information on participants such as their role on the farm, the primary farming type and years of experience. The questionnaire used various question types most of which were closed questions as they are quicker to answer, which increased the likelihood that the questionnaire would be completed (Rowley, 2014). Open ended questions were used where the opinion of the respondent was needed. On the questionnaire there was a brief introduction to inform the respondents that the survey was being carried out for the purpose of an honours research project. A prediction of the approximate time demand to answer the survey was included on the page to ensure maximum response rate from the respondents who started the questionnaire minimising only half answered responses (Booker, Austin and Balasubramanian, 2021). The survey was left open for a period of three weeks to allow for the maximum number of responses to be collected.

3.2.2 Pilot study

A pilot study was carried out where the questionnaire was sent out to six participants who had no relation to the industry, allowing it to be tested to ensure that there were no mistakes and that all the questions were formatted in a way that they could be understood by anyone. The use of the pilot study allowed for a predicted length of time to be generated as the participants were asked to time themselves while going through it for the first time. Any mistakes that were pointed out in the feedback on the questionnaire were fixed before the final distribution. Additionally, the pilot study allowed for the refinement of the research questions (Sen, 2012), study design and sampling technique improving the overall questionnaire. Carrying out the pilot study provided an opportunity to practice the research technique and anticipate any challenges that may arise when carrying out the final data collection, thus increasing the likelihood of success and reliability in the final study (Julia Simkus, 2023).

After the pilot study was completed, grammatical corrections were made, and it was established that the questionnaire would take five to ten minutes to complete. There were changes made to the question structure and wording to minimise ambiguity and increase conciseness. Additional questions were included to gain deeper insights, such as rating the importance of compaction in land-use using a Likert scale of one - five. These refinements enhanced the questionnaire's effectiveness and ensured meaningful results from the pilot study.

3.2.3 Data analysis

The data was entered into Microsoft Excel where it was used to produce graphs, tables and allow for the open-ended questions to be thematically analysed. Microsoft Excel allowed for some more basic calculations such as the mean, mode, median and range. Microsoft Excel was used to carry out more advance statistical test such as, chi^2.

Qualitative analysis was carried out using thematical analysis to identify trends and common phrases used in the open-ended questions from the questionnaire. There were very few open-ended questions that mostly required respondents to add detail if there was not an option on the multiple-choice question. This was a comprehensive method of carrying out analysis in other research surveys (Bletzer, 2015).

3.2.4 Validity and reliability

The validity and reliability of the data collected was dependent on the types of questions and how they were formatted, as well as the responses that were received from carrying out a pilot study. There were changes made after carrying out the pilot study which increased the reliability (Srinivasan and Lohith,2017). The reliability of the data that was collected from the questionnaire came from the number of responses that were gathered. If the questionnaire were to be sent out again for the same period, a similar number of responses could have been gathered.

When carrying out the questionnaire there was a threat to the reliability as self-administration was required. The respondents may have answered the questions randomly to decrease the time taken for completion or may have answered the questions based on what they thought was socially acceptable. However, by carrying out the questionnaire anonymously it allowed for more honest answers to be gathered. This allowed for a reduction in bias as there was no influence of an interviewer being present. To mitigate response bias, most questions on the questionnaire were multiple choice questions. The questions were written in a non-judgemental tone which further reduced the risk of creating response bias.

3.3 Ethics

Prior to research being carried out the research had to be approved by the Research Committee and follow the Harper Adams Universities Ethics Policy, to ensure that research was carried out in a way that was ethically and normally acceptable. The participants were informed that they had the right to withdraw from the questionnaire at any time as well as how the data was going to be used in the study. The survey was carried out anonymously to ensure the participants' information was not kept. After the data was collected it was stored on a password protected device to minimise the risk of a data breach occurring.

3.4 Limitations of data collection

The main limitation of the data collection proved to be with the collection of respondents from the questionnaire. As it was an open link on Facebook and farmer forums, there was no way of ensuring that respondents would answer the questionnaire as they would only do it if they felt like completing it. Had the questionnaire been posted for a longer period, a greater number of responses may have been collected which would have increased the reliability of the results. To ensure the highest chance of gathering respondents, the questionnaire had to be reposted several times on the same groups. In addition, a broader selection of distribution methods could have been used to mitigate a lower number of responses.

Chapter Four - Results and Analysis

The results presented in this section are the key findings which have been selected from the 94 responses to the questionnaire.

4.1 Demographic information

4.1.1 Role on farm

Table 1 illustrates the distribution of the respondents based on their role in the farm management process. The majority (89%) of the respondents were farmers while 11% were farm managers, suggesting the data is primarily reflective of individuals who are directly engaged in the field work rather than those making management decisions. Since farm managers often oversee the larger decision making, their lower representation may indicate that compaction management is often left to the individual farmer.

Table 1, Role on farm

Role in management process	Responses	Percentage
Farmer	84	89%
Farm manager	10	11%
Other	0	0%

4.1.2 Type of farming carried out.

The mode of farming operation was arable farming which represented 50% of the total respondents, creating a correlation with the identification of heavy machinery as the main cause of compaction on farm as seen in Figure 7. Arable farming was followed by mixed operations, with livestock farming at the bottom with 17% (Figure 4). The high proportion of arable farmers suggest that targeted intervention, such as precision agriculture, could mitigate compaction risks. Hefner *et al.* (2019) indicated that controlled traffic farming can mitigate compaction by restricting it to certain areas in the field.

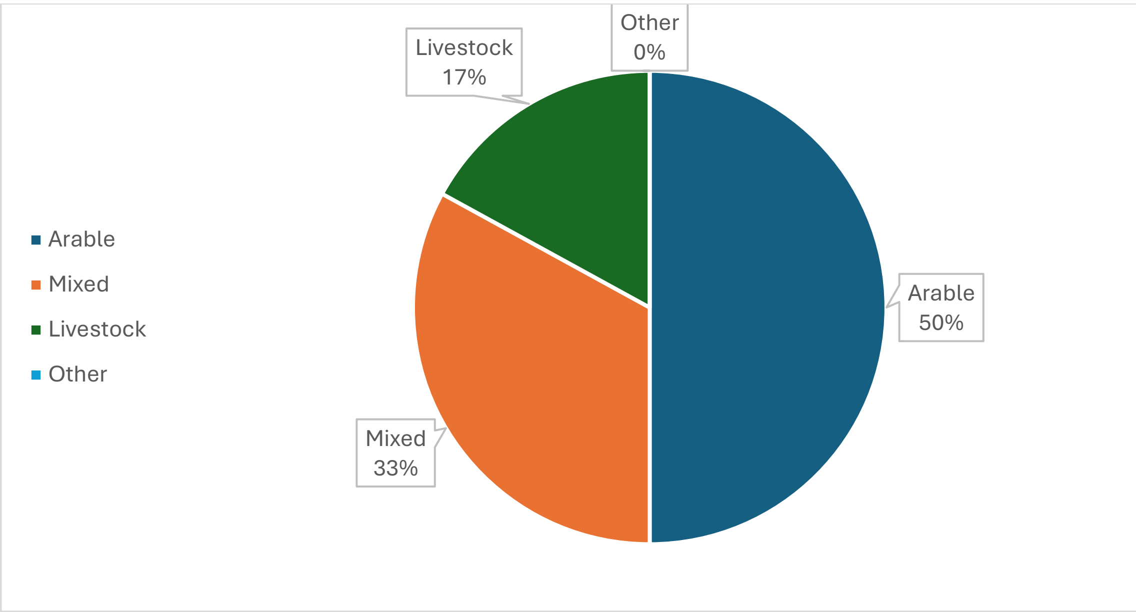


Figure 4, Method of farming

4.1.3 Years of experience

The participants ranged from <5 years of experience to >20 years for experience with most respondents having over 20 years of experience in farming indicating a seasoned participant pool (Figure 5). However, experienced farmers may rely on traditional methods of testing, such as visual assessments, rather than scientific methods such as penetrometer testing. Adoption strategies should be aimed at experienced farmers, potentially emphasising the long-term benefits of testing to the soil. The respondents may have perceived this question as years working on farms rather than working as a farm manager or a farmer.

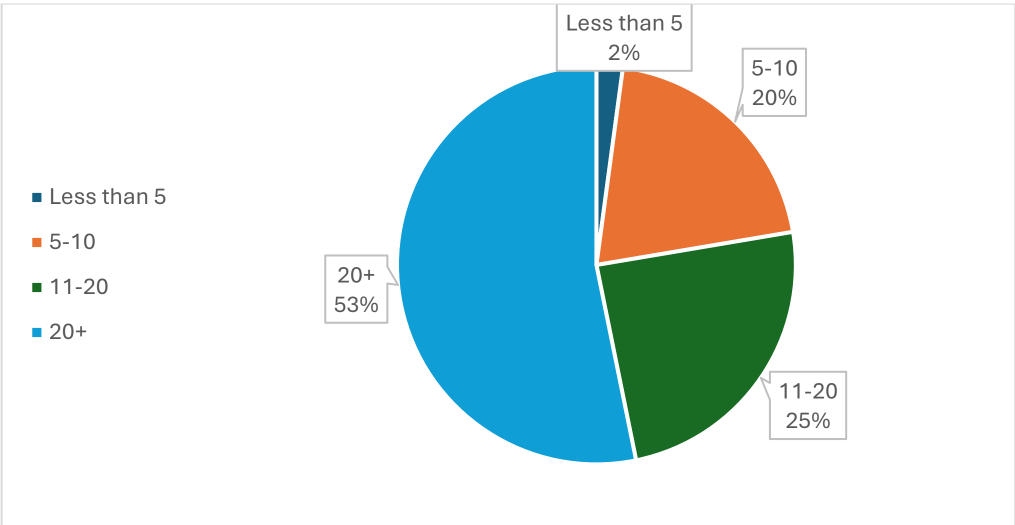


Figure 5, Years of experience

4.2 Background information regarding compaction

4.2.1 Familiarity with compaction

Table 2 shows that farmers and farm managers are familiar with the concept of compaction or soil consolidation on the farm with 63% stating they were very familiar. No respondents stated that they were unfamiliar with compaction. This suggests that compaction is a very well-known issue on farm and is well understood among farmers and farm managers. The high familiarity with the concept of compaction suggests that lack of knowledge on compaction is not the primary reason testing is not carried out. Instead, it could be due to time constraints or the cost of carrying out testing. However, the data presented in Figure 10 demonstrates a lack of knowledge on the methods of carrying out compaction testing, meaning awareness does not translate to proactive testing.

After comparing the type of farming (Figure 4) with familiarity with compaction in a chi^2 test a p value of 0.02 was calculated. This value shows a significant association where arable and mixed farmers are more familiar with compaction compared to livestock farmers, indicating a possible correlation between farming type and exposure to soil structure concerns.

Table 2, Familiarity with compaction

Option	**Count**	**Percentage**
Very	59	63%
Somewhat	34	37%
Not familiar	0	0%
Grand Total	**93**	

4.2.2 Concern with compaction

Figure 6 shows the mode of “concern for compaction” of the respondents on the Likert scale is four out of five as four was selected by 43% of the respondents indicating significant concern with compaction. However, Table 3 demonstrated that the farmers with high concern levels do carry out testing. While with lower levels of concern there is a lack of testing as farmers may not see compaction testing as an urgent priority, suggesting other factors may be preventing effective action.

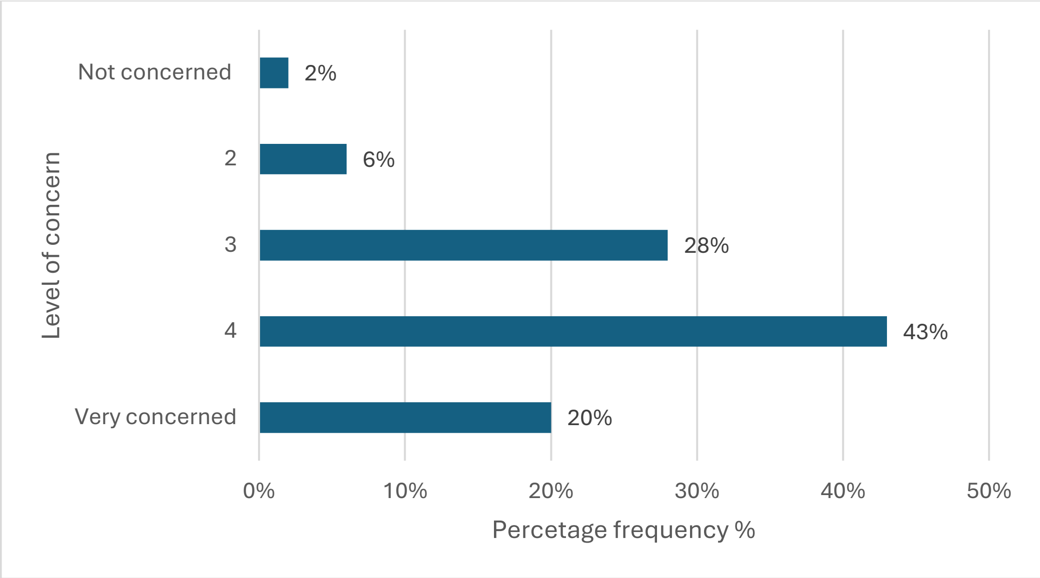


Figure 6, Level of concern

4.2.3 Main cause of compaction

Figure 7 identifies heavy machinery (44%) as the predominant cause of soil compaction, followed by natural factors (24%). This aligns with the high percentage of arable farmers surveyed, whose operations predominantly involve heavy machinery as seen in Figure 4. Recognising heavy equipment as the primary cause of compaction reinforces the need for equipment-based solutions such as controlled traffic farming or the use of tracks (Keller and Arvidsson, 2016) to reduce soil impact.

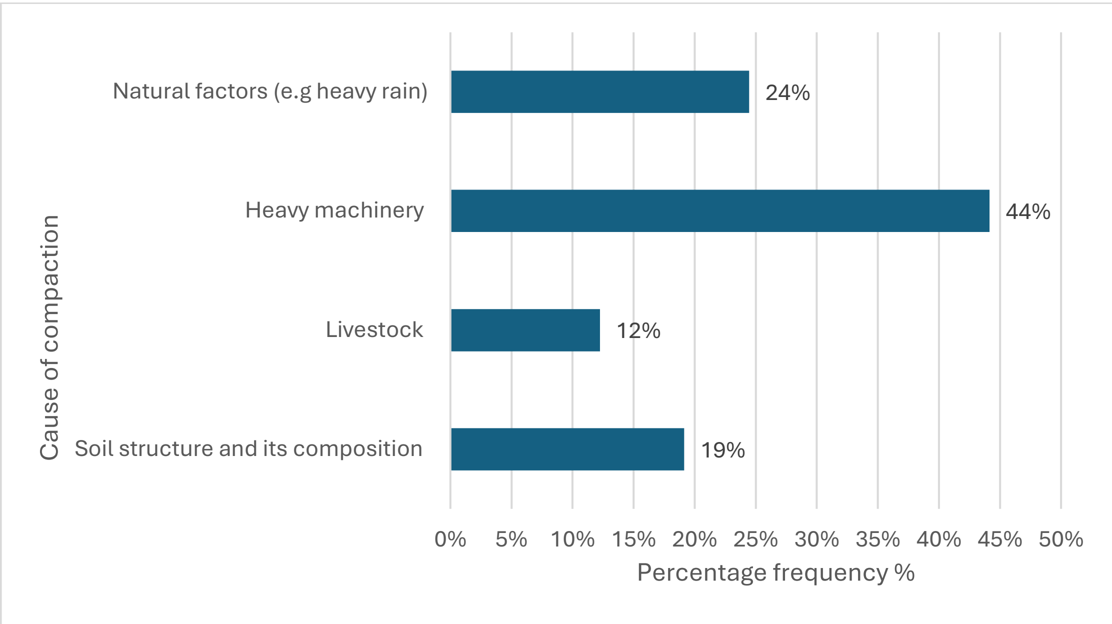


Figure 7, Causes of compaction

4.3 Is compaction testing carried out

Despite the high familiarity with compaction, only 43% of respondents conduct compaction testing, while 57% do not (Table 3). This suggests that awareness of compaction is not significant enough to drive adoption of scientific testing methods. This further shows there is a disconnect between the knowledge of what compaction is and the implementation of testing methods, reinforcing the need for accessible and cost-effective testing solutions. Training programmes or financial incentives could help adoption rates of compaction testing.

Table 3, Compaction testing

Option	Count	Percentage
No	54	57%
Yes	40	43%

4.4 Testing is carried out

4.4.1 Method of testing

The mode of testing method was visual assessments of the soil structure (59%) by respondents who carried out testing, followed by soil core sampling (14%). Soil penetrometer and infiltration rate measurements had the same number of responses with (12%), there were no responses for compaction meter (Figure 8). This implies that 23 of the 40 respondents who carry out testing rely on visual assessment. The reliance on visual assessment may be due to its low cost and ease of implementation, despite being less precise than scientific methods. However, visual assessments require less analysis of information to carry out the test, and yield less accurate results.

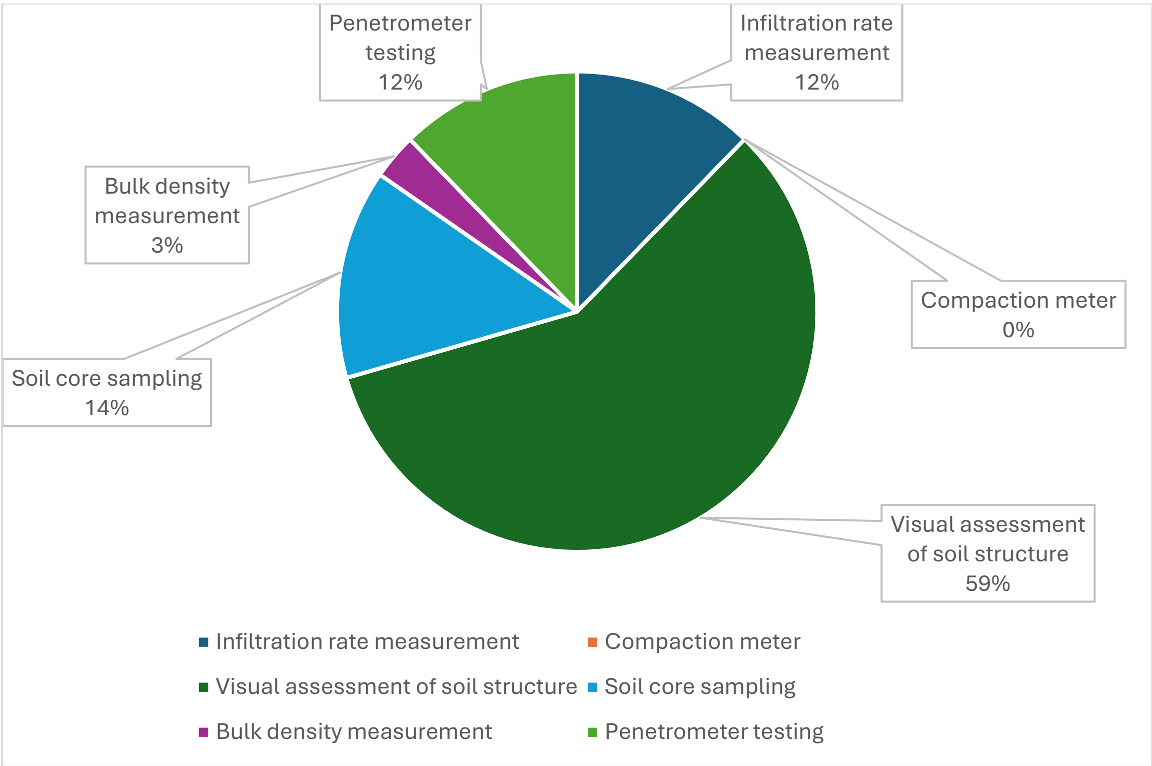


Figure 8, Method of testing

4.4.2 Observation used to assess compaction

Figure 9 presents the observations that farmers use to assess the level of compaction they have on farm. The respondents were able to select all that apply; the two most common both had 26% response selection which was decreased water infiltration and poor root growth, followed by reduced crop yields 21%. These findings align with Lipiec, Jerzy *et al.* (2012)

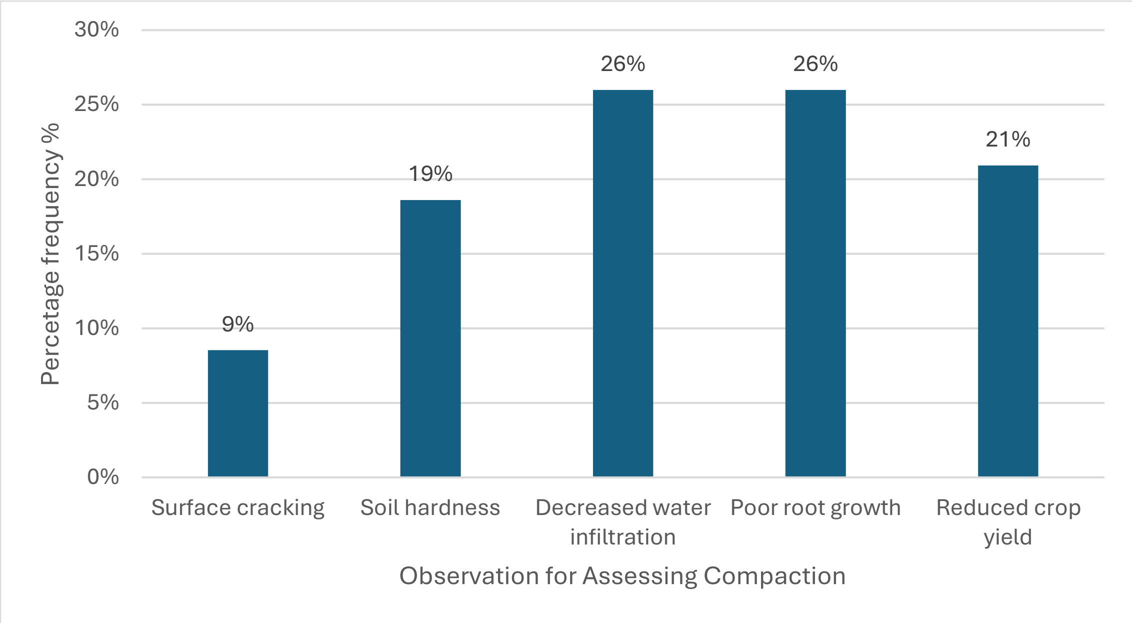


Figure 9, Observation used to assess level of compaction

4.4.3 Challenges faced when measuring compaction

Table 4 outlines the most common challenges experienced by respondents who conduct compaction testing. The most common was time constraints with 35% followed by lack of proper equipment with 28% and difficulty interpreting test results 25%. This suggests that even if farmers have access to equipment, they may struggle to apply their findings effectively. However, for the 35% who selected time constraints, this may indicate that compaction is not a very big concern or that they do not fully appreciate the significance of compaction on the economy, yields and soil conservation on their farms.

Table 4, Challenges faced when measuring compaction

Option	Count	Percentage
High cost of equipment	7	12%
Difficulty interpreting results	15	25%
Time constraints	21	35%
Lack of proper equipment	17	28%

4.5 Compaction testing is not carried out

4.5.1 Thematical analysis of open-ended question

After thematically analysing the results, Figure 10 was produced where the mode theme was a lack of training with (44%) of the responses followed by farm knowledge at (34%). This suggests that education and outreach programmes could significantly improve adoption rates.

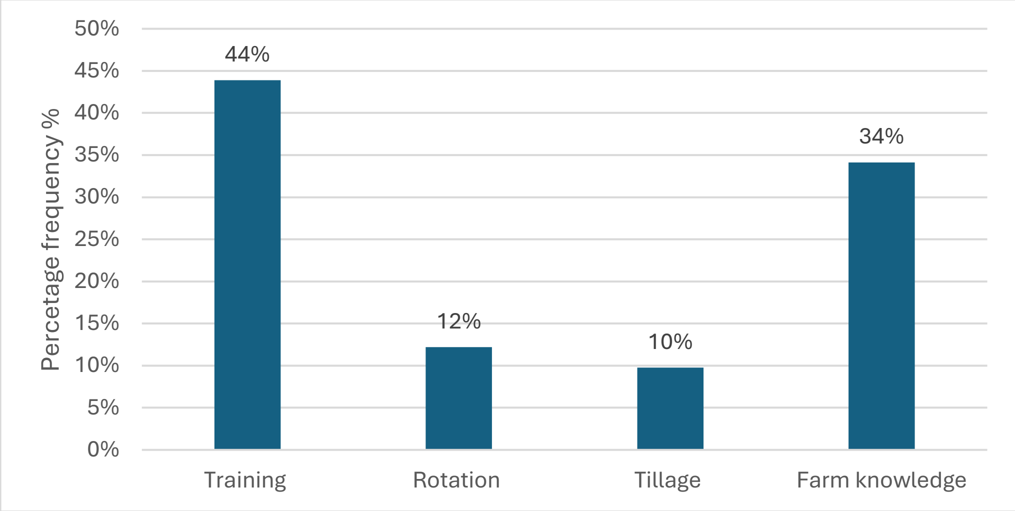


Figure 10, Thematical analysis

4.5.2 Observations made when compaction is present

Figure 11 presents the findings for respondents who do not carry out compaction testing. Their observations show signs of compaction present, the most common of which being poor infiltration in fields (38%), followed by poor plant growth (30%) of the total responses gathered. These observations are consistent with the previous studies that link soil permeability and plant health (Lipiec, Jerzy *et al.*, 2012).

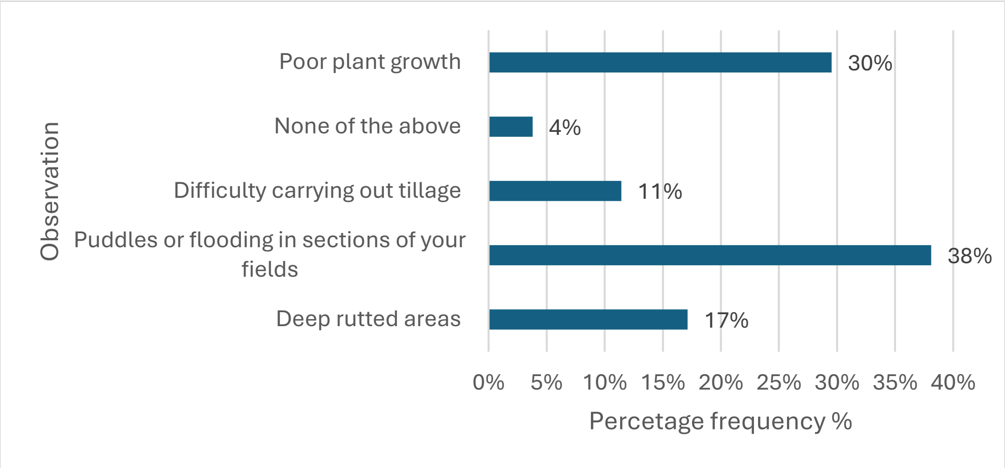


Figure 11, Compaction observations

4.5.3 Motivation to carry out compaction testing

When asked what would incentivise them to conduct compaction testing, respondents most frequently cited training (25%), followed by access to equipment (22%), improved knowledge and evidence that compaction affects productivity (21%). This further reinforces the need for more extension programmes focused on compaction testing techniques.

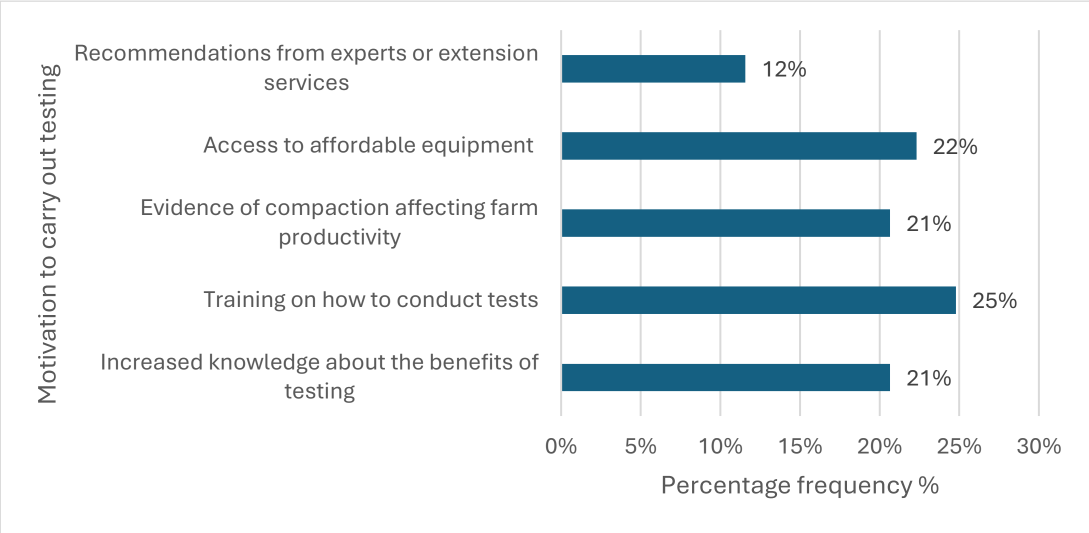


Figure 12, Motivation to carry out testing

4.6 Tillage methods used

Figure 13 illustrates the tillage methods that are being used on farm. The most common tillage method is ploughing (60%) followed by minimum tillage (16%). Ploughing is known to mitigate compaction in the short term but can contribute to long-term soil degradation (Martínez *et al.,* 2008) This suggests that a greater awareness of conservation tillage methods and controlled traffic farming could be beneficial. As a method of tillage, ploughing is seen to be detrimental to soil health and there is a push for farmers to become more sustainable and work regeneratively by taking up conservation or minimum tillage methods. This is clearly not the case in the findings in Figure 13.

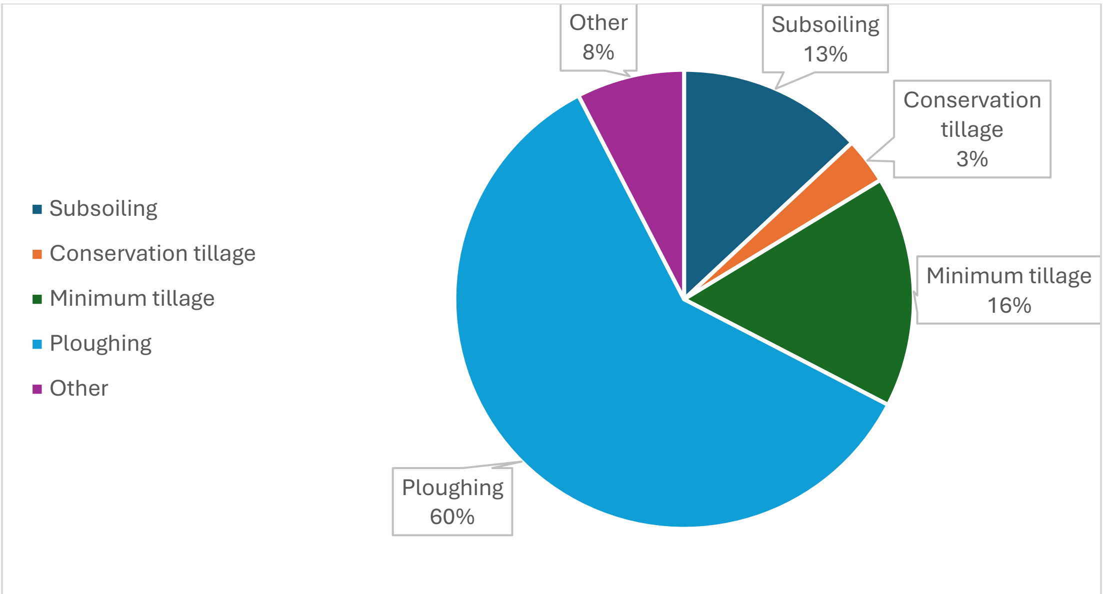


Figure 13, Main tillage methods used

Chapter Five – Discussion

The results from this study provide valuable insight into the current practices, challenges and opportunities related to soil compaction testing among farmers and farm managers. By comparing these finding to the existing literature, it is apparent that compaction testing remains a critical yet underutilised tool in the sustainable agriculture process.

5.1 Are farmers measuring soil compaction/consolidation ahead of cultivation?

A significant finding from the study was a noticeable gap between the high level of awareness of soil compaction ((63%) of respondents stated they were familiar), and the low adoption of testing practices, with only 43% of farmers and farm managers actively engaging with compaction testing, and even less taking up formal or scientific testing methods. This disconnect suggest that awareness about compaction is not sufficient to translate into active testing. Factors such as time constraints, financial limitations, and accessibility appear to be critical barriers, as seen in Table 4. Previous research by Keller and Arvidsson, (2016) identified similar barriers, where they noted that tools such as penetrometers and bulk density testing offer more reliable data, but that their use is limited due to the perception of the methods presenting technical difficulty, high cost and lack of interpretive training. These barriers were also evident in this study, where 44% (Figure 10) of farmers mentioned limited training, and 28% (Table 4) identified lack of proper equipment as the key deterrents to adopting scientific measurement.

The results indicate that awareness alone is insufficient to drive proactive behaviour. While farmers recognise the detrimental effects of compaction on water infiltration/flooding and root growth, the lack of accessible solutions continues to prevent the widespread adoption of testing practices. This aligns with the findings of Håkansson and Lipiec (2000) who emphasised the need for education and training to bridge the gap between available technologies and their practical use on farms This could be done with the addition of extension work and collaborative field trials, which would not only raise awareness of the benefits of regular soil testing but build on technical capabilities as well.

5.2 What are the current methods used to measure soil compaction/consolidation?

The reliance on visual assessment (59% Figure 8) as the primary method for compaction evaluation reflects the farmers' preference for cost effective and accessible techniques. However, while this method is a practical, it lacks the precision required for more informed decision-making techniques. Scientific approaches, such as penetrometer testing (12%) and bulk density measurement (3% Figure 8), though more reliable, are underutilised despite their proven efficiency and effectiveness for delivering accurate data (Raper, 2005). The lack of use may be due to the cost and technical skills required to interpret the results as cited previously.

The study revealed a notable preference for low-cost methods that rely on the observable signs of compaction, such as reduced crop performance or flooding.

These practices are like Schlotzhauer and Price (1999), who demonstrated how visual assessments provide the baseline understanding of soil structure but fail to account for deeper compaction layers. This further shows the need for more affordable and accessible tools to measure compaction, especially with the varying rates of compaction at different depths of soil. This would enable farmers to vary the type of tillage they choose depending on the level of compaction.

5.3 What options are being used to reduce this?

The study showed that even though there is widespread concern and awareness about soil compaction, most farmers rely on reactive strategies rather than preventative measures. Tillage, in particular ploughing (60%, Figure 13), remains the dominant practice, suggesting a preference for conventional methods of tillage to address compaction issues present on farm. While ploughing will reduce the compaction within the topsoil, carrying out repetitive ploughing can contribute to deeper structural compaction (Martínez *et al.,* 2008). This over reliance on conventional ploughing suggests that there is a gap in farmer knowledge, or they do not have the access to alternative tillage methods.

The data established heavy machinery (44% Figure 7) as the primary cause of soil compaction, particularly in arable farming systems, where machinery use is more intensive. This correlation shows the need for targeted intervention in mechanised farming systems. Methods such as controlled traffic farming and the use of reduced tyre pressures or rubber tracks on tractors, as highlighted by Keller and Arvidsson (2016) as well as McPhee *et al.* (2015), are practical solutions to mitigate compaction while maintaining operational efficiency. However, despite their effectiveness, these methods require financial investment, which could prevent their adoption among small-scale farmers.

Despite the substantial evidence supporting conservation tillage practices like minimum tillage, strip tillage or the use of cover crops in rotation (Nawaz, Bourrié and Trolard, 2013), their adoption rates remain relatively low amongst respondents. Only 16% reported using minimum tillage as their main form of tillage, suggesting these practices are not widely understood or perceived as less effective withing certain soil types or climates. This highlights the need for more location-specific research to demonstrate how such practices perform under varying conditions.

Cover crops, as shown in the literature, not only reduce compaction but enhance the soil structure and water infiltration. Their effectiveness relies on long term commitment and an understanding of species selection and management. If barriers such as training and demonstration were addressed or with the addition of government incentives, cover cropping could become a more widely adopted strategy.

Chapter Six – Conclusion and Recommendations

6.1 Conclusion

This research set out to investigate the current practices farmers and farm manager use to measure and manage soil compaction ahead of cultivation. Through a combination of literature review and primary data collection, it has become clear that although compaction is widely recognised as a problem, few farmers are actively carrying out tests prior to cultivation. In addition, most of the highly scientific testing has been carried out for academic research, to produce recommendations for appropriate tillage methods and show the cost benefit associated with this. There is little evidence that this is a mainstream practice. Most farmers rely on visual indicators such as poor crop performance or waterlogging which, while helpful, do not always provide a picture of compaction below the surface. Barriers such as lack of training, cost of equipment and time constraints were cited as major reasons for not adopting more advanced testing practices. The study found that ploughing remains the dominant tillage method, even though conservation tillage-based systems such as minimum tillage and cover cropping have been shown in the literature to improve long-term soil health and reduce compaction. The machinery and information are available, but it may be costly and dependant on the farmer researching the information surrounding it themselves.

In conclusion, improving how soil compaction is monitored and managed will require not just technological solutions, but behaviour and educational change. Farmers are already making complex decisions in highly variable environments, and compaction testing needs to become more routine for sustainability, as soil is a finite resource. Testing needs to be simpler, affordable and clearly beneficial. With the correct education and support, testing can help the agricultural sector move towards a more data driven industry with better soil management to ensure continued or increased productivity and to protect the wider environment.

6.2 Further Research

This study has identified a clear gap between awareness of compaction and the active use of monitoring techniques and mitigation practices on farm. While farmers and farm managers understand that compaction is a significant issue, many are still relying on observation-based methods, with very few using scientific tools to assess soil conditions before carrying out cultivation. This suggests several areas where further research could help bridge the gap between knowledge and implementation.

More research into how soil type and regional climate conditions affect the adoption of compaction testing and tillage methods is needed, as the data from this study suggest that despite the global move towards reduced tillage systems and cover cropping, traditional ploughing remains dominant amongst the respondents. Investigating whether this choice is influenced by local soil behaviour, drainage capacity or perceived reliability of conventional methods could offer clearer guidance to farmers operating in similar conditions.

Future studies should explore the effectiveness of training programmes and whether hands-on demonstrations would improve the uptake of soil testing techniques. Respondents consistently identified a lack of training as a key barrier, and there is scope to evaluate how training impacts the confidence and willingness to adopt methods such as penetrometer or bulk density testing.

It could be beneficial to explore how farmers and farm managers perceive cost-benefit trade-offs associated with compaction management, particularly in small to medium sized farms. While some methods are robust, their return or practical value may not be well communicated to farmers. Further research that quantifies the financial benefits of improved compaction diagnosis, such as reduced fuel usage, improved yields, or fewer inputs could encourage a wider adoption.

Future studies could also break down the question of position on farm into three groups rather than just being farmer and farm manager. Farmer should be separated into farm owner, and farm worker, which would provide more information into who is practically working on farm and who is carrying out more managerial roles.

There is the potential to expand this study by conducting semi-structured interviews to build on the results of the survey. This would provide more in-depth insight into farmer decision-making and allow for a richer exploration of how compaction is understood and managed in different systems.

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Chapter Eight – Appendices

Appendix 1 – Distributed Questionnaire

Harper Adams University

Honours Research Project on Farmers Compaction Testing

Thank you for participating in this survey. Your responses will help us understand the various methods used by farmers and farm managers to measure soil compaction. Your insights will contribute to research aimed at improving soil management practices.

Consent Form

Consent to Participate in a Research Questionnaire

Title of the Study: Are Farmers assessing soil compaction/consolidation prior to cultivation?

Principal Investigator: William Mayer , Student at harper Adams University, 21149000@live.harper.ac.uk

Purpose of the Study: You are being invited to participate in a research study. The purpose of this study is to find out what methods you are using . Your responses will help us gain valuable insights into this topic.

Procedures: If you agree to participate, you will complete a questionnaire that will take approximately 15-20 minutes. You will be asked questions about what methods you are using to measure compaction.

Participation and Withdrawal: Participation in this study is completely voluntary. You have the right to withdraw from the questionnaire at any time or skip any question you prefer not to answer without penalty.

Confidentiality: Your responses will be kept confidential. Data will be securely stored and only accessible to the research team. No personal identifiers will be linked to your responses.

Contact Information: If you have questions or concerns about this study, you may contact William Mayer
21149000@live.harper.ac.uk.

Consent: By checking the box below and proceeding with the questionnaire, you indicate that you have read and understood this information, and that you consent to participate in this study.

1. Consent *

- ◯ I agree to carry out this questionaire
- ◯ I do not agree to cary out this questionaire

Section 1: Demogrphic Infromation

2. What is your role in the farm management process?

- ◯ Farmer
- ◯ Farm Manager
- ◯ Other (please specify):

3. What type of farming do you primarily engage in?

- ◯ Arable
- ◯ Livestock
- ◯ Mixed

4. How many years of experience do you have in farming?

- ◯ Less than 5
- ◯ 5-10
- ◯ 11-20
- ◯ 20+

5. How familiar are you with the concept of compaction / soil consolidation?

- ◯ Very
- ◯ Somewhat
- ◯ Not at all familiar

6. On a scale of 1-5, how concered are you about soil compaction on your farm? (1 being not worried)

Not concerned

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5

7. From the options what would you say is the main cause of compaction?

- ◯ Heavy machinery
- ◯ Livestock
- ◯ Soil structure and its composition
- ◯ Natural factors (e.g heavy rain)

8. Do you curently use any method to measure compaction levels on your farm?

- ◯ Yes
- ◯ No

You test for soil compaction prior to carrying out tillage

9. If yes, which of the following methods do you use? (Select all that apply)

- ☐ Visual assessment of soil structure
- ☐ Penetrometer testing
- ☐ Bulk density measurement
- ☐ Soil core sampling
- ☐ Compaction meter
- ☐ Infiltration rate measurement

10. On a scale of 1–10, how effective do you find the current methods you use for measuring soil compaction?

- ◯ Ineffective
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ Unsure
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ Effective

11. How often do you measure soil compaction?

- ◯ Monthly
- ◯ Annually
- ◯ When there are visible signs of compaction

12. What indicators do you look for when assessing soil compaction? (Select all that apply)

- ☐ Decreased water infiltration
- ☐ Poor root growth
- ☐ Surface cracking
- ☐ Reduced crop yield
- ☐ Soil hardness

13. What challenges do you face when measuring soil compaction? (Select all that apply)

- ☐ Lack of proper equipment
- ☐ High cost of equipment
- ☐ Time constraints
- ☐ Difficulty interpreting results

You do not test for soil compaction prior to carrying out tillage

14. Why do you not Carry out compaction testing before cultivation?

15. Have you observed any of the following?

- ☐ Puddles or flooding in sections of your fields
- ☐ Deep rutted areas
- ☐ Difficulty carrying out tillage
- ☐ Poor plant growth
- ☐ None of the above

16. What would motivate you to to start testing compaction before tillage?

- ☐ Access to affordable equipment
- ☐ Increased knowledge about the benefits of testing
- ☐ Training on how to conduct tests
- ☐ Evidence of compaction affecting farm productivity
- ☐ Recommendations from experts or extension services

Final question

17. Did this questionaire make you think more about soil compaction / consolidation?

- ◯ Yes
- ◯ No