Faculty of Engineering and Environment
Department of Geography and Environmental Sciences

Dissertation submitted for:

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The impacts of organic and conventional farming practices on soil chemical and physical characteristics in the Yorkshire Wolds.

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I. ABSTRACT

A comparative study between organic and conventional farming methods was conducted in the Yorkshire Wolds to determine the effect that these farming methods have on chemical and physical soil properties. Soils from three organically farmed fields and three conventionally farmed fields were analysed through laboratory and statistical methods as well an enquiry about different management practices among the farmers. Organic management is known primarily for the absence of synthetic fertilisers and pesticides. After rigorous laboratory, soil quality indicators and farming methods were compared using graphs, two sample T-test, analysis of variance and Pearson's correlation. It was concluded that soil quality was greater in conventionally farmed fields due to the addition of green waste compost and synthetic fertilizer.

The clear and significant differences between farming systems suggests that green waste compost provides more essential nutrients and organic matter content than the simple addition of farmyard manure, whilst also suggesting that a mixture of organic and inorganic practices, is more favourable in improving soil quality.

Abstract:

Main text: 12,098

II. Contents

III. ABBREVIATIONS

ANOVA	Analysis of variance
Ca	Calcium
CG	Conventional Grass
CO	Conventional Oats
CW	Conventional Wheat
K	Potassium
Mg	Magnesium
N	Nitrogen
Na	Sodium
NVZ	Nitrate vulnerable zones
OCC	Organic carbon content
OG	Organic Grass
OMC	Organic Matter Content
OO	Organic Oats
OW	Organic Wheat

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V. ACKNOWLEDGMENTS

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CHAPTER 1: INTRODUCTION

The properties of soil under different farming methods are going to be investigated in the Yorkshire Wolds. With an increasing awareness across the western hemisphere regarding consumer behaviours, sustainable development and the need for modification to food consumption patterns, there has been a rising demand for organic produce across Europe (van Stappen et al. 2015). Such produce is usually perceived as more environmentally friendly than conventionally farmed food (van Stappen et al. 2015). A widespread interest regarding organic farming methods has stemmed from the use of policies by the European Union, which looks at organic farming in an attempt to be environmentally sensitive (van Diepeningen et al. 2006). The need for environmentally sensitive farming methods has also derived from the heavy application of modern management systems and the need for external inputs to achieve high yields (Hole et al. 2005). The high level of inorganic inputs has increased the level of resistance to pesticides (Heap, 1997; Jutsum et al. 1998; Moss, 2004), along with increased environmental impacts (Tilman et al. 2002). Therefore, sustaining productivity amongst arable crops without increasing environmental impacts is a vital challenge for the future (Bilsborrow et al. 2013).

A better understanding of soil quality variation between organic and conventional methods is vital in helping to improve sustainable land management (McGarth & Zhang, 2003), so this study aims to analyse the impacts that both conventional and organic farming methods have on soil quality in the Yorkshire Wolds. This study will benefit not only the landowners of the sampled fields, but also other farmers in the Yorkshire Wolds and those who may be considering the switch from conventional to organic methods, and whether such a switch is beneficial to soil quality, or whether slight improvements to current conventional methods is the way forward.

CHAPTER 2: LITERATURE REVIEW

2.1 YORKSHIRE WOLDS

The Yorkshire Wolds covers a vast area from the West of Hull up to the North Sea coast at Flamborough Head, just North of Bridlington. The Yorkshire Wolds also includes the area from the Vale of York (West of Hull), and then up to the North where it meets the Vale of Pickering, with the Holderness plain to the East of the Wolds (Natural England, 2015).

The geology in the Yorkshire Wolds mainly consists of chalk and limestone, with this area representing the most northern chalk formation in Britain (English Nature, 1997). The chalk bedrock that forms the Yorkshire Wolds was originally deposited in the Cretaceous period (Price et al. 2011) with the thickest coastal development of chalk (over 500m) being in the region of Hornsea, located on the Holderness coast (Sumbler, 1999).

The majority of the soils in the Yorkshire Wolds are shallow and free draining, with 29% being free draining lime-rich loamy soils while another 45% is covered with shallow lime-rich soils (Natural England, 2015).

As time has passed, the land use within the Yorkshire Wolds has changed. The area which was once a predominantly chalk grassland is now an area that is being used for arable and intense agricultural practices. As a result of land changes to the Yorkshire Wolds, only 1.3% of the area now remains as chalk grassland, with the majority of this chalk grassland being poorly managed (English Nature, 1997).

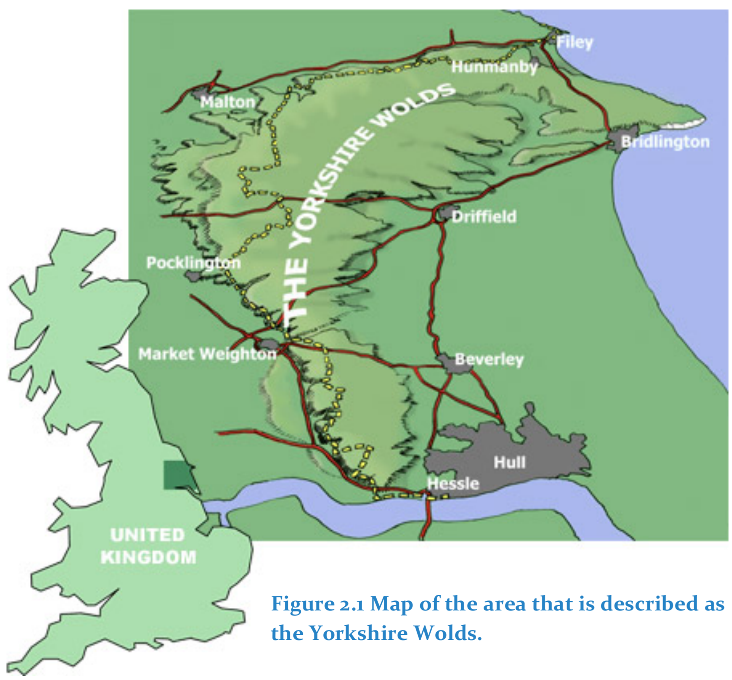


Figure 2.1 Map of the area that is described as the Yorkshire Wolds.

2.2THE FUTURE OF FARMING

The world's population is expected to reach 9 billion people by 2050, which also increases the competing demand for land and energy production (Bilsborrow et al. 2013). It is therefore vital to maintain and sustainably increase crop yields.

There are to be many changes to farming with future changes occurring to the EU Pesticide Directive (91/414/EEC), which is likely to have detrimental effects on crop production as around 20% of the active ingredients in pesticides will have to be withdrawn (Hillocks, 2012). Such changes will result in more food needing to be produced to meet the needs of the growing population but with less input from pesticides (Bilsborrow et al.2013). An example includes the production of wheat as azole fungicides are used to control Septoria and Powdery Mildew. However, this may not be available in future years if the registrations were to be withdrawn, due to these compounds having endocrine disrupting activity (Chandler, 2008).

The key challenge that is faced in sustaining the continuous arable crop productivity for future generations, without compromising environmental sustainability (Bilsborrow et al. 2013). It has been estimated that crop yields should be on the up with an increase of 2.4% each year to meet food demands by 2050 (Ray et al. 2013). However, the current estimated rate is well below this figure, with wheat yields only increasing by 0.9% each year (Ray et al. 2013). Wheat yields have been static since 1996 (Clarke et al. 2012), with cereal stagnation not been fully accounted for in several analysis reports that have taken place (Brisson et al. 2010; Petersen et al.2010). It is commonly suggested that the static yields are often due to the changes in the current climate and the soil degradation that is occurring (White et al. 2015).

Organic farming seems to be vital to sustaining the future of agriculture as it avoids the direct and routine use of synthetic fertilisers and pesticide (Ammann, 2008). Instead, it relies upon crop rotations, cultivation system, varietal resistance and sowing date (Bilsborrow et al. 2013). However organic farming systems produce a lower and more variable yield as a consequence of longer crop rotations and the lack of input from fertilisers and pesticides (Wolfe et al.2008), meaning that more land would need to be turned to arable crop to make up the lost yield and to meet food demands. In 2014, it was found that organic farming practices covered 43.7 million hectares worldwide, which included around 1% of total agricultural land in 172 countries (Willer and Schaack, 2016). It has also been estimated that the organic food and drink market has increased by 235% from 1999 to 2008, with it reaching nearly $51 billion worldwide (Mactaggart, 2010). The organic food market has expanded on a global scale since 2013 with a growth rate of 10% (Willer & Lernoud, 2015).

Organic farming provides some benefits as many farmers have willingly moved on from conventional agricultural methods and switched to organic farming practices with a total area of 508 thousand hectares farmed organically or is being converted from conventional to organic farming methods in the UK in 2016 (DEFRA, 2017). However, this figure is down 32% from data collected in 2008 (DEFRA, 2017) (See **Figure 2.2**). The land that is farmed organically in the UK only makes up 2.9% of all agricultural land (DEFRA, 2017)

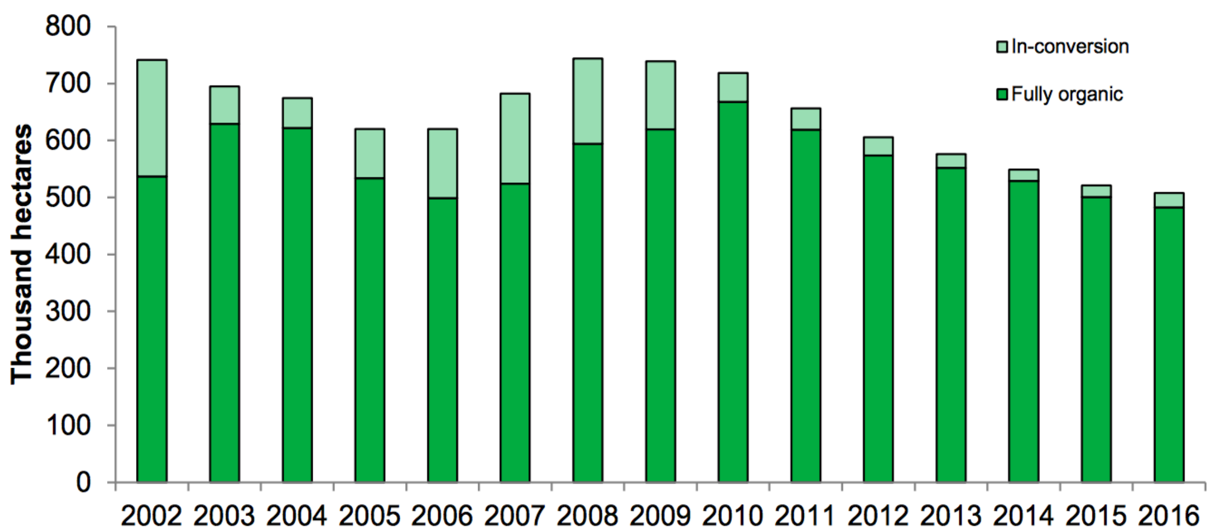
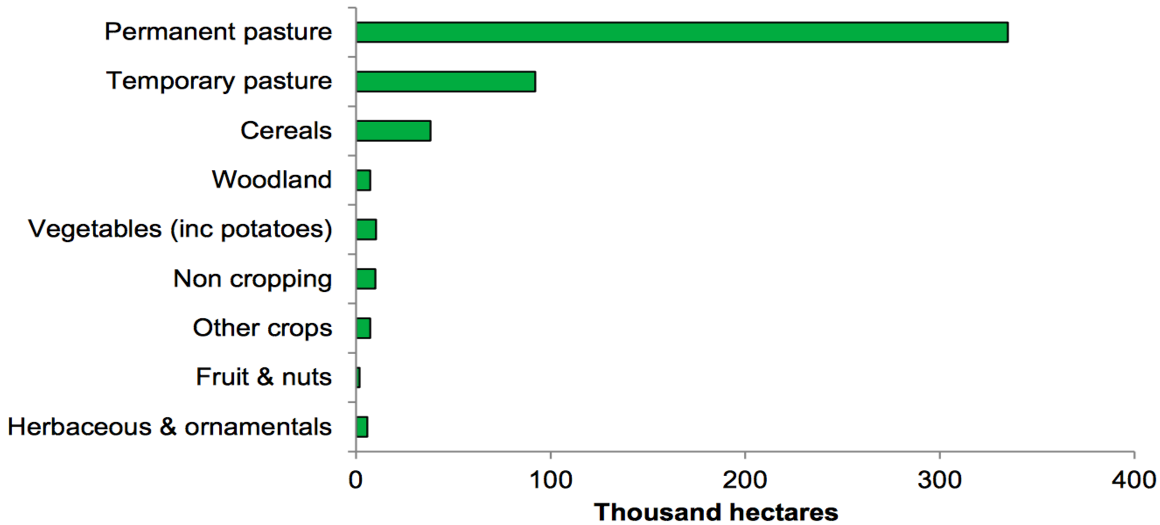


Figure 2.2 Land area farmed organically in the United Kingdom, showing that there has been a decline in the number of thousand hectares of land farmed organically. Source: DEFRA (2017)

Figures also show that it is not necessarily crops such as cereals and vegetables that are being farmed organically and make up the 508 thousand hectares of organically farmed land, but instead, it is permanent and temporary pastures that make up the hectares that's organically farmed (DEFRA, 2017) (See **Figure 2.3**). The farming of organic crops has been following the same decline since 2008 that the general organic farming community has experienced (DEFRA, 2017).



(a) Includes fully organic land and land in-conversion

Figure 2.3 A graph showing what crop occupies organically farmed land in Thousand hectares with permanent pasture being the main land use. Source: DEFRA 2017

2.3 AGRICULTURAL PROCESSES

There has been a growing concern regarding modern farming practices as it is degrading soil quality (Pretty, 1998). Although current farming practices and its soil quality have been linked to soil productivity (Al-Kaisi et al. 2005), the soil quality and thus productivity is increasingly affected by human activities (Huang et al. 2007). Research has previously indicated that soil quality could be improved if appropriate agricultural processes were to occur, such as tillage, irrigation, fertilizer, the use of lime, and the incorporation of crop residues (Rasmussen & Parton, 1994; Fischer et al. 2002; Karlen et al. 2006; Kaiesi, 2006; Huang et al. 2007). Although such human events can increase soil quality, the excessive and inappropriate use of inorganic and chemical fertilisers and the use of sewage sludge irrigation, decreases soil quality (Ewards & Lofty, 1982; Stamatiadis et al. 1999b; Ward, 2001; Datta & de Jong, 2002; Qi & Chang, 2005). Such inappropriate actions have resulted in increased land degradation, with around 40% of agricultural land degradation been human-induced (Oldeman et al. 1990).

2.4 TILLAGE PRACTICES

Some issues are underpinning the research comparing organic and conventional farming practices and whether they are a sustainable way of managing the land. Over the last century, many farmers have changed their methods of farming to those that are more modern and intensive. Due to the enhanced farm machinery that is now available such as drills which can cope with a variety of soil conditions and Combines which have larger headers allowing for harvests to be more time efficient as a more substantial area is covered (Farmers Guardian, 2017). The increase in the use of modern technology systems stems from the efficiency and the ability that modern machinery provides in helping to produce higher crop yield (Benites & Vaneph, 2001). However, such conventional and intense farming methods have had a severe impact on environmental systems (Pimentel et al. 1995), with the most significant consequences stemming from the new methods of farming as they often require extensive and highly efficient machinery (Tuomisto et al. 2012). Implications include the removal of field boundaries such as hedges to allow the new larger machinery to access the fields (Johannsen & Armitage, 2010). Monoculture farming methods were also introduced often leaving areas of land bare for an extended period with crop rotations becoming rare amongst the farming community (Blunden & Curry, 1985; Arden-Clarke & Hodges, 1987; Robinson & Sutherland, 2002).

Tilling is one of the primary methods that is performed in conventional farming methods. Originally tilling was beneficial to the soil as it disrupts the compacted areas as it aerates and loosens the earth, while mixing nutrients and organic matter, thus maintaining soil fertility due to the promotion of micro-organisms (Johannsen & Armitage, 2010). However, the process of tilling has changed dramatically, from once being cultivated by human labour and hoofed animals pulling a plough to specialized machinery (Johannsen & Armitage, 2010). In turn, this has had a significant effect on the structure of the soil (Papadopoulos *et al.* 2006), including the undesired impact of poor crop development (Huwe, 2002) but conventional yields still tend to be higher than organic yields. The level of damage that can occur in soils depends on several factors including the type of land that is being farmed, organic matter content, soil moisture levels and the timing of ploughing as more impoverished structured soil (i.e., sandy and loam soils) are more at risk of mechanical damage (Johannsen & Armitage, 2010). The timings at which process occur such as ploughing depends on the type of crop that is being grown and the length of the crop season (Johannsen & Armitage, 2010). However, the timings of ploughing can have negative impacts on the soil structure, oxidation of organic matter and disrupt the functions of soil organisms (Holland, 2004). For successful crops to grow the soil needs to be fertile, as this provides the essential nutrients that help crop growth.

Soil fertility also supports a diverse and active biotic community, exhibits a typical soil structure and allows for an undisturbed decomposition (Maeder *et al*., 2002). The structure of the soil is also necessary as it influences the physical, chemical and biological characteristics within the soils, as the soil structure determines the accessibility of water, air, and nutrients, while also controlling the drainage, resistance to erosion, root penetration and the seedling emergence (Gerhardt, 1997). In the long term, the intensification of conventional farming practices will cause a loss of organic carbon content in the soil due to the damage to soil structure (Webb et al. 2001) along with productivity due to the pressures on the earth (Foley et al. 2005).

2.5NUTRIENT AND PEST MANAGEMENT

Crop and soil management practices such as the application of fertiliser, land use change and crop rotation have a considerable influence on soil chemical properties over time (Liu et al. 2010). To try to relieve the problems that arise with conventional and organic farming methods the ideal solution would be a method of sustainable farming that produced high yields of the crop but without the effect on ecological systems and soils (Pimentel *et al*., 1997). It has been stated by Philipps (2003) that ‘organic farming aims to achieve sustainability through the duplication of the natural biological cycles present in soils,' with organic farming methods aiming to manage the soil so that soil fertility is sustained. Therefore, organic farming has been perceived to have fewer effects on the environment than conventional farming methods due to some conventional means relying heavily on external inputs (Gomiero et al. 2008). Organic methods prefer to use crop rotations as a form of pest and weed control, with pesticides only being used as a last resort if crops are in danger of failing (Tuomisto *et al.* 2012). Several critical biophysical interactions need to be developed for organic farming to be successful (See **Figure 2.4)**.

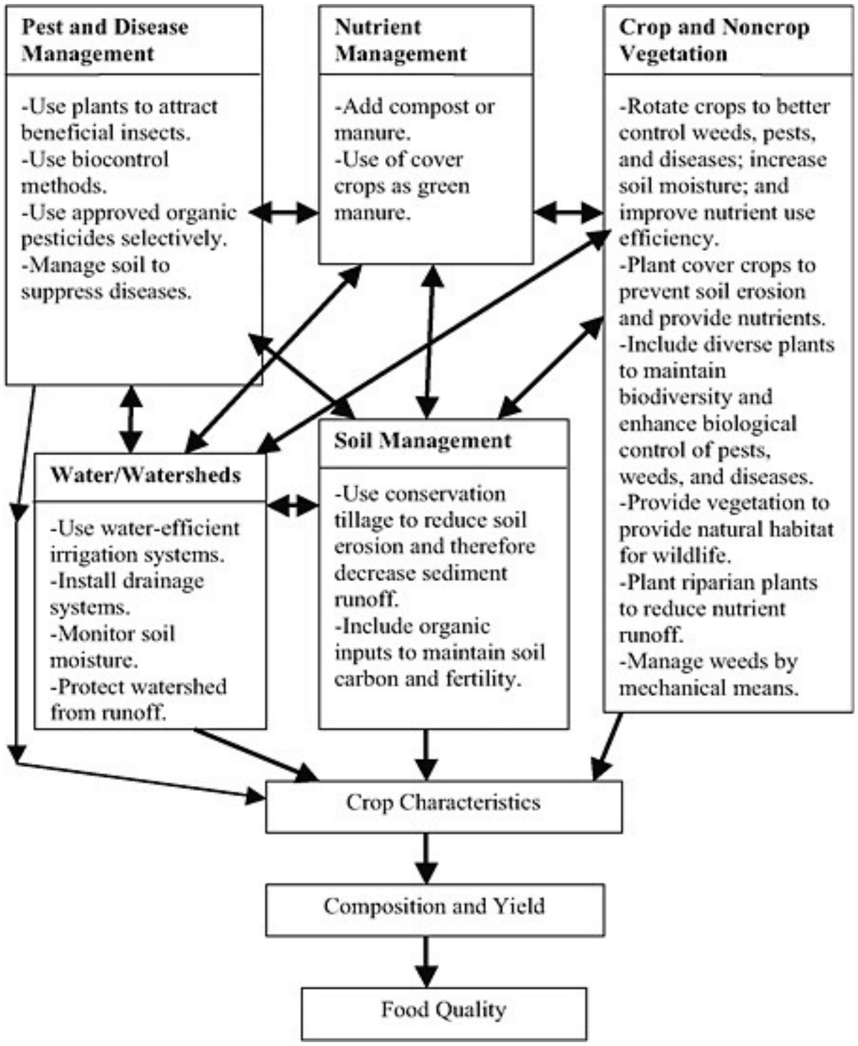


Figure 2.4 Practices and interactions used in organic farming methods

Source: National Research Council (2010)

There are two fundamental differences between organic and conventional farming methods, which are the levels of crop rotations that occur, and the level of fertiliser that is applied as a way of protecting and managing the crop. Crop rotation is primarily used in organic farming methods to avoid pests and disease, while they also rotate crops to help improve the structure of the soil as different crops have different root structures (Philipps, 2003). Fertiliser application to organic crops are restricted as only certain types of fertiliser are eligible for use, as well as there being guidelines regarding the length of time that compost is required to mature (Philipps, 2003).

Due to the differences between the two methods of farming, organic farming is seen to be critical for managing soil health, by protecting and also developing the soil structure, fertility and the biological activity within the soil (Soil Association, 2010). Fertility management within organic farming practices relies on a long-term approach rather than the short term, which is the case in conventional farming due to the targeted solutions (Watson et al. 2002). It has been argued that organic farming has its weaknesses due to lower yields as a result of lower inputs and more pests and weeds been present (Köpke *et al.* 2008). Therefore, fewer farmers are encouraged to make the switch from intensive methods of farming to organic. Other issues with organic farming methods include the timing at which nutrient and herbicides are applied as this depends on the type of crop that is being grown and the length of the crop season (Johannsen & Armitage, 2010). These timings influence the soil, including changes to soil structure, oxidation of organic matter and disrupts the functions of soil organisms (Holland, 2004) all of which also occur as a result of tilling. Because of the effects on the soils structure and the loss of soil nutrients, farmers have become reliant on the extensive use of agrochemicals to control pests and weeds and fertilise soils.

An increase in crop yields has been observed over the last three decades. This increase has been a direct result of the development of high yield crop varieties alongside the increasing use of chemical and organic fertilisers, pesticides and irrigation (Bindrabon et al. 2000). The increased use of pesticides and fertilisers, especially ammonium-based fertilisers, has contributed to the increase in soil acidification (Gudmundsson et al. 2004; Rodriguez-cruz et al. 2006).

2.6 SOIL QUALITY

There are many ways to define soil quality, as agricultural soil quality is often referred to as the condition and capacity of land including soil, climate, and the biological properties, for production, conservation and environmental management (Pieri et al. 1995; Stamatiadis et al. 1999a), while it has also been defined as ‘the capacity of a soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation' (Karlen et al. 2005).

Soil quality also describes the condition of the soil as a result of it management (Karlen et al. 2003). If the soil quality is high, then fields produce higher productivity, with the soil having little environmental degradation (Fuentes et al.2009). Soil quality includes some factors that can be tested, including pH, the supply of mineral nutrient elements, water content, the composition of soil atmosphere and biotic factors (Marinari et al. 2000). Several studies completed have shown that organic matter improves soil quality (Drinkwater et al. 1995; Reganold et al. 2001) with a previous research showing that organically farmed soil was of a better quality as it tended to have a lower bulk density than those which were farmed conventionally (Liu et al. 2007). Therefore, soil quality was improved by organic farming methods (Reganold et al. 2001).

2.7 SOIL BUFFERING CAPACITIES

Calcareous soils, which are found in the Yorkshire Wolds, cover around 47% of the Earths entire land area (Lal, 2009). Many of these soils properties are affected by the nature and the reactivity of the carbonate minerals present (Rovira & Vallejo, 2008), which is dissolved through soil acidification (Zhang et al. 2016). Increased conventional farming methods continue to contribute to the acidification of soils, along with the increase in atmospheric Nitrogen deposition (Guo et al. 2010; Lui et al. 2013). Increased soil acidification can affect the fertility of the soil as there is often a depletion of base cations including Magnesium, calcium, and potassium (Bowman et al. 2008). As the reduction of base cations occurs and soil infertility increases, the productivity of the soil is also likely to decrease (Hoegberg et al. 2006). pH buffering capacity is measured to assess the rate of acidification within soils. It is said that calcareous soils have the highest buffering capacity as a result of resistant, caused by the long-term application of fertilisers and atmospheric Nitrogen deposition (Helyar et al. 1990; Moody & Aitken, 1997).

2.8 NITRATE VULNERABLE ZONES

Nitrate vulnerable zones were introduced due to the concerns regarding the nitrate concentrations found in surface and ground waters and the impact that it has on drinking water quality as well as surface water habitats (Burt et al. 1993). NVZ's were designated to areas above an aquifer, where nitrate concentrations either were above or were likely to exceed 11.3mg/l NO_3-N (Worral et al. 2009). Around 56% of the UK's agricultural land is in NVZ's, meaning they have to farm their land while complying with the relevant legislation (Lord et al. 2009). Landowners are required to follow the Nitrate vulnerable zone Action programme measures as part of the Nitrates Directive (European Commission 1991) (Lord et al. 2009). These measures aim to reduce the nitrate pollution as agricultural practices make up for more than half of the nitrate that is found in English waters (Hughes et al. 2008). The nitrate directive implements specific measures including the timing of fertilizer and manure application to the land, the storage of manure and the capacity of storage vessels, the quantities of N that are applied to soil through chemical and organic fertilisers and ensuring that appropriate farm records are kept (Lord et al. 2009). NVZ's are based on pollution to surface water and groundwater. A more extensive area of the UK is sensitive to surface water pollution than groundwater pollution (**Figures 2.5 & 2.6**). The Yorkshire Wolds is subject to NVZ for both groundwater and surface water, with the study area chosen being located within this area.

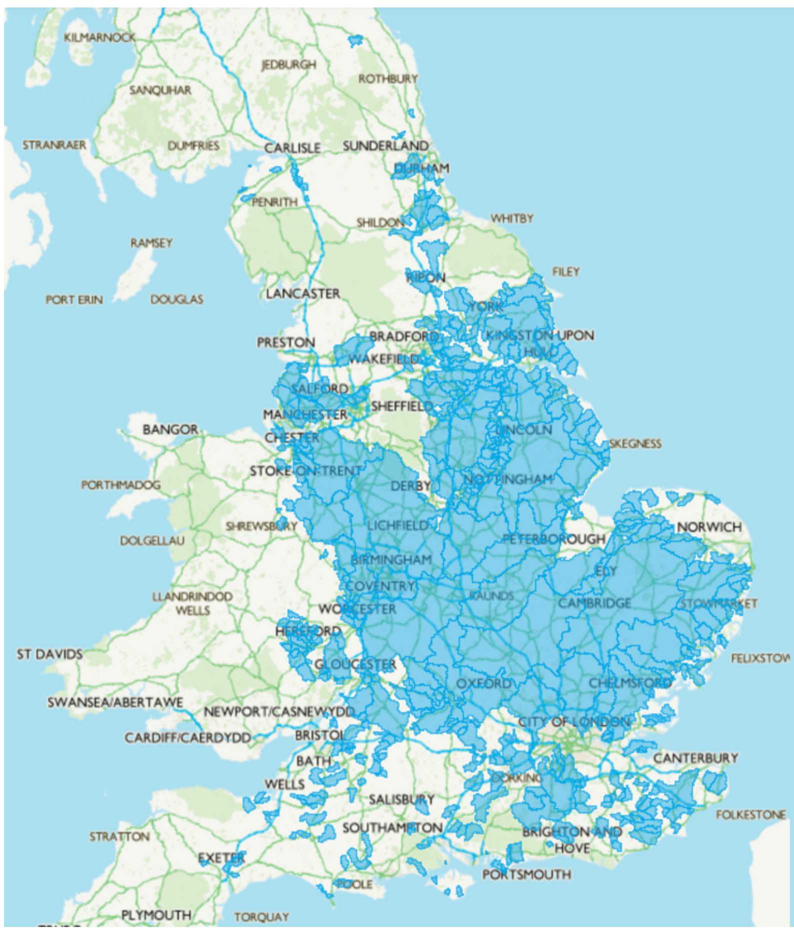


Figure 2.5 Location of Nitrate Vulnerable zones for surface waters in the UK. Source: Environment Agency (n.d.)

Figure 2.6 Location of Nitrate Vulnerable zones for Groundwater's in the UK. Source: Environment Agency (n.d.)

2.9 SUSTAINABLE FARMING IN DEVELOPING COUNTRIES

It has been estimated that there are around 1.5 million organic producers worldwide, with a quarter of this figure being based in India (Mactaggart, 2010). Organic production occurs in many countries with Africa been home to around half of the world's organic producers (Willer & Kilcher, 2009). However, organic production in Africa is mainly smallholdings whose total organic coverage is insignificant (Schoonbeck et al. 2013). Africa's overall coverage of organic agriculture only amounts to 900,000 hectares (Schoonbeck et al. 2013) compared to Argentina whose organically farmed coverage amounts to 5.8 million hectares (Yussefi & Willer, 2007). Although Africa may not contribute to a significant coverage of organically farmed land, it can be said that nearly 11 million hectares of the organically farmed land is based in developing countries (Willer & Kilcher, 2009).

Organic farming methods would provide many benefits to developing countries as it reduces energy use and provides environmental protection while it also benefits wider issues such as food insecurity, as it only uses sustainable resources while increasing crop yield without the extra cost of inputs such as fertilizer (Stockdale et al. 2001).

Land degradation, scarcity of resources, more chronic weather events such as heavy rainfall or severe drought and pest problems all pose a threat to food security, with these threats only worsening as changes occur to the global climate (Schoonbeck et al. 2013). Organic agriculture would provide many benefits to farmers in developing countries as it could be a more flexible alternative that deals with climate change, biodiversity and the need for sustainable food production (Schoonbeck et al. 2013). In the long run organic farming methods could help fight the issue of undernourishment in many developing countries (Schoonbeck et al. 2013). However for it to be effective, identification of suitable crops for the region/ country needs to occur as some crops are unable to cope with certain climates as well as identifying what is suitable for the regions market demand (Yadav et al. 2013).

Although organic farming methods may be the answer to helping fight undernourishment in developing countries, problems still lie with the productivity and market access to organic produce (Schoonbeck et al. 2013). Lower yields lead to lower incomes, thus increasing the possible risk of undernourishment. It is therefore essential that conventional farming methods still occur in developing countries alongside organic agriculture (Schoonbeck et al. 2013).

2.10 PREVIOUS INVESTIGATIONS

Previous investigations have occurred by comparing the environmental impacts from conventional and organic methods, with data showing significant environmental impacts (Williams *et al.* 2010). Results that were collected from previous investigations have demonstrated that Carbon (C), Phosphorous (P), Potassium (K), Magnesium (Mg) and Calcium (Ca) were higher in organically farmed soils. The levels of exchangeable bases and phosphorous were higher in organically farmed soils due to the application of manure and cover crop incorporations (Clark *et al.* 1998). Previous investigations have also been conducted for soil mineral N, with results showing that the levels varied by crop, the farming system that was used and the source and the amount of N fertiliser that was applied (Poudel *et al*. 2002). However, sources have also shown that the availability of N has been a significant factor in limiting the yield of organic systems (Clark *et al*. 1999). When nitrogen first enters the soil it's known as ammonium, which is then nitrified to be called nitrate. This process acidifies the soil due to the creation of hydrogen ions (Istas *et al.* 1988). When plants absorb ammonium, it can cause several adverse effects, mainly if the conditions include low soil pH, drought or low temperatures. The deposition of ammonium is most likely to cause impacts in communities where the nutrient status is low and the pH of the soil critical (Skinner *et al.* 1997).

CHAPTER 3: STUDY AIM AND RESEARCH QUESTIONS

3.1JUSTIFICATION OF STUDY

A critical and extensive review of the literature has revealed the broader problem that is faced with declining soil quality and the need for sustainable farming methods. Little research has been conducted in Yorkshire so this study aims to fill the gaps and see if organic farming methods are more sustainable than conventional methods.

3.2 STUDY AIM & RESEARCH QUESTIONS

This study aims to analyse the extent to which soil physical and chemical characteristics differ in response to organic and conventional farming practices. To tackle this aim, a number of research questions have been composed to establish answers that are more definitive:

1. Is organic matter content affected by the type of farming method or influenced by crop variety?
2. Studies have shown that bulk density and compaction are often influenced by organic matter content. Are the levels of bulk density and compaction affected by organic matter content or controlled by the farming method?
3. Are exchangeable base levels higher in organically farmed fields than conventional due to the large amounts of manure application?
4. Are pH levels more acidic in conventionally farmed fields, or is the pH affected by crop type rather than the farming method?
5. Is carbon content influenced by the farming method?
6. Does crop variety influence the factors more than the farming method applied?

CHAPTER 4: STUDY AREA

The investigation and fieldwork are to take place at two separate farms at Garrowby in the Yorkshire Wolds. High Callis Wold farms using both methods of organic and conventional, with the organically farmed fields following a specific 7-year crop rotation since 1999. The conventionally farmed fields also follow a specific 4-year rotation. Within the crop rotations are several different crop varieties, which all provide different root structures. The organic crop rotation follows winter wheat, winter oats, spring beans, rye, spring oats and then grass for two years, while conventional follows the rotation of winter wheat, spring oats, a cover crop such as grasses or legumes and then winter barley. The conventional oat field that was tested is still in the Yorkshire Wolds. However, it was further from the Homestead as seen in **Figure 5.2**. This field location could potentially affect the results; although precautions have been taken to ensure that the field is of similar slope angle and soil variety. Unfortunately, High Callis Wold only farms organic grassland, so another local farm was chosen for fieldwork on conventionally farmed grassland to take place. Fordham Farm is the neighbouring farm to High Callis Wold, allowing the same soil type to be analysed. Fordham farm, however, does not apply crop rotations to the grassland field tested as the land has been grass for the last four years. The field is grazed by sheep all year round, which may have some effects on the results. Both farms have been farmed since the 1800's with little changing to field boundaries. In some fields at High Callis Wold, there was once chalk pits. However, signs of these have gone, while one field-tested has a clear burial mound present **(See Appendix A).**

CHAPTER 5: METHODOLOGY

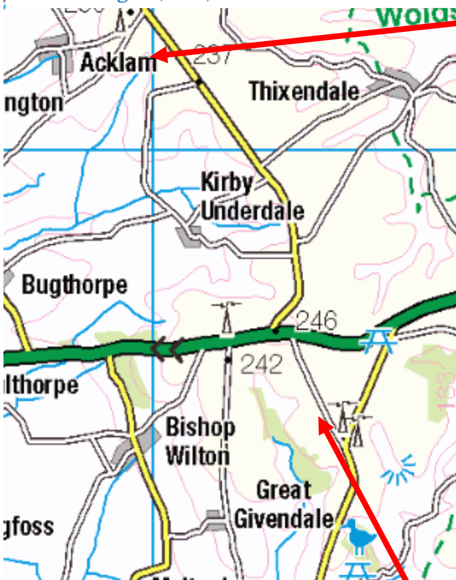
5.1SAMPLING METHOD

Sampling took place during the last week of August and the first week of September depending on when the crop had been harvested. The timing of soil sampling was influenced by harvest and ploughing, as the ideal sampling time is when the field is recognized as stubble. Samples were taken after harvest and before ploughing or sowing begins, as live crop roots could influence possible results if sampled in spring (Papadopoulos et al. 2006), while sampling after ploughing may affect the newly planted seedlings.

Sample collection is based upon the crop species, which are wheat (*Triticum aestivum*), oats (*Avena sativa*), and grass (*Herba*). The fields were sampled are shown in **Figure 5.1** with the individual fields being displayed in **Figure 5.2** and **Figure 5.3**. From both organic and conventionally farmed fields one field of each crop species is tested. Six fields were tested altogether, with ten samples collected from each field, with 60 soil samples gathered in total. Samples are taken to a depth of 10cm to allow for the incorporation of topsoil to be analysed, while the low depth of sampling ensures that aesthetic damage is minimal. Sampling design has been based upon a number of studies that also looked at the differences in farming methods (**Table 5.1**). As well as ten soil samples from each field, ten-core samples are also taken from each Wheat and Oat field in the same location as the ten soil samples. The samples are collected using the core method, which involves multiple core samples taken from each profile at around 200mm. The cylindrical core is approximately 7cm in length and 2 inches in width (Diameter), which allows the volume to be calculated. Once in the lab bulk density samples will be oven dried and then weighed to determine the bulk density of the soil at each sample site (Twum & Nii-Annang, 2015).

While in the field soil compaction will be measured in the grassland fields using a penetrometer rod that will be driven into the soil at a constant and steady rate for each sample to avoid inconsistency. Soil compaction is to be measured as it allows correlations to be found between the different physical soil properties (Davidson, 1965), while it can also be used to study the effects of fertilisers on the soil (Donaldson et al. 1984).

Figure 5.1 Map to show the location of study sites
Source: Contains OS data © Crown copyright and database right (2018)



Conventional Oats

Figure 5.2 Location of the conventional oats field sampled at Acklam Wold.

Conventional Wheat

Organic Wheat

Conventional Grassland

Organic Grassland

Figure 5.3 Location of sample sites farmed by High Callis Wold and Fordham Farm

Organic oats

Author	Location	Methodology	Results
Van Diepeningen et al. 2005	The Netherlands	13 organic farms and 14 organic farms tested. Fields paired based on their soil type and the crop species. Ten samples were collected for each field up to 20cm depth. pH was determined in water.	Organic carbon levels did not differ between the farming methods. No significant difference was found for pH between the different farming methods.
Papadopolous et al. 2006	Pickering, North Yorkshire	Two organic and two conventionally farmed fields from the same soil type. Sampling was conducted after sowing of crops to avoid live crop roots and soil was taken from 0-15cm in depth.	Organic matter content was found to be higher in organic fields
Marinari et al. 2006	Central Italy	Two adjacent fields, one farmed organically and one conventionally. The soil was taken from a depth of between 5-20cm at three times of the year: April, September, and November.	No consistent differences in Carbon content between farming methods were observed
Fuentes et al. 2009	Mexico	Soils sampled after harvest, in two fields for each farming method. 15 samples were taken from each field.	Bulk density was found to be higher in conventional fields. Organic C was found to be highest in field's organic fields than conventional. pH was affected by treatment but only in the first 5cm of soil pH was more acidic in organic soils.

Table 5.1 Previous investigations that were taken into consideration for the sampling design of this study.

5.2LABORATORY ANALYSIS

Before laboratory analysis is to be carried out, the individual soil samples collected in the field are spread on drying trays and air dried for a week. The individual samples are then ground gently using a rubber pestle and mortar and passed through a <2mm sieve. The coarse (>2mm) fraction is discarded, and the fine fraction is retained and re-bagged for analysis.

Soil acidity is measured as a pH value, which is relative to the concentrations of H+ ions expressed on a logarithmic scale (Rowell, 1994). The standard soil suspension is expressed as:

$$pH= -\log[H^+]$$

The pH of agricultural soils is normally measured in water; however, the pH can be measured in calcium chloride if it is for research (Blake et al. 1999). Soils are usually measured in calcium chloride for research purposes as it stimulates the soil solution better than water and there provides a more accurate value of the true soil pH. Due to water been the normal measurement, but calcium chloride been suitable for research, the pH was recorded in both.

Soil pH is determined by measuring 10g of air-dried <2mm fraction soil into a 50ml glass beaker. Deionised water (25ml) is added and stirred using a glass rod. After four minutes, the electrode was added to the solution and stirred for 30 seconds before taking the reading. 2ml of 0.125 Mol CaCl2 is then added to the solution, mixed and pH recorded after another four minutes. The pH probe was put through a two-point calibration of 4 and 7 with the pH electrode being decontaminated between each use using deionized water.

Soil organic matter concentrations are derived from using the procedure of Loss of Ignition (LOI) (Boyle, 2004). To determine the SOM, 5g of the <2mm fraction of soil was pre-weighed into porcelain crucibles and dried in an oven of 105^{O}c for sixteen hours minimum (Rowell, 1994).

Care was taken when handling the crucibles, and extended drying time in the oven allows for the sufficient removal of residual hygroscopic moisture contained in the air-dried soil. These actions allow for the minimization of random error from spillage and residual moisture (Hoskins, 2002).

Samples were allowed to cool and weighed to determine the water content. Samples were then placed in the furnace at 800^{o}c for 30 minutes, and when removed were left to cool before been reweighed (Rowell, 1994). Loss of ignition has been chosen to measure organic matter as the organic matter content within the soil is the equivalent to the mass loss (Wright et al. 2008), while the loss on ignition method is also inexpensive yet reliable and suitable for measuring organic matter (Konen et al. 2002).

Organic matter content is calculated by using the following equation:

$$\text{LOI (\%)} = \frac{\text{Mass of oven dried soil (g)} - \text{Mass of ignited soil (g)}}{\text{Mass of oven dried soil (g)}} \times 100$$

From the loss on ignition method, organic carbon content of the soil will be measured by dividing the organic matter reading by 1.7.

To measure exchangeable bases, including Ca, Mg, K, and Na, the soil samples will be extracted, with acetic acid. 10g of <2mm fractioned soil is added into a plastic bottle before adding 50ml of 2.5% acetic acid and being placed on the shaker for 30 minutes. The supernatant liquid is then filtered and refrigerated until needed for Flame photometer and atomic absorption spectrophotometer. To the filtered liquid a 1/10 dilution is created, so 1 ml of sample is added to a test tube with 9ml of deionized water. The machines are then calibrated, and samples analysed. For the flame photometry, a calibration curve will be used to obtain the results of sodium and potassium. The results recorded in ppm need to be converted from concentrations in extract solutions to the concentrations in the soil where they originate (Me/100g). This is done by the following equations:

- Ca = ppm x 0.0499
- Mg = ppm x 0.0822
- K = ppm x 0.0256
- Na = ppm x 0.0435

Even though these extractions come with disadvantages, they have been chosen to test the exchangeable bases as the problem can be fixed and the test provides suitable results (Walworth, 2011).

The bulk density samples collected were freeze-dried for a week, so that moisture is retained. Once weighed, the samples are then oven dried for another week before been weighed again. The equation for bulk density is as follows:

$$\text{Bulk Density g/cm}^3 = \frac{\text{Mass of oven dried soil (g)}}{\text{Volume of cylinder (cm}^3\text{)}}$$

Bulk density samples were limited to arable fields only as the ground was too hard to apply the cores. Instead, compaction was measured in the grassland fields, which allows for a similar result. Compaction analysis did not take place on the arable farms because the landowner had already ploughed the fields before the investigation could take place. A handheld penetrometer was used, which allows for soil penetration resistance to be measured. The penetrometer was fitted with the 2.5cm^2 cone and was pushed steadily into the ground, with the reading been measured in Newtons. Specific cone resistance then has to be determined by the following equation:

$$\text{Cone resistance N/cm}^2 = \frac{\text{Reading}}{\text{Cone base area (2.5)}}$$

5.3 STATISTICAL ANALYSIS

Once the samples have been analysed in the laboratory, some statistical tests can be applied to the raw data seen in **Appendix B**. To compare chemical and physical properties for both farming methods a two-sample t-test will be used (van Diepeningen et al. 2006) as it tests to see whether the means are different for the physical or chemical properties in the organic and conventionally farmed fields (Mcdonald, 2014). All variables will also be tested using Pearson's correlation as it allows for a correlation between the variables to be found (Mcdonald, 2014). The smaller the p-value (probability) that occurs, the more association there is between the farming method and the variables (Diener-West, 2008). A one-way analysis of variance (ANOVA) test will also be conducted so that a difference between the different crop species can be observed. It applies the same technique as the two-sample t-test by producing a P- value but allows for more than two variables to be tested.

CHAPTER 6: RESULTS

This chapter will present the statistical data that has been derived from the raw data produced in the laboratory **(See Appendix B).** It intends to answer the research questions in **Section 3.2** through some statistical tests as mentioned in **Section 5.3**. Table 2 allows for the T-test result between organic and conventional for each variable to be shown.

	Conventional mean	Organic mean	T-Value	P-value	Degrees of freedom
pH	6.37	6.72	1.77	0.083	49
OMC (%)	9.69	8.26	4.37	<0.001*	46
OCC (%)	5.75	4.88	4.32	<0.001*	48
Ca (me/100g)	1.29	1.12	0.72	0.476	41
Na (me/100g)	0.044	0.042	0.79	0.433	50
K (me/100g)	0.021	0.018	0.56	0.581	51
Mg (me/100g)	0.24	0.15	4.06	<0.001*	35
Bulk density (g/cm^3)	0.32	0.29	0.76	0.451	29
Compaction (N/cm^2)	93.0	107.8	2.96	0.005*	37

Table 6.1 The mean and T-test values of farming methods for all soil quality indicators

*Less than 0.05, so is statistically different between the two faming methods

6.1 PHYSICAL PROPERTIES

6.1.1 BULK DENSITY

Figure 6.1 displays the mean of bulk density in organically and conventionally farmed fields with conventional having a higher mean (M=0.322g/cm^3, SD=±0.16) than organic (M=0.291 g/cm^3, SD=±0.085). However, the errors bars displayed portray that the concentration of the bulk density values is high, allowing for the average value to be more certain due to the spread of the error bar being less than conventional. The two sample t-test conducted reported that there was no significant difference between organic and conventional (T=0.76, P=0.451) **(Table 6.1).**

A two-sample t-test was also applied for to bulk density readings of crops regardless of the farming method. The test showed no significant difference between crop species (T=1.03, P=0.315), with oats (M=0.29 g/cm^3, SD=±0.085) having an average lower bulk density than wheat (M=0.33 g/cm^3, SD=±0.16) **(Figure 6.2).** The error bars included in the graph show that the spread of data for wheat is higher than in oats, which shows that the concentration of data close to the mean is lower.

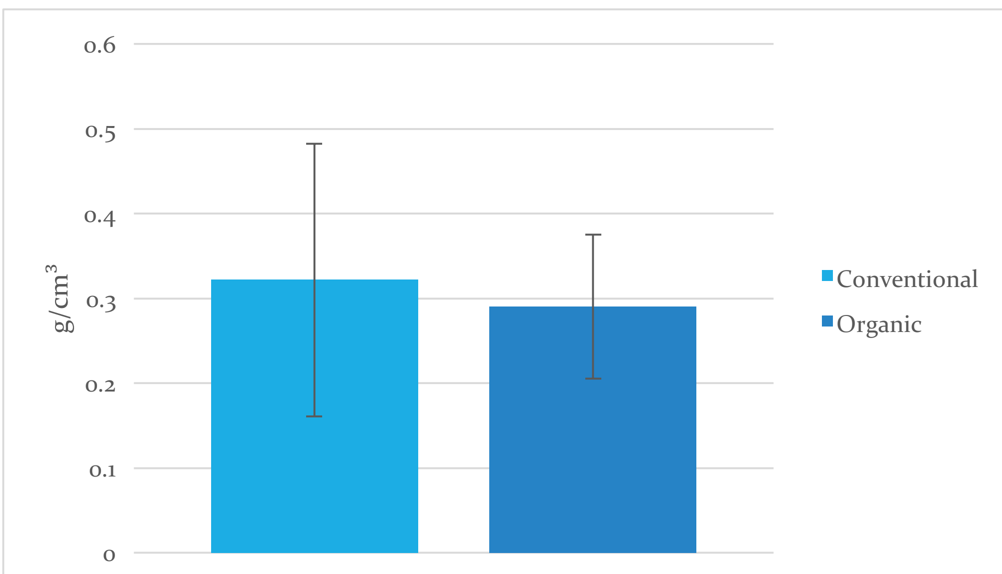


Figure 6.1 The mean and standard deviation error bars bars of conventional and organic for Bulk density. It shows that conventional has higher levels of bulk density

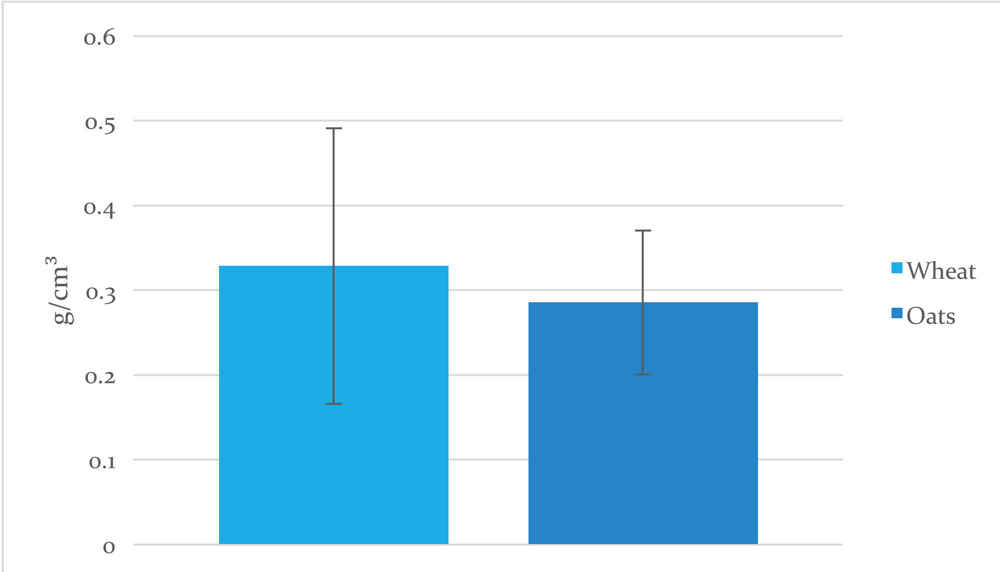


Figure 6.2 The mean and standard deviation error bars of bulk density for different crop species. The graph shows that bulk density was higher in wheat fields than oat fields

Pearson correlation analysis was used to examine the relationship between bulk density and other soil quality indicators **(Table 6.2).** Results indicated an inverse relationship between bulk density and Organic carbon content (r=-0.273, P=0.093), Calcium (r=-0.107, P=0.517), potassium (r=-0.074, P=0.653) and OMC (r=-0.277, P=0.088). This suggests that as bulk density increases within the soil the soil quality indicator levels decrease.

There was found to be a positive relationship between bulk density and magnesium (r=0.240, P=0.141), sodium (r=0.284, P=0.080) and pH (r=0.085, P=0.605), therefore as bulk density levels increase so does pH, sodium, and magnesium present in the soil.

However, although inverse and positive relationships were observed between bulk density and soil quality indicators, it is not possible to say that these correlations are statistically significant; therefore it cannot be concluded that the correlations are different from 0 **(Table 6.2).**

	Bulk density	
	Pearson correlation	P-value
pH	0.085	0.605
Organic matter content	-0.277	0.088
Organic carbon content	-0.273	0.093
Calcium	-0.107	0.517
Magnesium	0.240	0.141
Sodium	0.284	0.080
Potassium	-0.074	0.653

Table 6.2 Correlation matrix to show the Pearson's correlation between Bulk density and chemical indicators

6.1.2 COMPACTION

Figure 6.3 displays the average reading of compaction for conventional and organic farming methods, with is showing that compaction readings were on average higher in organically farmed fields (M=107.8N/cm^2, SD=±16.3) than in conventionally farmed (M=93.0 N/cm^2, SD=±15.2). From the errors bars displayed in **Figure 6.3** it can be said that there is a high concentration of results around the mean value in both organic and conventional compaction levels. The two sample t-test conducted on grass compaction readings showed a significant difference (T=2.96, P=0.005) (**See Table 6.1**) between different farming methods suggesting that conventional farming methods in grassland fields produce less compaction than those of organic. Different crop species was not tested as compaction readings were only taken in grass fields.

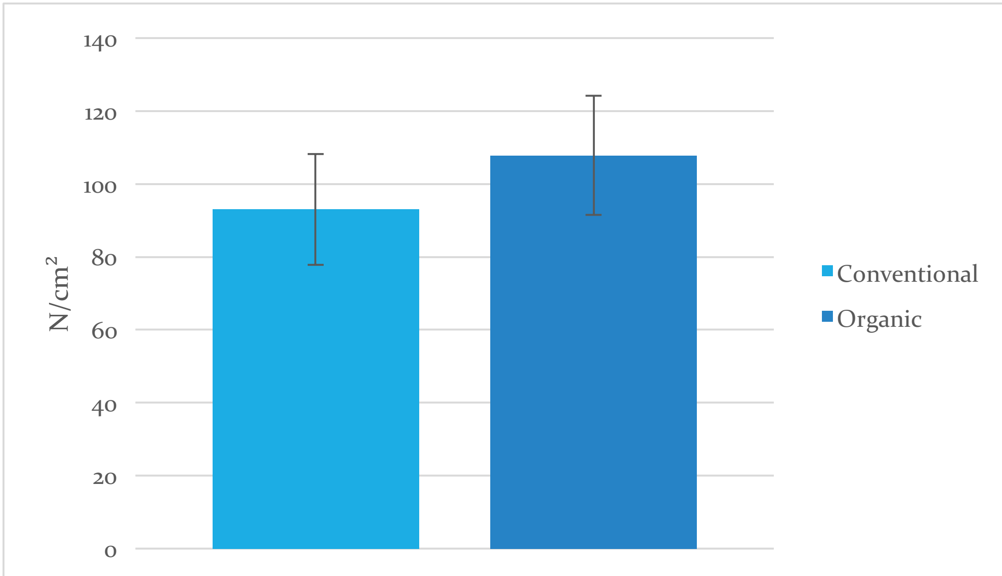


Figure 6.3 Graph showing the mean and standard deviation error bars of compaction measured in organic and conventionally farmed fields. It shows that compaction is higher than in conventional

6.2 CHEMICAL PROPERTIES

In addition to a two-sample T-test and Pearson's correlation, a one-way analysis of variance test has been included to allow the three crop species to be tested against one another. The following table **(Table 6.3)** provides for the One-way analysis of variance results between crop varieties for each variable to be shown.

	Oats	Wheat	Grass	P- value	F- value
pH	7.12 (±0.093)	6.93 (±0.38)	5.59 (±0.43)	<0.001*	123.07
OMC	9.21 (±2.15)	8.37 (±0.77)	9.35 (±2.15)	0.066	2.86
OCC	5.51(±0.62)	4.92 (±0.45)	5.51 (±0.61)	0.052	3.12
Ca (me/100g)	1.45 (±0.50)	1.50 (±1.67)	0.50 (±0.13)	<0.001*	12.83
K me/100g)	0.013 (±0.028)	0.015 (±0.0037)	0.030 (±0.038)	0.044*	3.31
Na (me/100g)	0.040 (±0.0069)	0.045 (±0.0078)	0.044 (±0.170	0.379	0.99
Mg (me/100g)	0.14 (±0.061)	0.25 (±0.10)	0.19 (±0.018)	<0.001*	5.75

Table 6.3 Mean, Standard deviation and P-value results of crop species for chemical indicators

6.2.1 EXCHANGABLE BASES

As shown in **Figure 6.4** the average calcium levels were higher in the conventionally farmed fields (M=1.29 me/100g, SD=±1.19) than in organically farmed fields (M=1.12 me/100g, SD=±0.55). The error bars show that the concentration of data closer to the mean is higher than in conventional, as the samples collected in conventional fields is spread over a wider range, although the t-test reported that there was no significant difference between the farming methods (T =0.72, P=0.476) **(See Table 6.1).** The average levels of calcium as seen in **Table 6.3** were lower in the grass (M=0.50 me/100g, SD=±0.13) than in wheat (M=1.67 me/100g, SD=±1.25) and oats (M=1.45 me/100g, SD=±0.50)**.** The one-way ANOVA test showed a significant difference (F=12.83, P=<0.001) between the levels of calcium found in each crop variety due to the grassland fields having lower levels of calcium than arable as seen in **Figure 6.5**.

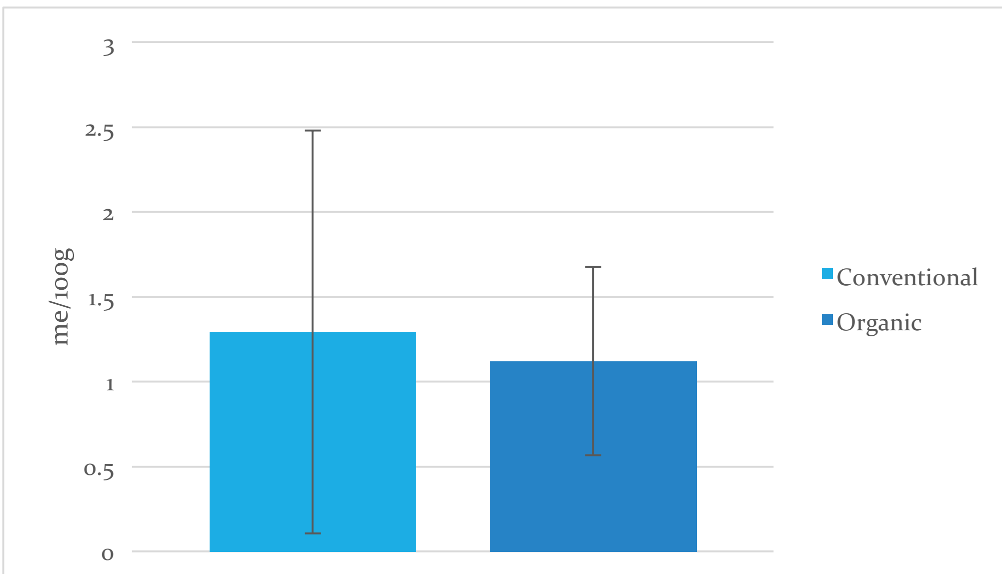


Figure 6.4 Graph showing the mean and standard deviation error bars of calcium measured in organic and conventionally farmed fields with calcium levels been lower in organic fields

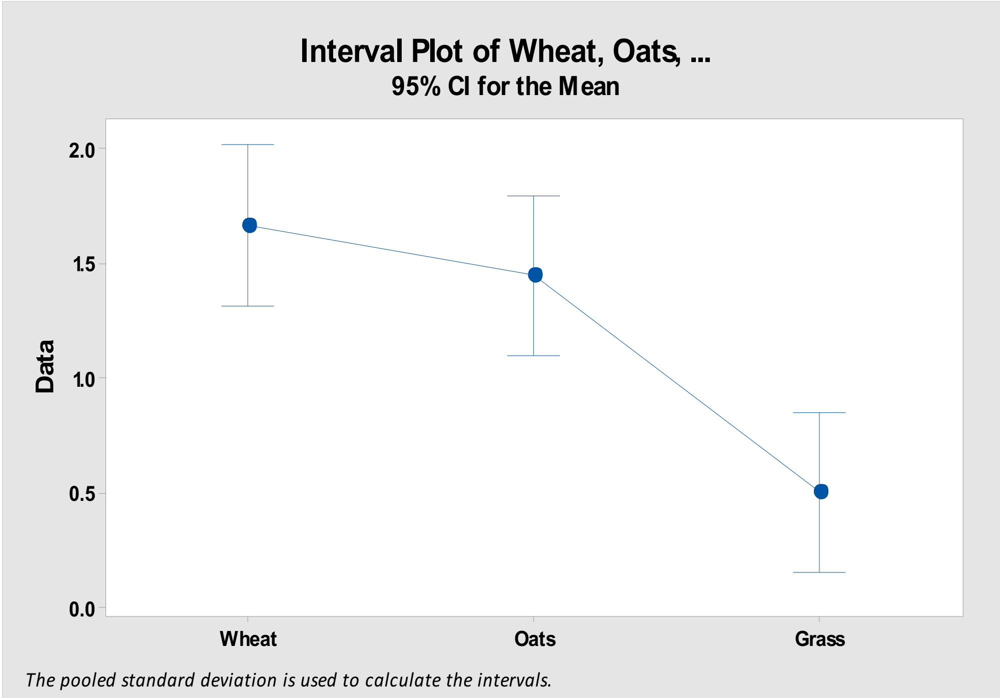


Figure 6.5 A graph to show the difference of calcium levels between crop species, and that the significant difference between calcium levels occurred due to the low levels in grass land

Average levels of magnesium were found to be higher in conventional fields (M=0.24, SD=±0.12) than in organic fields (M=0.15 me/100g, SD=±0.039) as seen in **Figure 6.6**. From **Figure 6.6** the error bars display that the data analysed from organic samples are spread over a smaller range, so the average value is more certain for organic magnesium than conventional magnesium due to there been a lower concentration of results around the mean value. The T-test conducted showed a significant difference between farming methods (T=4.30, P=<0.001) (**See Table 6.1**).

The magnesium levels for crop varieties varied with wheat (M=0.25 me/100g, SD=±0.10) having the highest levels of magnesium present compared to levels found in oats (M=0.14 me/100g, SD=±0.061) and grass (M=0.19 me/100g, SD=±0.018). A significant difference (F= 5.75, P=0.005) was seen between the crop varieties **(Table 6.3),** with **Figure 6.7** showing that the cause of the significant difference was due to there been higher levels of magnesium in wheat than there was in oats.

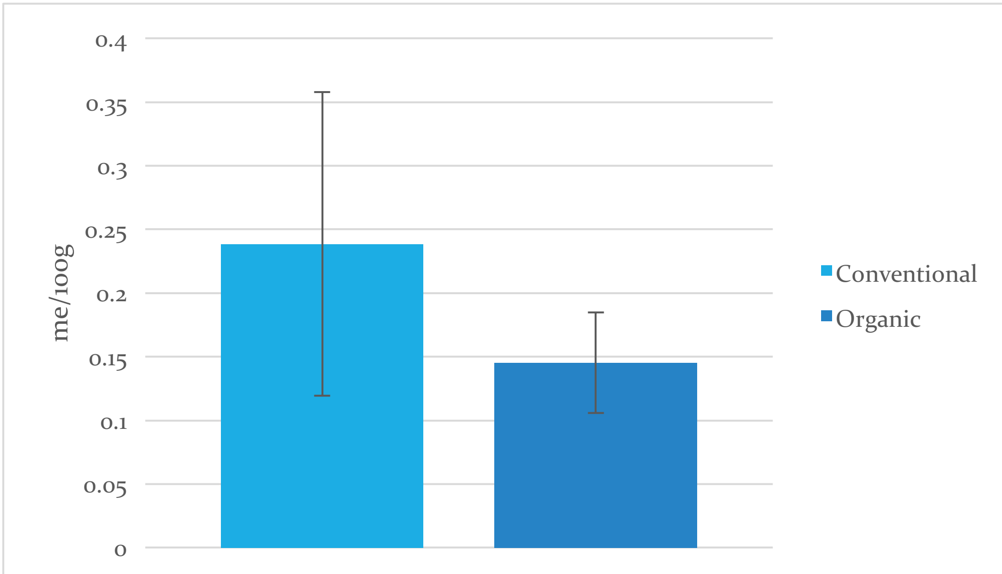


Figure 6.6 Graph showing the mean and standard deviation error bars of magnesium measured in organic and conventionally farmed fields, with the graph showing that magnesium levels are highest in conventionally farmed fields

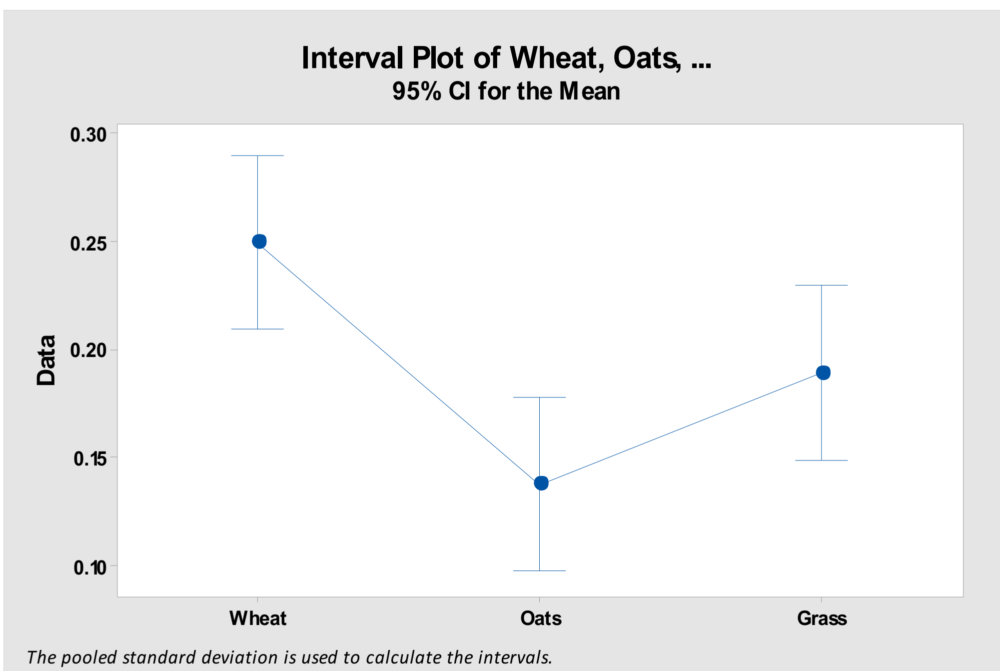


Figure 6.7 A graph to show the difference of magnesium levels between crop species, and that the significant difference occurred as a result of magnesium been low in oat fields

Figure 6.8 displays the average of sodium levels found in the sampled soils, with conventionally farmed fields (M=0.044me/100g, SD=±0.014) having higher sodium levels than organic (M=0.042 me/100g, SD=±0.009). **Figure 6.8** also displays that the range of sodium levels recorded in the organic samples is less than conventional sodium levels showing that the levels recorded are closer to the mean value. The t-test conducted showed no significant difference (T=0.56, P=0.581) between the sodium levels Sodium levels (**See Table 6.1**).

Levels of sodium were higher in wheat fields (M=0.045 me/100g, SD=0.008) than oats (M=0.040 me/100g, SD=±0.007) and grass (M=0.044 me/100g, SD=±0.017). Crop types were also tested with the one-way ANOVA test revealing that there was a significant difference (F=58.69, P=<0.001) as sodium levels were higher in grass than they were in the arable fields **(Table 6.3).** The significant difference was a result of sodium levels in oats been much lower than in grass and wheat as wheat and grass has similar average level of sodium present (**Figure 6.9**).

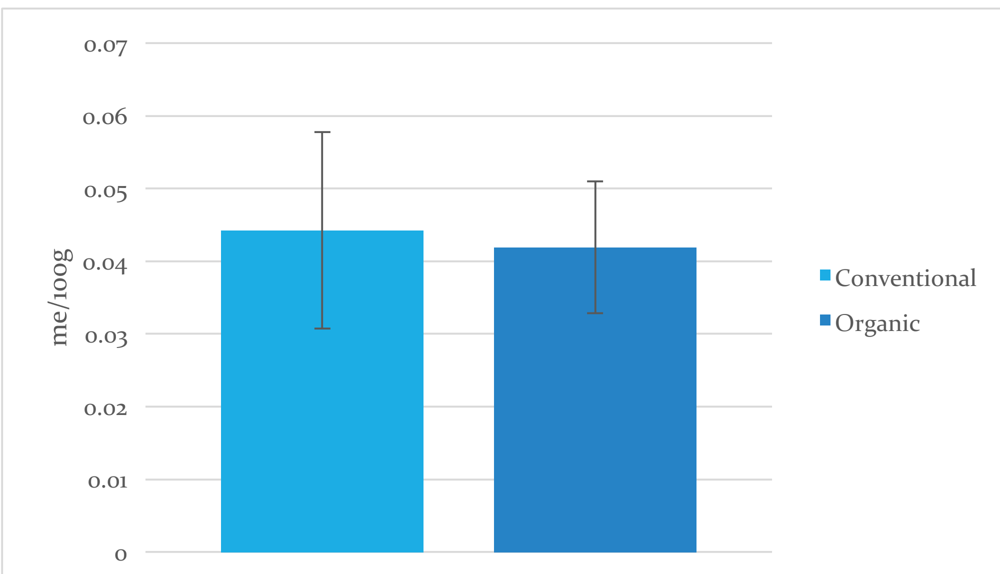


Figure 6.8 A graph showing the mean and standard deviation error bars of sodium measured in organic and conventionally farmed fields, showing that there is little difference between the sodium levels

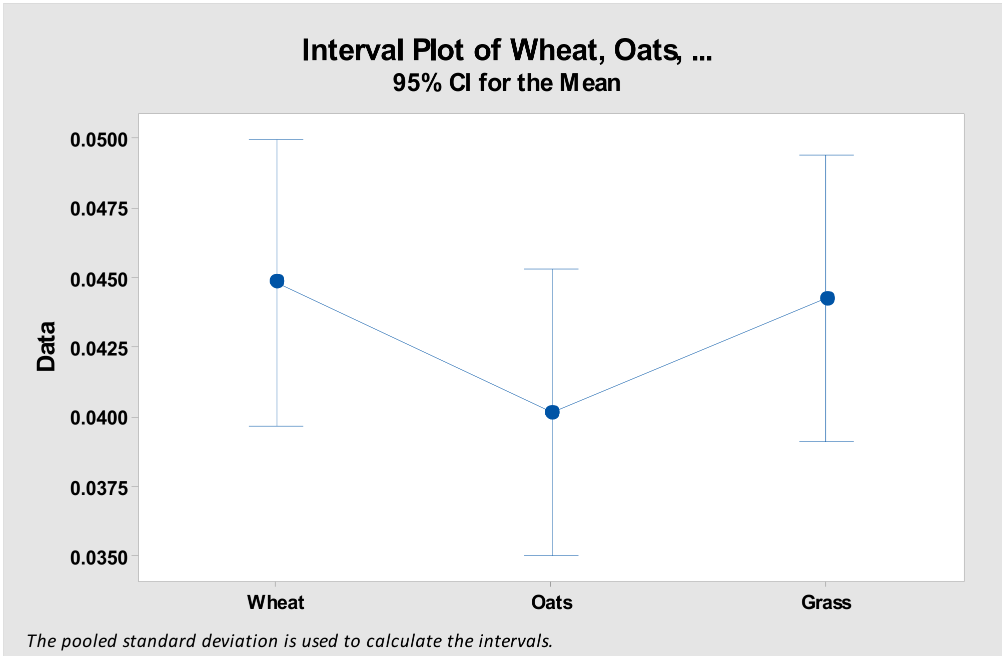


Figure 6.9 A graph to show the difference of sodium levels between crop species, and that a significant difference occurred between crop species due to sodium levels been low in oat fields

The last exchangeable base to be tested was potassium with **Figure 6.10** showing that conventional (M=0.021me/100g, SD=±0.019) had higher levels of potassium than organic (M=0.019me/100g, SD=±0.027). The error bars displayed in **Figure 6.10** show that there is a very low concentration of results surrounding the mean, with the range of potassium levels been much higher than in conventional, however the t-test showing no significant difference (T=0.56, P=0.581) between farming methods **(Table 6.1).** The one-way ANOVA test conducted did show a significant difference between the different crop species (F=3.31, P=0.044) with grass (M=0.030me/100g, SD=±0.038) having higher levels than in oats (M=0.014me/100g, SD=±0.0028) and wheat (M=0.0015me/100g, SD=±0.0037). The significant difference was a result of potassium levels been substantially higher in grass fields than in wheat and oats (**Figure 6.11**).

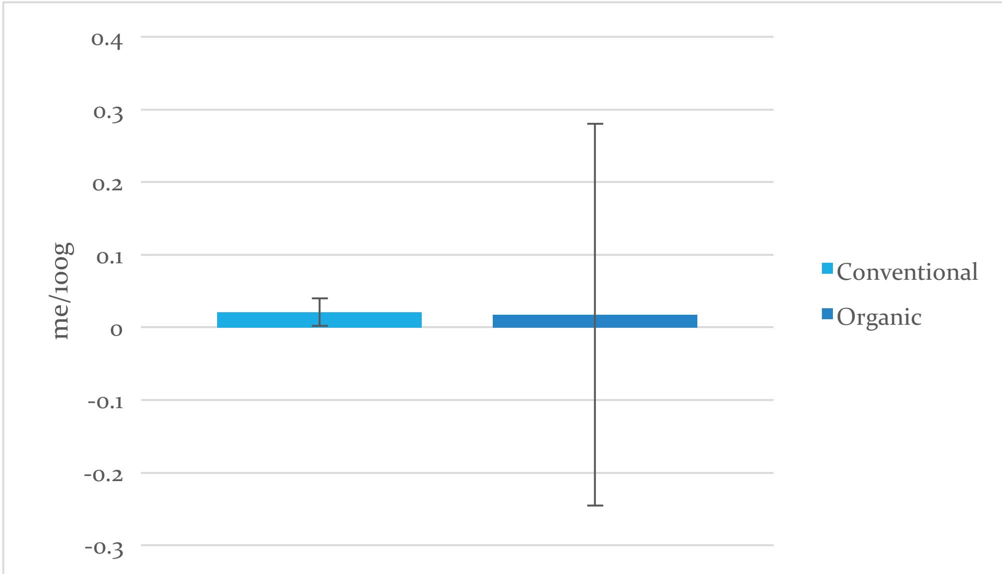


Figure 6.10 Graph showing the mean and standard deviation error bars of potassium measured in organic and conventionally farmed fields with potassium levels been higher in conventional fields

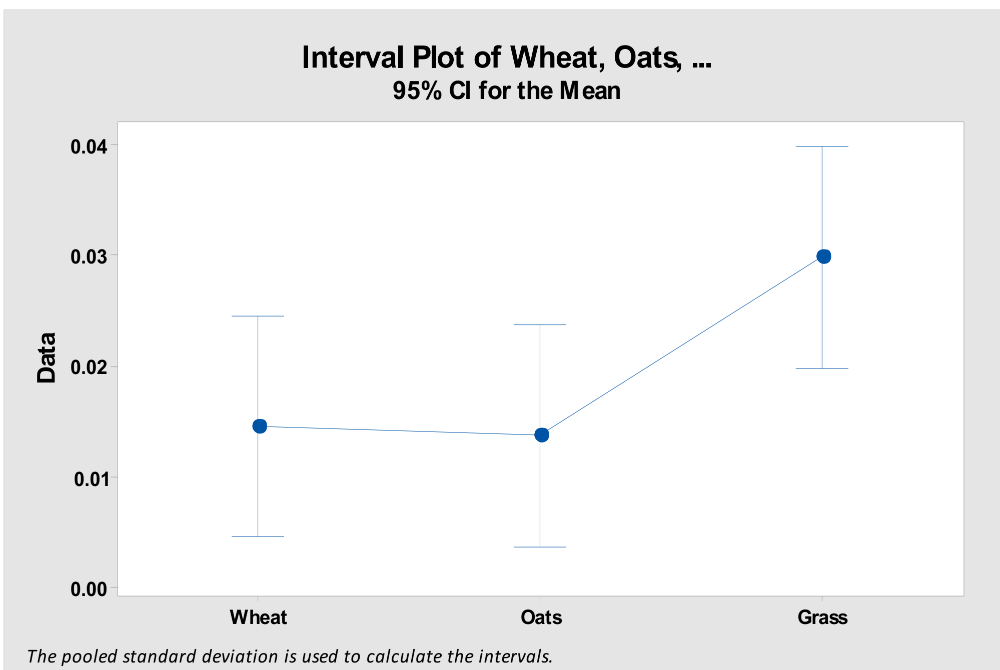


Figure 6.11 A graph to show the difference of potassium levels between crop species, and that high levels of potassium were found in grass fields, thus a significant difference between crop species

There was found to be several positive correlations including a positive correlation between pH and calcium (r=0.630, P=<0.001), sodium (r=0.105, P=0.426), and magnesium (r=0.082, P=0.535), whilst pH was found to have an inverse correlation with Potassium (r=-0.020, P=0.882). A correlation between organic carbon content and exchangeable bases was also conducted with there been a positive correlation between OCC and calcium (r=0.104, P=0.746) and OCC and potassium (r=0.173, P=0.186). An inverse correlation was observed between OCC and sodium (r=-0.017, P=0.896) and OCC and magnesium (r=-0.361, P=0.005). OMC was found to have an inverse relationship with calcium (r=-0.043, P=0.746), magnesium (r=-0.201, P=0.123) and sodium (r=-0.068, P=0.606). No relationship was found between OMC and potassium (r=-0.00, P=0.997). Further tests we used to observe a relationship between each exchangeable base, with a positive correlation been observed between potassium and sodium (r=0.394, P=0.002), while inverse correlations were observed between calcium and magnesium (r=-0.038, P=0.773), potassium (r=-0.005, P=0.969) and sodium (r=-0.031, P=0.817). Magnesium also showed an inverse relationship with potassium (r=-0.0121, P=0.356) and sodium (r=-0.111, P=0.397). Interpretation of the Pearson's correlation indicates that although there were several inverse and positive relations, the correlations were not significant enough to be considered a relationship (**See Table 6.4**).

	Calcium		Magnesium		Potassium		Sodium	
	Pearson correlation	P-value	Pearson correlation	P-value	Pearson correlation	P-value	Pearson correlation	P-value
Mg	-0.038	0.773						
K	-0.005	0.969	-0.121	0.356				
Na	-0.031	0.817	-0.111	0.397	0.394	0.002		
pH	0.630	<0.001	0.082	0.535	-0.020	0.882	0.426	0.105
OMC	-0.043	0.746	-0.201	0.123	-0.000	0.997	-0.068	0.606
OCC	0.104	0.430	-0.361	0.005	0.173	0.186	-0.017	0.896

Table 6.4 Correlation matrix for all chemical indicators

6.2.2 PH

Figure 6.12 displays the average pH levels observed in each farming method, with pH being higher in organic (M=6.72, SD=±0.57) than conventional (M=6.37, SD=±0.89), however, the T-test found no significant difference (T=1.77, P=0.083) between the pH levels in the different farming methods (**Table 6.1**). There is seen to be a high concentration of ph results similar to the means of both conventional and organic mean ph values, however the range of ph levels is less in organic **(Figure 6.12).**

The different crop species when subject to a one-way ANOVA test did show a significant difference between the crop species (F=123.07, P=<0.001), as a result of grass (M=5.59, SD=±0.43) pH levels been much more acidic than the pH levels in oat (M=7.12, SD=±0.093) and wheat (M=6.93, SD=±0.39) **(Table 6.3).** As seen in **Figure 6.13** the significant difference occurred due to the grassland pH being lower than arable crops.

As seen with exchangeable bases several Pearson's correlation tests have already been conducted. Further, Pearson's correlation tests between pH and OMC showed an inverse correlation (r=-0.535, P=<0.001), with an inverse relationship also been observed between pH and OCC (r=-0.246, P=0.058). Although the relationship between pH and OCC were not significant enough to be considered a relationship.

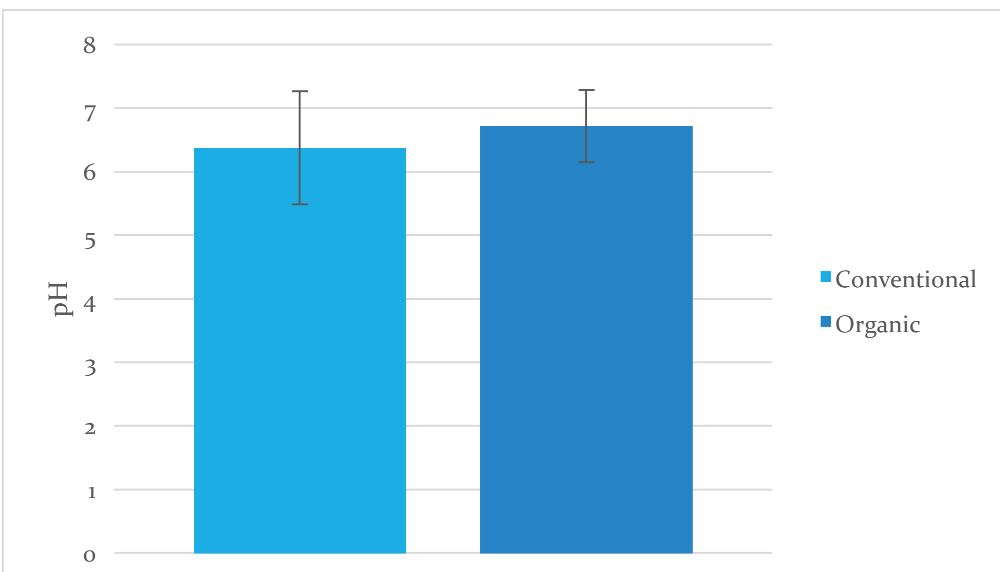


Figure 6.12 Graph showing the mean and standard deviation error bars of pH levels measured in organic and conventionally farmed fields with pH being higher in Organically farmed fields

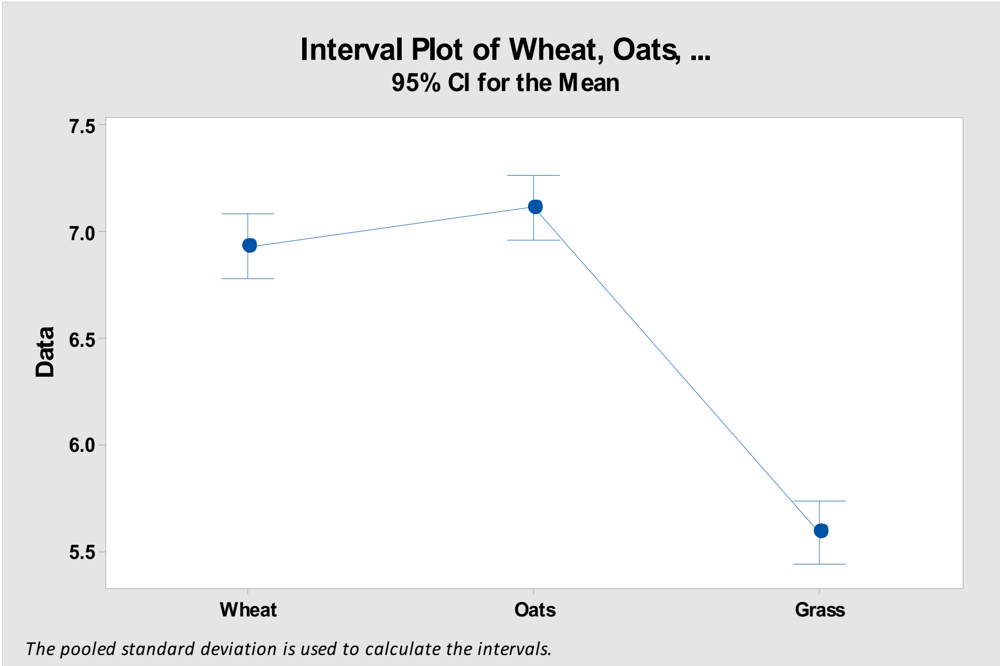


Figure 6.13 A graph to show the difference of pH levels between crop species, and that a significant difference occurred due to pH being acidic in grass

6.2.3 ORGANIC MATTER CONTENT AND CARBON CONTENT

As seen in **figure 6.14** the levels of OMC found in the soil were higher in conventional (M=9.69%, SD=±1.55) than organic (M=8.26%, SD=±0.89). The T-test conducted showed a significant difference (T=4.37, P=<0.001) between farming method **(Table 2).** Errors bars show that the mean of conventional organic matter content stems from a large range of data, while organic data covers a smaller range and the levels found are closer to the mean. The one-way ANOVA test showed no significant difference between the three crop varieties (F=2.86, P0.066) **(Table 4)** as grass (M=9.35%, SD=±2,15), wheat (M=8.37%, SD=±0.77) and oats (M=9.21%, SD=±0.84) showed similar levels. Although there looked to be a difference between grass and arable fields **(Figure 6.15),** the levels were similar throughout causing there to be no statistical difference.

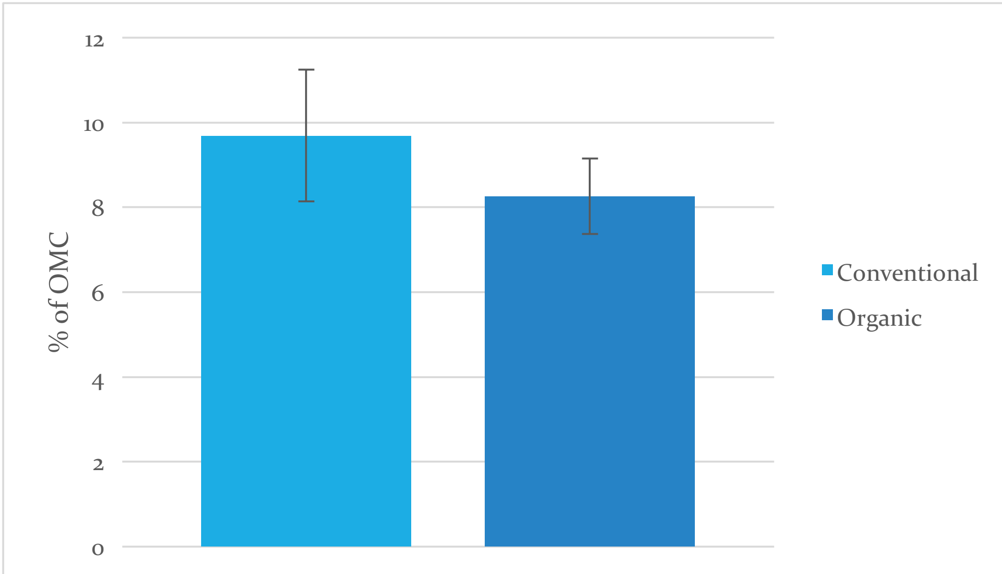


Figure 6.14 Graph showing the mean and standard deviation error bars of organic matter content measured in organic and conventionally farmed fields, with OMC being higher in conventional fields

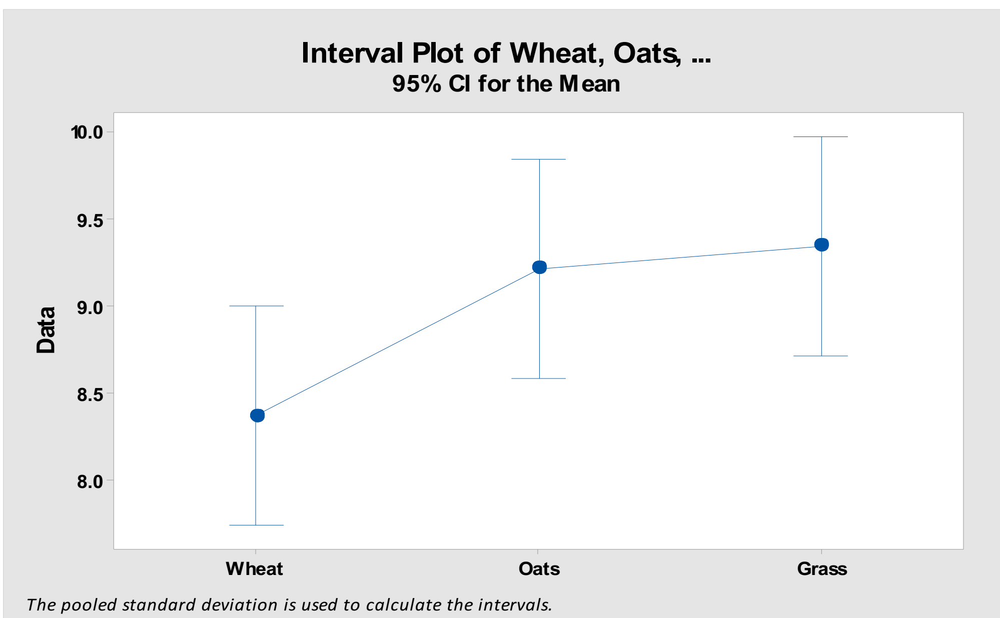


Figure 6.15 A graph to show the difference of organic matter content between crop species, and that there was no significant difference as crop species all had similar values of OMC

From the t-test conducted there was found to be a significant difference (T=4.32, P=<0.001) between farming methods **(Table 6.1)** with conventionally farmed fields (M=5.748%, SD=±0.936) have higher amounts of organic carbon present in the soil than organic (M=4.880%, SD=±0.578) (**Figure 6.16**). Error bars were smallest for organic OCC levels as the data spanned over a smaller range and the values are therefore closer to mean. A one way ANOVA test conducted showed no significant difference (F=3.12, P=0.052) **(Table 6.3)** between the crop types as even though wheat (M=4.923%, SD=±0.452) had lower OCC compared to oats (M=5.511%, SD=±0.618) and grass (M=5.507%, SD=±1.271). The levels of OCC between each crop variety was not considered to be significantly different as occ levels were similar **(Figure 6.17).**

The final Pearson's correlation test conducted showed a positive correlation between OMC and OCC (r=0.646, P=,0.001), with the relationship been statistically significant.

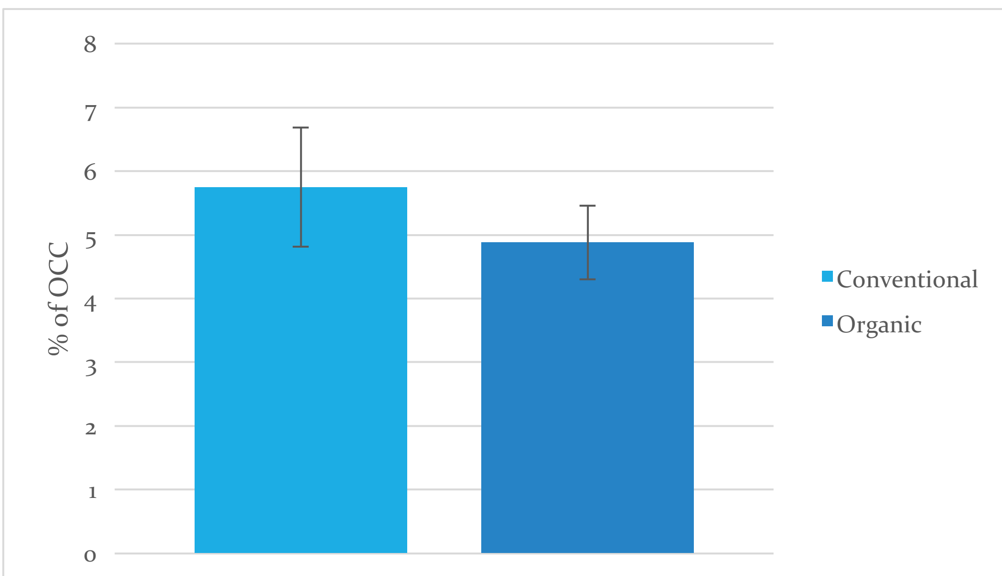


Figure 6.16 Graph showing the mean and standard deviation error bars of organic carbon content measured in organic and conventionally farmed fields, with OCC being higher in conventional fields

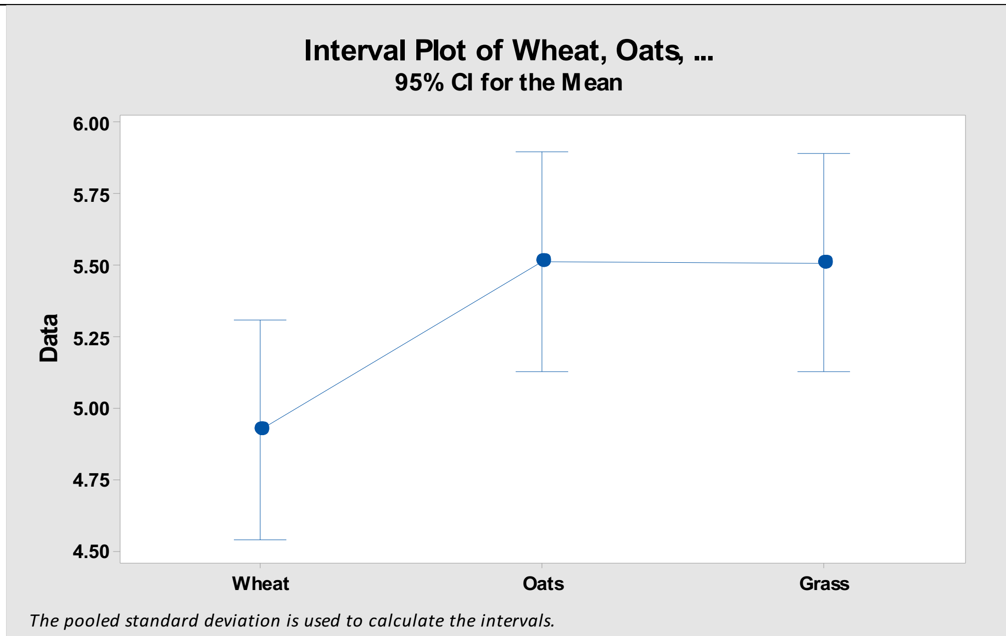


Figure 6.17 A graph to show the difference of organic carbon content levels between crop species, and that there was no significant difference as OCC was similar for all crops

CHAPTER 7: DISCUSSION

7.1AGRICULTURAL PRACTICES

Soil organic matter is known to improve the structure, water holding capacity and the nutrient supply within soils (Johnston et al. 2009), so soil organic matter is often seen to be an indicator of soil fertility (Reeves, 1997). Over recent years' organic matter content within soils has seen to be declining in European soils (Morari et al. 2016; Toth et al. 2008), so proposals have been made to ensure that organic matter levels are kept so that soil productivity doesn't decline.

OMC is often improved by the application of manure, fertilisers and by putting crop rotations into the management of fields (Marinari et al. 2006). It is therefore said that levels of OMC should be higher in organically farmed fields as they often receive higher rates of Manure and crop rotations (Shepard et al. 2002). However, this study found that conventionally farmed fields had higher levels of OMC than organic, with there been a significant difference in the percentage of organic matter present. The statistical significance suggests that methods used in the conventional fields are more effective at improving soil quality than organic.

The fields tested in this study both received similar inputs that potentially increase OMC with conventionally farmed fields receiving OMC in the form of green waste compost while organically farmed field receive OMC in the form of manure.

The green compost waste that is applied to the conventional fields derives from a variety of biodegradable materials which include: Garden botanical waste, Landscape contractors green arising, Civic amenity green waste (OLUS, n.d). Green waste compost is often used as it provides organic matter to the soil in a stable form, allowing for organic matter contents to rise while delivering other benefits such as increased yield which is a by-product of improved soil structure (Anon, 1991; Anon, 2000; Naeini & Cook, 2000). As green waste compost was added to conventional fields, the increased levels of organic matter content could be explained, due to the composts properties. Although green waste compost was not added to conventional grassland, it still had much higher levels of organic matter which is a result of permanent grassland usually having the highest level of organic matter content until it is ploughed where some organic matter is oxidized until it reaches a new equilibrium at a lower balance (Naeini & Cook, 2000).

Differences in OMC between the farming methods could also be influenced by several different factors. OMC has previously been affected by nitrogen requirements. Although the inputs of the conventional and organic farms were similar as they both received some form of organic fertilizer, the levels of organic matter may be higher as the addition of mineral nitrogen satisfies the nitrogen requirements of micro-organisms, thus increasing the rate that organic residues decompose (Birkhofer et al. 2008). Some other explanations for high organic matter content involve the use of less intensive drilling and the addition of cover crops added into the rotations (Canali et al. 2009; Quintern et al. 2006), which is the case for both organic and conventional fields at High Callis Wold. There have been arguments regarding the addition of cover crops to crop rotations and its effect on organic matter content. Gosling and Shepard (2005) argued that it may not be the cause of higher organic matter levels as they have a low carbon-nitrogen ratio, which causes the rapid decay of organic matter. They also argued that intensive tillage is required for the addition of cover crops such as grass or legumes, so its likely that any benefits gained are neutralized when the cover crop is in place (Gosling & Shepard, 2005). Although all evidence suggests that organic matter content should be higher in organically farmed soils, it has been observed that the higher yields that are produced in conventional farming systems leave higher levels of crop residue, with leftover crop residue compensating for the lower level of organic inputs that conventional soils usually receive (Gosling and Shepard, 2005).

7.2 SOIL COMPACTION

Soil bulk density is increased by anthropogenic and natural processes (Rain, Root Structures), which all rearrange soil particles (Nawaz et al. 2012), which in turn effects different crops as they all respond differently to soil compaction, depending on their root structure (Guimaraes et al. 2002).

Bulk density also depends upon the soils texture and the amount of organic matter present, as this effects the soils structure and therefore the soils water, air and mechanical resistance (Benites et al. 2007; Reichert et al. 2009). Although not all increases in bulk density are detrimental to the growth of crops as an increase in bulk density can often contribute to the soils ability to store water and provide load supportability when trafficked with large farm machinery (Reichert et al. 2009).

Bulk density has often found to be affected by the compaction present in the soil, with high levels of compaction leading to higher levels of bulk density (Horn et al. 2001). A high bulk density and a high compaction rate has been observed in several studies and can be due to the compression that occurs from the use of heavy machinery (Hansen, 1996; Twum & Nii-Annang, 2015). The most common cause of compaction and bulk density in soils is due to the increased use of heavy machinery as the wheel's push aggregates together, reducing the number of large pores in the soil and creating denser soil (Wolkowski & Lowery, 2008). The increase in more extensive equipment and the increased use of tyres that allow operations to occur on wet soils are all responsible. Many machines used on soils exceed 10 tons, especially loaded combines, which overwhelms the soils bearing weight and therefore increasing compaction and bulk density (Wolkowski & Lowery, 2008).

Organic matter is also seen to influence bulk density in soils, as OMC decreases bulk density through the dilution of the denser mineral fraction of soil (Wallingford et al.1975). Within this study it was found that bulk density was lower in organically farmed fields, suggesting that bulk density and organic matter content don't influence one another as conventionally farmed arable fields had the highest levels of OMC, however the average OMC percentages were not significantly different, suggesting that there was little difference between the portion of OMC present.

Several measures can increase organic matter content within the soil including the addition of cover crops, manure and rotations into the farming systems, the minimization of soil disturbance, the use of multi-crop systems and the use of sub-soiling to disrupt any compacted layers (USDA, n.d.). Soil organic matter contents have also been seen to rise with the increased use of organic and inorganic fertilisers (Qi et al. 2011).

The type of soil that is farmed also effects compaction as the clay soils mixed with chalk, which is a characteristic of the Yorkshire Wolds and the site which was sampled, are highly compatible to compaction especially when soils are wet, as the clay minerals present in the soil are bound with water, which acts as a lubricant, allowing for soils particles to move more readily, thus creating compaction (Wolkowski & Lowery, 2008).

Compacted soils usually have a bulk density reading of between 1.3 and 1.6 g/cm^3 (British Columbia, 2015), however both the average conventional and organic bulk density reading was below this at 0.322 and 0.2905 g/cm^3 respectively, showing that there was little compaction in these fields and that the soils were well structured as soils which have high OMC have readings of 0.9g/cm^3 (British Columbia, 2015).

Compaction was also low in grassland fields compared to other studies. Compaction is not seen as an issue to soil productivity or soil quality until compaction reaches 400 to 500 pounds per square inch (Government of Alberta, 2010) which equates to 275.8 to 344.7 N/cm^2. The average compaction for conventional and organic in this study was 93 N/cm^2 and 107.8 N/cm^2 respectively. Little compaction will be seen in these grassland fields due to low activity from large machinery. Although machinery does cross the land for fertilizer and crop cutting purposes, the farmers keep to tramlines, allowing for compaction to be kept to a minimum. Although some studies have shown that grazing increases bulk density and therefore compaction (Donkor et al. 2002b; Daniel et al. 2002; Chanasyk & Naetn, 1995), this is seen to have little effect in this study. Small grazing animals such as sheep do not have substantial enough hooves to make such compaction.

Although bulk density is seen to be minimal, bulk density has been found to differ based on the soil depth as the majority of organic matter is in the upper profile of the soil (Balland et al. 2008). As the study was only conducted at a soil depth of up to 10cm it may not be a realistic indication of the bulk density at different soil profiles.

7.3 SOIL IMPROVEMENTS

As soil quality is a crucial influence on crop yields and productivity, it is essential as mentioned previously that correct management of soils takes place. To allow for correct management the pH of soils should be considered.

It is said that the ideal pH in UK agricultural fields should range from 5 to 7.5 with acidic pH being found in un-limed mineral soils and the neutral pH being observed in chalk or limestone soils (Goulding, 2016). The soils which were tested in this study were taken from chalk soils which allowed for the average pH readings in conventionally (M=6.374) and organically (6.717) farmed fields to be between 5 and 7.5, with some readings in arable crop fields been as high as 7.144. Although conventionally farmed fields were slightly more acidic than organic, it cannot be said that the farming practice was a cause of these readings, which is supported by a study conducted in the Netherlands which also found little difference in pH between farming methods (van Diepenigen et al. 2006).

Little difference between farming methods may be a result of several management factors including the addition of green waste compost to conventionally farmed arable fields. As green waste compost is made of botanical garden waste and green cuttings, it's often used as a pH buffer (OLUS, n.d.). The above neutral pH of green waste compost, buffers the effects of high nitrogen inputs by offering negatively charged ions which bind with H+ in acidic soils, thus pushing soil pH towards neutral (OLUS, n.d.). The mechanisms involved in increasing pH levels in soils are dependent on the different varieties of organic matter (Wang & Swift, 1995). Previous studies have made distinctions between un-decomposed plant materials such as manure and compost and the occurrence of high pH levels (Opala et al. 2012). It could also be explained by the H+ proton exchange that occurs between the soil and the addition of manure (Wong et al. 1998; Tang et al. 1999). The decomposition of manure can often form phenolic humic material (Narambuye & Haynes, 2006), and therefore organic anions which consume the protons from the soils, thus increasing the pH to equilibrium (Haynes & mokolobate, 2001).

The little difference between the farming methods can therefore be a result of the management with both receiving inputs of OMC as previous studies have shown that the application of organic amendments whether it be green waste compost of manure can increase the pH of the soil (Naramabuye & Haynes, 2006; Wang et al. 2009).

A difference was however observed between crop varieties, as a significant difference was observed between the crop type with grassland having more acidic readings than oat and wheat fields. Many studies have found similar findings with there been many reasoning's for such results. pH is often influenced by a variety of factors and depends on the composition of cations and anions within the soil and the soils relation with pE (Electron activity related to redox potential) (Renegasamy, 2016). The different root structures that come with the different crop types, how long the field has been grass or arable for and the management that takes place such as the grazing of sheep as the addition of urea can often lead to soil acidification (Flieβbach et al. 2007), as well as the addition of ammonia-based fertilisers, due to the adsorption of ammonia by plant roots (Fuentes et al. 2009) could all be influencing soil pH and the differences that occur. Different plants have different tolerances to soil acidity. The pH values displayed in Table 7.1 show the Ph values which will restrict crop growth and and productivity.

Crop	Critical soil pH
Wheat	5.9
Oat	5.3
White Clover	5.6
Ryegrass	4.9

Table 7.1 Critical pH values for crop species analysed in this study. Adapted from Goulding (2016)

The pH that is observed in soils often reflects the alkalinity of organic materials that have been applied to the soils due to the reaction between the H+ in the soil and the organic bases (Rukshana et al. 2012) and the biological decarboxylation that occurs within the soil (Rukshana et al. 2011). A negative correlation was found between the pH levels and organic matter content, as when pH levels rise in the soil OMC decreases. It was expected that there would be a positive correlation as studies have found that pH levels are usually closer to neutral when there are more significant percentages of OMC found in the soil due to the addition of organic fertiliser (Cong & Merckx, 2005; Narambuye & Haynes, 2006). However, this only occurred in the fields which were arable, were as the grassland fields had acidic pH levels but had highest levels of OMC (M=9.346%). As previously mentioned the OMC in grassland is often affected by the length of time that the field has been grass, as permanent grassland has high levels of OMC before its ploughed and then oxidizes thus creating a new lower equilibrium (Naeini & Cook, 2000).

The pH of the grassland soil is likely to be acidic due to both fields been grazed by sheep, thus there been a greater nitrogen fertilisation rate than in the arable fields. The greater the nitrogen fertilisation rate, the more H+ ions are released, with these ions often combining with basic cations such as magnesium and leach from the topsoil into the subsoil, especially If the plant doesn't directly absorb the ammonium ions then the soil acidity increases (Crop Nutrition, n.d.). The leaching of these cations means that those basic cations are replaced by H+ ions, making the soils more acidic (Crop nutrition, n.d.).

For mineral and organically farmed soils, it is recommended that a target pH should be 6.7 for arable crops and 6.2 for grass (AHDB, 2017). Although the arable crops reached this level of pH, the grassland soils didn't, suggesting that further action should be taken to decrease the acidification of the soil. Liming is recommended in the fertilizer manual due to its alkalizing effects on pH (Defra, 2010). Liming is essential for proper soil management, while also been useful in helping crop growth, improving the efficiency if nutrient use and providing environmental protection (Goulding, 2016).

7.4 NUTRIENT REQUIREMENTS

The nutrient requirements of crops include carbon, hydrogen, and oxygen. However, there are 13 other essential elements that should be present in soils (AHDB, 2017). Macronutrients are those elements that are required in large amounts and include nitrogen, phosphorous, calcium, magnesium, potassium, and sulphur, while the other nutrients needed are classified as micronutrients (AHDB, 2017). This includes trace elements such as iron, copper, zinc, boron, manganese, chlorine and molybdenum (AHDB, 2017). As seen in section 6.2.3 levels of organic carbon varied between the different farming methods and also between the different crop types. As observed in Figure 30 the highest organic carbon levels were observed in conventional grassland. Other studies have also found the same result with the highest levels of carbon been found in the land that has converted from arable farming systems to grassland (Schlesinger, 1977; Silver et al. 2010; Conant et al. 2001; Follett & Kimble, 2002; Mcsherry & Ritchie, 2013). High levels of Organic carbon are often found in grassland, as grasses can allocate Carbon that is belowground, whilst also been able to extend their root structures to great depths, which allows them to reach the thick soil horizons that are rich in organic matter and thus rich in Organic carbon (Machmuller et al. 2015). Increases of soil organic matter have been observed in the conversion of arable to grassland and cover crops (Lai, 2004), which in turn drives the accumulation of organic Carbon (Franzluebbers et al. 2001; Contant et al. 2003). Although grassland has higher levels than that of arable crops, levels of Carbon in grassland have also been found to rise as a result of optimizing pasture by the use of fertilisers, irrigation and grazing intensity (Reference). A previous study showed that if intensive management was applied to grassland, then rates of C accumulation could be as high as 2.9 mg C ha^{-1} yr^{-1} (Contant et al. 2003).

Organic carbon levels can also be related to the levels of soil pH. This study has shown a negative correlation between the pH and organic carbon, however other studies have shown positive relationships between organic carbon and pH as high dissolution of organic carbon is often observed in high pH soils which contain HCO^{3-} and CO_3^{2-} ions (Tavakkoli et al. 2015).

Low levels of Carbon in organically farmed soils in this study could be a result of the type of organic matter that is applied to the soil, and organic farming systems used farmyard manure while conventional used green waste compost. Organic C found in the soils were also significantly increased by the application of organic and mineral Nitrogen and phosphate fertilisers, but there was no significant interaction between the fertilizer and the use of manure (Liu et al. 2010). Crop residues have also proved to increase OMC and induce the accumulation of organic carbon within the soil (Rasmussen & Parton, 1994; Fischer et al. 2002; Karlen et al. 2006; Raiesi, 2006; Haung et al. 2007), suggesting that organic carbon content should be higher in conventional fields as observed in this study.

The pH of soil has been found to influence the nutrient bioavailability and thus the uptake that is available to crop species. The optimum pH values for several exchangeable bases in displayed in **Table 7.2**:

Nutrient	Optimum pH
Potassium	>6
Calcium	7-8.5
Magnesium	7-8.5

Table 7.2 Optimum pH values that the nutrients observed in this study are available to crops. Adapted from Foth (1990)

Base forming cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) are large molecules that struggle to stick to soil particles, so at a low pH are easily displaced (McCauley et al 2017). The H^+ take up the negatively charged space on the soil, so when there is more H^+ at a lower pH, more cations are displaced and not available to crops due to leaching and uptake (McCauley et al. 2017). The exchangeable bases tested in this study follow the same trend, as the Pearson correlation conducted between pH and exchangeable bases showed that Sodium, Magnesium and Calcium levels rose as pH does, due to exchangeable bases being more available in soils with a pH of between 6.5 and 8 (McCauley et al.2017). Potassium was the only nutrient that didn't have a positive correlation with pH. Potassium was lowest in organic fields however it was expected to be higher as potassium can often be supplied through the addition of manure. As potassium rises in the soil, pH becomes more acidic, as potassium is mainly found in manure and fertilisers, so low levels of these inputs cause potassium to reduce, but pH to rise as less ammonia and urea is inputted into the soil (Mishima et al. 2013). As the input of organic matter is increased, then Potassium also increases (Obara & Nakai, 2003), which is shown through the results as conventional fields have higher levels of potassium due to the high inputs of fertilizer and green waste compost (OLUS, n.d.). This observation also applies to the potassium and calcium levels that are found in grass fields. Grassland pH was more acidic due to high levels of potassium that has been supplied through urea, therefore decreasing pH and calcium levels (Mishima et al. 2013).

Levels of magnesium observed in the soil were found to be highest in conventionally farmed fields which is a result of the green waste compost that is added to the soils, as this source of organic matter offers a slow release system of magnesium into the soil (OLUS, n.d.). Magnesium was also highest in conventionally farmed soils due to the lower levels of potassium. High exchangeable potassium concentrations in the soil have an adverse effect on the amount of magnesium that is available for uptake in the soil, as the two cations compete for root uptake, which often occurs after the addition of fertilization (Mikkelsen, 2010).

Calcium levels were similar between both farming methods due to the dominant chalk soils that characterize the Yorkshire Wolds. Although Calcium levels are naturally high in the sampled soils, it can have an impact on other cations in the soil including magnesium. Loss of cations through the leaching of soils declines nutrient availability; however, the addition of Calcium and potassium into the soil increases magnesium's solubility in soils, making it more susceptible to leaching (Mikkelsen, 2010). This can be seen to occur within this study as shown by the Pearson correlation completed, which showed a negative relationship between magnesium, potassium, and calcium, indicating that as calcium and potassium increased the levels of magnesium in the soils decreased.

CHAPTER 8: CONCLUSION

Using laboratory and statistical analysis this study aimed to analyse and compare the impacts of organic and conventional farming methods on the chemical and physical properties of soil in the Yorkshire Wolds.

From the study the following was observed:

- Organic Matter content is effected by the farming method used, as OMC was found to be higher in conventional than organic. However the difference between the methods was not statistically significant suggesting that input levels of each farming method were similar.
- Bulk density was not affected by the farming method, but was influenced by OMC. Pearson's correlation displayed a negative correlation (r=-0.277), meaning that bulk density decreased as OMC increased.
- The bulk density and compaction levels observed were very low so should not bee seen as a problem. This suggests that current management for both farming methods is not very intrusive and does not cause heavy impaction.
- All exchangeable bases were higher in conventionally farmed fields as a result of the high inputs of organic and inorganic fertilizer that the soil received.
- Potassium was effected by the pH levels as this suggests there was more ammonia present within the soils. The presence of ammonia is a source of potassium and is also acidic, thus decreasing pH.
- Calcium was high due to the chalk soils of the Yorkshire soils, but was effected by high levels of potassium which cause calcium levels to decrease, as the primary source of potassium is urea.
- Magnesium was found to have a negative correlation with calcium and potassium. Magnesium levels decreased when there were high levels of calcium an potassium as they increase magnesium's susceptibility to leaching.
- PH was to be slightly lower in conventional fields than organic, however this was not a statistically significant difference. However, pH was significantly effected by the crop type, with grassland pH being much lower than arable. This extreme difference is a result of the high rate of ammonia based fertilization that the soils received due to the intense grazing of sheep.
- There was a significant difference for organic carbon content between organic and conventional farming methods. OCC was higher in conventionally farmed fields as a

result of organic matter being higher. This stemmed from the application of green waste compost rather than farmyard manure.

This investigation showed a variety of results, however it can be clearly stated that crop species does not impact upon all soil quality indicators, but farming method does. Those farming methods which receive high levels of inputs are found to have improved soil quality as exchangeable bases, pH and organic matter were all found to be higher.

From the results of this study it is clear that the type of input is crucial in deciding whether a farming method is to improve soil quality. It could be stated from this investigation that a mixture of both organic inputs such as green waste compost or farm yard manure along with the addition of chemical fertilisers, increases the nutrient requirements within the soil along with organic matter content which improves soil structure.

Although conventional methods have found to have less impact and provide higher levels of nutrients needed for improved soil quality and crop growth, this might not always be the case on many farms. For farms who primarily farm arable, farmyard manure is hard to source, however as shown by the management practices at High Callis Wold green waste compost is just as effective in improving soil quality as farmyard manure.

Many farms do not find the balance between organic and synthetic fertilisers which causes for conventional farming methods to have more significant impacts on soil quality. It could be suggested that farmers should follow the method of mixed farming by using organic and chemical processes, as this has proven to be more beneficial than either organic or conventional methods alone.

CHAPTER 9: SUGGESTIONS FOR FUTURE RESEARCH

For future research projects, it could be suggested that more samples were collected from a greater number of fields with the same crop varieties, i.e., the expansion to 12 fields, 2 of each crop, for each farming method. It would allow for the study to be presented with a more valued and reliable data set as the results are not restricted to one field and show the difference between a variety of fields.

For more extensive research product, the sampling could be spread over several different farms, with samples been collected from two organic and two conventional farms, as no farming practices are the same. It may also be beneficial to chose farms which are located in other regions of the UK, (i.e. one organic and one conventional farm located in the Yorkshire Wolds and one organic and one conventional farm located in Northumberland). This would allow for the farming method to be tested on different soil types, which may influence management practices that occur.

For future studies, it would also be suitable to choose two different farms which don't have similar farming methods applied to them, so that it can be fully understood whether organic farming is more sustainable than conventional.

It would also be useful to measure the nitrate that is present in the soil as nitrate levels vary based on fertilizer application and the addition of farmyard manure. Ammonia should also be tested as this may differ between fields that receive manure application. As The study was conducted in a nitrate sensitive zone, it would also be suitable to test to see if the nitrate levels are lower or higher than the average.

Samples could also be collected up to 30cm depth, to ensure that not just the topsoil is being including in sampling. Different soil profiles may hold different nutrient contents due to leaching and tilling practices, so it would be beneficial to include these lower soil profiles in the samples.

Finally, bulk density should be measured in all fields not just arable, along with compaction, as the literature states that bulk density is often affected by compaction. It would, therefore, be of value to any research conducted, as it would be interesting to see if such assumptions were accurate within the Yorkshire Wolds.

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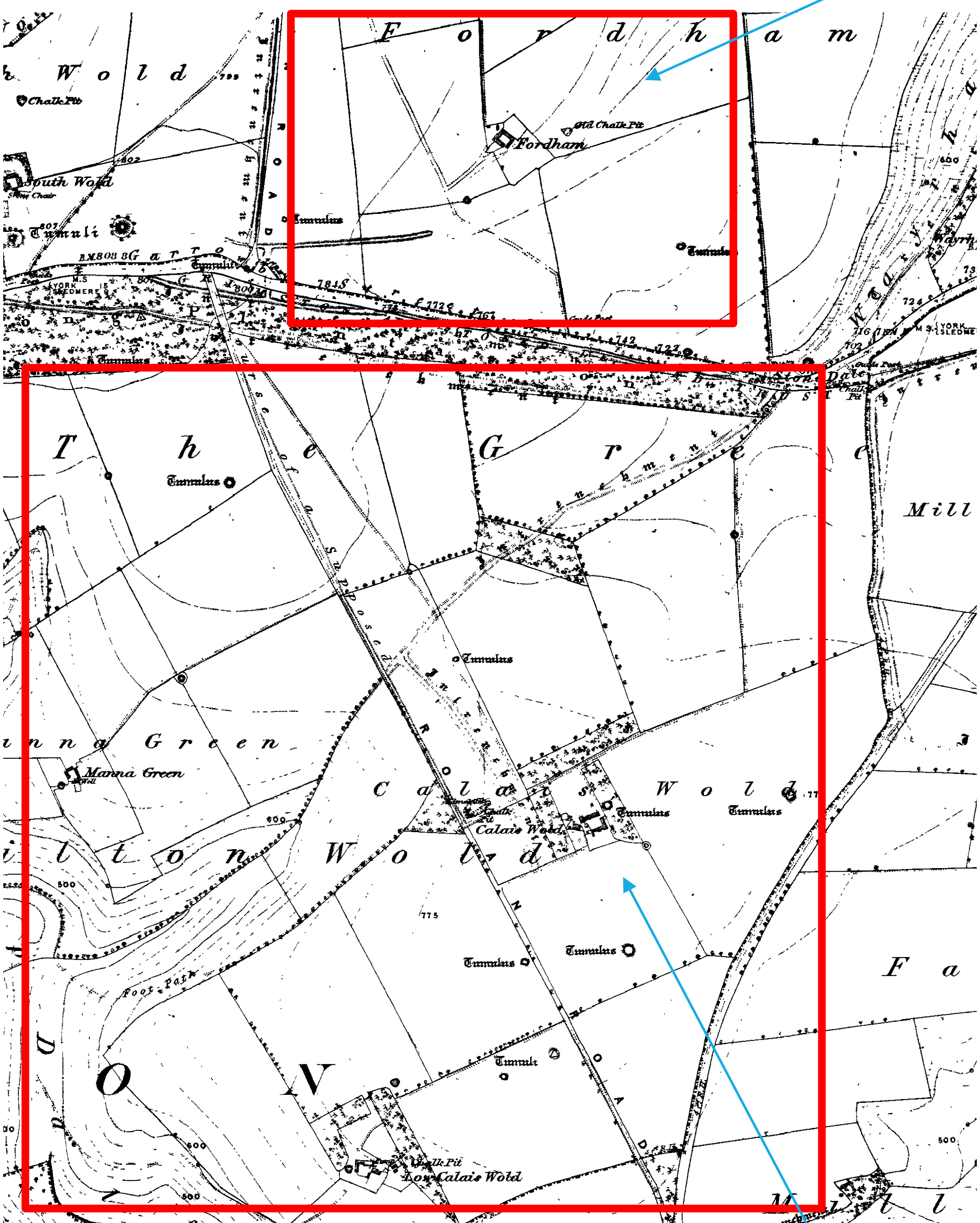
1:250 000 Scale Colour Raster [Shape geospatial data], Scale 1:250000, Tile(s): Yorkshire Wolds, Updated: June 2017, Ordnance Survey, Using: EDINA Digimap Ordnance Survey Service, + URL + , Downloaded: March 2018

11.0 APPENDIX A – HISTORIC MAPS

Historic map of High Callis Wold and Fordham Farm. Source: © Crown Copyright and Landmark Information Group Limited (2018). All rights reserved. (1850).

Fordham Farm



High Callis Wold

12.0 APPENDIX B- RAW DATA

12.1 RAW DATA- BULK DENSITY

Field Name	Cold reading	Dried reading	g/cm3		Field Name	Cold reading	Dried reading	g/cm3
OW 1	MISSING	MISSING	N/A		CW 1	157.9	151.8	0.267
OW 2	153	140.3	0.247		CW 2	157.7	151.3	0.66
OW 3	181.8	166.6	0.293		CW 3	173.9	167.5	0.295
OW 4	120.1	114.1	0.201		CW 4	142.9	137.8	0.242
OW 5	173.9	162.6	0.286		CW 5	145.4	138.5	0.244
OW 6	192.2	175.5	0.309		CW 6	182.1	176.4	0.31
OW 7	156.4	149.2	0.315		CW 7	177.6	172.3	0.303
OW 8	153.4	147.8	0.26		CW 8	168.8	163.7	0.88
OW 9	188.4	163	0.287		CW 9	177.5	161.7	0.284
OW 10	165.2	158.6	0.279		CW 10	167.5	159.4	0.28
Field Name	Cold reading	Dried reading	g/cm3		Field Name	Cold reading	Dried reading	g/cm3
OO 1	154.8	149.2	0.262		CO 1	129.7	125.7	0.221
OO 2	154	148.3	0.61		CO 2	188	178.4	0.314
OO 3	159.5	154	0.271		CO 3	176.7	170.2	0.299
OO 4	122	108.4	0.181		CO 4	151.7	145.7	0.256
OO 5	184.3	176.6	0.311		CO 5	140.9	135	0.237
OO 6	188.4	177.9	0.313		CO 6	157.8	151	0.266
OO 7	158.5	151.4	0.266		CO 7	138.5	133.3	0.234
OO 8	163.8	155.8	0.274		CO 8	138.4	133.8	0.235
OO 9	161.7	155	0.273		CO 9	152.4	148	0.26
OO 10	165.8	160.3	0.282		CO 10	205.9	214.5	0.348

12.2 RAW DATA- COMPACTION

Field name	Reading	N/cm2	Field name	Reading	N/cm2
OG 1	285	114	CG 1	260	104
OG 2	330	132	CG 2	270	108
OG 3	250	100	CG 3	290	116
OG 4	290	116	CG 4	260	104
OG 5	270	108	CG 5	160	64
OG 6	290	116	CG 6	260	104
OG 7	300	120	CG 7	270	108
OG 8	150	60	CG 8	240	96
OG 9	260	104	CG 9	270	108
OG 10	300	120	CG 10	220	88
OG 11	270	108	CG 11	190	76
OG 12	290	116	CG 12	280	112
OG 13	265	106	CG 13	200	80
OG 14	300	120	CG 14	240	96
OG 15	180	72	CG 15	200	80
OG 16	250	100	CG 16	220	88
OG 17	280	112	CG 17	160	64
OG 18	270	108	CG 18	210	84
OG 19	290	116	CG 19	230	92
OG 20	270	108	CG 20	220	88

12.3 RAW DATA- PH

Field name	water	Cacl2		Field name	water	Cacl2
OW 1	7.65	6.97		CW 1	7.6	7.34
OW 2	7.22	6.94		CW 2	7.51	7.07
OW 3	7.56	7.05		CW 3	7.13	6.69
OW 4	7.68	7.31		CW 4	7.67	7.36
OW 5	7.55	7.18		CW 5	7.29	6.78
OW 6	7.46	7.04		CW 6	6.68	6.05
OW 7	7.53	7.15		CW 7	7.03	6.54
OW 8	7.41	7.02		CW 8	6.75	6.2
OW 9	7.57	7.02		CW 9	6.88	6.59
OW 10	7.45	6.83		CW 10	7.68	7.55
Field name	water	Cacl2		Field name	water	Cacl2
OO 1	7.35	7.17		CO 1	6.92	7.19
OO 2	7.23	7.19		CO 2	7.39	7.18
OO 3	7.22	7.01		CO 3	7.29	7.15
OO 4	7.31	7.16		CO 4	7.36	7.13
OO 5	7.1	7.12		CO 5	7.45	6.98
OO 6	7.16	7.02		CO 6	7.33	6.96
OO 7	7.31	7.06		CO 7	7.52	7.12
OO 8	7.43	7.23		CO 8	7.27	6.95
OO 9	7.41	7.21		CO 9	7.56	7.07
OO 10	7.53	7.27		CO 10	7.48	7.15
Field name	water	Cacl2		Field name	water	Cacl2
OG 1	6.03	6.02		CG 1	5.78	5.66
OG 2	6.24	6.15		CG 2	5.27	5.18
OG 3	6.09	5.95		CG 3	5.11	4.87
OG 4	6.49	6.21		CG 4	5.34	5.2
OG 5	6.25	6.07		CG 5	5.35	5.25
OG 6	6.5	6.3		CG 6	5.25	5.13
OG 7	5.84	5.69		CG 7	5.27	5.22
OG 8	6.01	5.78		CG 8	5.13	5.17
OG 9	6.08	5.72		CG 9	5.77	5.1
OG 10	5.94	5.67		CG 10	5.61	5.39

12.4 RAW DATA- OMC AND OCC

Field name	weight of cruicible	weight of soil	After 105	After 800	OMC	OMC/ 1.7= OCC
OW 1	13.6831	5.5409	19.0717	18.6418	7.978	4.6929
OW 2	14.6722	5.6284	20.1431	19.6674	8.6951	5.1147
OW 3	13.7158	5.6572	19.2238	18.8346	7.0661	4.1565
OW 4	13.2977	5.636	18.7681	18.3193	8.2042	4.826
OW 5	14.1066	5.5597	19.5091	19.0566	8.3758	4.9269
OW 6	13.1006	5.2954	18.241	17.8225	8.1414	4.789
OW 7	13.9439	5.6923	19.4837	19	8.7313	5.136
OW 8	13.5156	5.0169	18.4019	17.9948	8.3314	4.9008
OW 9	13.968	5.6527	19.4622	18.9804	8.7692	5.1583
OW 10	13.1613	5.5191	18.5343	18.0822	8.4143	4.9495
Field name	weight of cruicible	weight of soil	After 105	After 800	OMC	OMC/ 1.7= OCC
OO 1	12.8936	5.3998	18.148	17.686	8.7926	5.1717
OO 2	13.2423	5.7483	18.8207	18.3227	8.9272	5.2512
OO 3	13.7023	5.3651	18.9345	18.4852	8.5873	5.0513
OO 4	13.2007	5.2652	18.3214	17.7969	10.2427	6.6251
OO 5	14.0655	5.1976	19.1182	18.6227	9.8066	5.7685
OO 6	12.0585	5.807	17.73	17.2597	8.2923	4.8778
OO 7	13.2438	5.912	18.9942	18.462	9.255	5.4441
OO 8	14.5757	5.2315	19.6695	19.1945	9.325	5.4852
OO 9	14.4768	5.3646	19.6958	19.2327	8.8733	5.2195
OO 10	14.0431	5.1375	19.041	18.5622	9.58	5.6352
Field name	weight of cruicible	weight of soil	After 105	After 800	OMC	OMC/ 1.7= OCC
OG 1	13.7733	5.8776	19.5128	19.0844	7.4658	4.3916
OG 2	14.582	5.4176	19.8723	19.4836	7.3474	4.322
OG 3	13.9742	5.3929	19.2492	18.8623	7.3346	4.3144
OG 4	16.1343	5.69	21.6863	21.2823	7.2766	4.2803
OG 5	13.9023	5.6731	19.4522	19.01999	7.7893	4.5819
OG 6	15.4969	5.8677	21.2318	20.7759	7.9495	4.6761
OG 7	17.5589	5.4856	22.9295	22.5462	7.137	4.1982
OG 8	13.8251	5.5306	19.2347	18.8651	6.8322	4.0189
OG 9	13.6562	5.3385	18.8886	18.509	7.2548	4
OG 10	7.5672	5.8995	13.3398	12.9316	7.0713	4.1595

Field name	weight of cruicible	weight of soil	After 105	After 800	OMC	OMC/ 1.7= OCC
CW 1	12.8359	5.5627	18.2387	17.6809	10.3242	6.073
CW 2	13.3432	5.4119	18.6209	18.1796	8.3615	4.9185
CW 3	14.1459	5.1495	19.1668	18.7444	8.4129	4.954
CW 4	13.8253	5.1949	18.8831	18.4196	9.164	5.3905
CW 5	14.4876	5.3071	19.6534	19.2231	8.3298	4.8998
CW 6	13.865	5.7492	19.4326	19.0125	7.5454	4.4384
CW 7	13.9882	5.5546	19.3939	18.9655	7.95	4.677
CW 8	12.8199	5.6989	18.385	17.9688	7.4788	4.3992
CW 9	13.4276	5.5394	18.8297	18.4308	7.3841	4.3435
CW 10	13.6988	5.1977	18.7672	18.2751	9.7091	5.7112
Field name	weight of cruicible	weight of soil	After 105	After 800	OMC	OMC/ 1.7= OCC
CO 1	14.0625	5.4409	19.3608	18.7444	11.6339	6.8434
CO 2	13.1969	5.2805	18.3021	17.8295	9.2572	6.8434
CO 3	14.3009	5.5251	19.6757	19.2268	8.352	5.4454
CO 4	13.5701	5.3419	18.747	18.2517	9.5675	4.9129
CO 5	14.2227	5.0418	19.1181	18.6993	8.555	5.6279
CO 6	14.0184	5.2454	19.1364	18.6639	9.2321	5.4306
CO 7	13.6998	5.8579	19.3934	18.8412	9.6987	5.7051
CO 8	12.62	5.8252	18.2933	17.842	7.9548	4.6792
CO 9	14.0244	5.694	19.5462	19.0839	8.3722	4.9248
CO 10	13.376	5.7598	18.9693	18.4669	9.9821	5.2835
Field name	weight of cruicible	weight of soil	After 105	After 800	OMC	OMC/ 1.7= OCC
CG 1	14.2469	5.0545	19.1081	18.5293	11.9065	7.0038
CG 2	13.0167	5.2962	18.1935	17.6385	10.7209	6.3064
CG 3	13.972	5.9568	19.7688	19.1519	10.0421	5.9071
CG 4	13.1337	5.14	18.153	17.5898	11.2206	6.6003
CG 5	12.8748	5.595	18.3104	17.6472	12.201	7.177
CG 6	14.3699	5.2502	19.4738	18.8746	11.7401	6.9059
CG 7	13.009	5.7746	18.6484	18.029	10.9835	6.6408
CG 8	12.1527	5.6364	17.662	17.1039	10.1302	5.9589
CG 9	20.3387	5.0051	25.2423	24.6471	12.138	7.14
CG 10	13.7173	5.6468	19.2252	18.5438	12.3876	7.2868

12.5 RAW DATA- CALCIUM

Field name	Initial reading	Me/kg		Field name	Initial reading	Me/kg
OW 1	18.2	0.90818		CW 1	69.1	3.44809
OW 2	24.8	1.23752		CW 2	29.8	1.48702
OW 3	19.4	0.96806		CW 3	25.7	1.28243
OW 4	51.2	2.55488		CW 4	50.1	2.4999
OW 5	32.2	1.60678		CW 5	19.6	0.97804
OW 6	35.1	1.75149		CW 6	17.2	0.85828
OW 7	22.3	1.11277		CW 7	21.4	1.06786
OW 8	17	0.8483		CW 8	21.8	1.08782
OW 9	25.4	1.26746		CW 9	23.6	1.17764
OW 10	21.2	1.05788		CW 10	123.3	6.15267
Field name	Initial reading	Me/kg		Field name	Initial reading	Me/kg
OO 1	37.3	1.86127		CO 1	62.8	3.13372
OO 2	34.2	1.70658		CO 2	21.8	1.08782
OO 3	26	1.2974		CO 3	32.2	1.60678
OO 4	29.6	1.47704		CO 4	30.9	1.54191
OO 5	24.6	1.22754		CO 5	24.6	1.22754
OO 6	25	1.2475		CO 6	18.5	0.92315
OO 7	27.9	1.39221		CO 7	25.2	1.25748
OO 8	38.4	1.91616		CO 8	15.1	0.75349
OO 9	29.1	1.45209		CO 9	22.2	1.10778
OO 10	33.3	1.66167		CO 10	22.4	1.11776
Field name	Initial reading	Me/kg		Field name	Initial reading	Me/kg
OG 1	9.9	0.49401		CG 1	10.5	0.52395
OG 2	9	0.4491		CG 2	5.2	0.25948
OG 3	10	0.499		CG 3	5.5	0.27445
OG 4	10.4	0.51896		CG 4	9.6	0.47904
OG 5	11.3	0.56387		CG 5	8.9	0.44411
OG 6	13.8	0.68862		CG 6	10.6	0.52894
OG 7	11.6	0.57884		CG 7	10.4	0.51896
OG 8	8.6	0.42914		CG 8	10.7	0.53393
OG 9	8.9	0.44411		CG 9	17.3	0.86327
OG 10	8.1	0.40419		CG 10	11.1	0.55389

12.6 RAW DATA- MAGNESIUM

Field name	Initial reading	Me/kg		Field name	Initial reading	Me/kg
OW 1	1.4	0.11508		CW 1	4.3	0.35346
OW 2	2	0.1644		CW 2	2.5	0.2055
OW 3	1.8	0.14796		CW 3	3.7	0.30414
OW 4	3	0.2466		CW 4	3.7	0.30414
OW 5	2.8	0.23016		CW 5	2.9	0.23838
OW 6	2	0.1644		CW 6	4.1	0.33702
OW 7	2.2	0.18084		CW 7	3.1	0.25482
OW 8	1.2	0.09864		CW 8	5.1	0.41922
OW 9	2.2	0.18084		CW 9	4.6	0.37812
OW 10	2.3	0.18906		CW 10	5.8	0.47676
Field name	Initial reading	Me/kg		Field name	Initial reading	Me/kg
OO 1	1.4	0.11508		CO 1	4	0.3288
OO 2	1.6	0.13152		CO 2	1.6	0.13152
OO 3	1.4	0.11508		CO 3	2.5	0.2055
OO 4	1.6	0.13152		CO 4	2.2	0.18084
OO 5	2.1	0.17262		CO 5	2.1	0.17262
OO 6	1	0.09864		CO 6	1.4	0.11508
OO 7	1.4	0.11508		CO 7	1.8	0.1796
OO 8	1.5	0.1233		CO 8	1	0.0822
OO 9	1.2	0.09864		CO 9	1.4	0.01508
OO 10	1.4	0.11508		CO 10	1.5	0.1233
Field name	Initial reading	Me/kg		Field name	Initial reading	Me/kg
OG 1	1.3	0.10686		CG 1	1.6	0.13152
OG 2	1.2	0.09864		CG 2	1.5	0.1233
OG 3	1.8	0.14796		CG 3	1.3	0.10686
OG 4	1.2	0.09864		CG 4	3.6	0.29592
OG 5	0.6	0.13152		CG 5	3.1	0.25482
OG 6	2.3	0.18906		CG 6	2.9	0.23838
OG 7	2.1	0.17262		CG 7	2.6	0.21372
OG 8	2	0.1644		CG 8	2.1	0.17262
OG 9	2.1	0.17262		CG 9	6.4	0.52608
OG 10	1.8	0.14796		CG 10	3.5	0.2877

12.7 RAW DATA- SODIUM

Field name	Initial reading	Callibration curve	me/100g		Field name	Initial reading	Callibration curve	me/100g
OW 1	19	0.92	0.04002		CW 1	24	1.16	0.05064
OW 2	24	1.16	0.05046		CW 2	19	0.92	0.04002
OW 3	23	1.12	0.04872		CW 3	20	0.97	0.042195
OW 4	21	1.02	0.04437		CW 4	20	0.97	0.042195
OW 5	17	0.82	0.03567		CW 5	21	1.02	0.04437
OW 6	20	0.97	0.042195		CW 6	22	1.07	0.046545
OW 7	22	1.07	0.046545		CW 7	18	0.86	0.03741
OW 8	16	0.78	0.03393		CW 8	31	1.5	0.06525
OW 9	20	0.97	0.042195		CW 9	29	1.42	0.06177
OW 10	19	0.92	0.04002		CW 10	30	0.97	0.042195
Field name	Initial reading	Callibration curve	me/100g		Field name	Initial reading	Callibration curve	me/100g
OO 1	17	0.82	0.03567		CO 1	21	1.02	0.04437
OO 2	18	0.86	0.03741		CO 2	18	0.86	0.03741
OO 3	29	1.42	0.06177		CO 3	18	0.86	0.03741
OO 4	17	0.82	0.03567		CO 4	20	0.97	0.042195
OO 5	15	0.72	0.03132		CO 5	21	1.02	0.04437
OO 6	19	0.92	0.04002		CO 6	16	0.78	0.03393
OO 7	21	1.02	0.04437		CO 7	19	0.92	0.04002
OO 8	24	1.16	0.05046		CO 8	15	0.72	0.03132
OO 9	19	0.92	0.04002		CO 9	20	0.97	0.042195
OO 10	18	0.86	0.03741		CO 10	17	0.82	0.03567
Field name	Initial reading	Callibration curve	me/100g		Field name			
OG 1	16	0.78	0.03393		CG 1	14	0.66	0.02871
OG 2	15	0.72	0.03132		CG 2	15	0.72	0.03132
OG 3	15	0.72	0.03132		CG 3	15	0.72	0.03132
OG 4	25	1.21	0.052635		CG 4	20	0.97	0.042195
OG 5	23	1.12	0.04872		CG 5	39	1.91	0.083085
OG 6	32	1.55	0.067425		CG 6	15	0.72	0.03132
OG 7	25	1.21	0.052635		CG 7	23	1.12	0.04872
OG 8	15	0.72	0.03132		CG 8	21	1.02	0.04437
OG 9	16	0.78	0.03393		CG 9	40	1.96	0.08526
OG 10	17	0.82	0.03567		CG 10	19	0.92	0.04002

12.8 RAW DATA- POTASSIUM

Field name	Initial reading	Calibration curve	Me/kg		Field name	Initial reading	Calibration curve	Me/kg
OW 1	48	0.39	0.009984		CW 1	76	0.64	0.016384
OW 2	75	0.63	0.016128		CW 2	52	0.43	0.011008
OW 3	62	0.51	0.013056		CW 3	75	0.63	0.016128
OW 4	109	0.9	0.02304		CW 4	50	0.41	0.010496
OW 5	65	0.55	0.01408		CW 5	49	0.4	0.01024
OW 6	72	0.6	0.01536		CW 6	79	0.75	0.0192
OW 7	57	0.47	0.012032		CW 7	62	0.51	0.013056
OW 8	40	0.32	0.008192		CW 8	75	0.63	0.016128
OW 9	79	0.75	0.0192		CW 9	78	0.74	0.018944
OW 10	62	0.5	0.0128		CW 10	73	0.61	0.015616
Field name	Initial reading	Calibration curve	Me/kg		Field name	Initial reading	Calibration curve	Me/kg
OO 1	55	0.45	0.01152		CO 1	95	0.8	0.02048
OO 2	58	0.48	0.012288		CO 2	58	0.48	0.012288
OO 3	76	0.64	0.016384		CO 3	62	0.51	0.013056
OO 4	71	0.59	0.015104		CO 4	83	0.68	0.017408
OO 5	68	0.57	0.014592		CO 5	69	0.575	0.01472
OO 6	61	0.5	0.0128		CO 6	47	0.38	0.009728
OO 7	74	0.62	0.015872		CO 7	70	0.58	0.014848
OO 8	69	0.58	0.014848		CO 8	51	0.36	0.009216
OO 9	54	0.44	0.011264		CO 9	53	0.42	0.010752
OO 10	54	0.44	0.011264		CO 10	74	0.62	0.015872
Field name	Initial reading	Calibration curve	Me/kg		Field name	Initial reading	Calibration curve	Me/kg
OG 1	63	0.52	0.013312		CG 1	134	1.09	0.027904
OG 2	33	0.25	0.0064		CG 2	58	0.48	0.012288
OG 3	55	0.45	0.01152		CG 3	63	0.52	0.013312
OG 4	60	0.49	0.012544		CG 4	30	1.05	0.02688
OG 5	62	0.51	0.013056		CG 5	155	1.26	0.032256
OG 6	73	0.625	0.16		CG 6	149	1.21	0.030976
OG 7	38	0.3	0.00768		CG 7	126	1.01	0.025856
OG 8	34	0.26	0.006656		CG 8	58	0.48	0.012288
OG 9	40	0.32	0.008192		CG 9	275	2.27	0.058112
OG 10	57	0.47	0.012032		CG 10	495	4.155	0.10624