AN INVESTIGATION INTO FARMING PRACTICE AND THE MAINTENANCE OR IMPROVEMENT OF SOIL ORGANIC CARBON LEVELS

Submitted by

Katherine Suzanne Deeks

To the University of Exeter

As a thesis for the degree of

Doctor of Philosophy by Research

In September 2014

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signature:...................................

ACKNOWLEDGEMENTS

I would first and foremost like to thank the sponsors NERC and ESRC for funding this project. Secondly, huge thanks go to all of the individuals who gave up their time to take part in the interviews, without whom, this thesis would not have been possible.

I am incredibly thankful for Simon Deeks and his extensive editorial help, assisting with soil sampling, his patience and support. Thanks also to Julia Marquard for editorial help and Tom Vigor for assisting with soil sampling.

Last but not least, thanks also to my supervisory team; Professors Henry Buller and Timothy Quine for their guidance, support and editorial help.

‘If we knew what it was we were doing, it wouldn’t be called ‘research’ would it?’

A. Einstein

ABSTRACT

Due to growing global concern regarding climate change and CO_2 emissions, the use of soil as a potential carbon (C) sink has become increasingly recognised as a potential mitigation measure. Global agricultural soil has the estimated capacity for sequestering C at around 20 to 30 Pg (Peta grams) of C over the next 50 to 100 years if correct land management practises are applied. The benefits on improving soil C levels are not limited to reduced CO_2 emissions and climate change mitigation however. It is widely accepted that improved organic C levels provide an array of positive benefits, including enhanced soil fertility, soil structure and water holding capacity and generally improve soil biodiversity and associated ecosystem services. Therefore, the pursuit of increasing soil organic carbon (SOC) levels in agricultural soil could create a win-win-win scenario. To improve SOC levels in agriculture, there are two key components that need to be fully effective. The first being the scientific understanding of SOC and its responses to different farming practices and systems. Secondly, the policy and advisory environment needs to be effective and conducive, promoting those practices and systems which are proven to increase SOC levels. This research therefore, explores these two components by conducting a series of investigations into current on-farm practices for managing SOC, the current policy and legislation structure, the quality and extent of farm-facing SOC related advice, and the scope for improving SOC levels through farm management practices and agri-environmental policy.

A critical review and synopsis of global, European and national policy and advice was conducted to identify those policies that encourage the improvement of SOC and to highlight those areas where SOC does not currently feature as a management issue. Whilst soil and SOC do not feature heavily at the European or national level, there are a number of mechanisms which have the potential to improve SOC levels through their ability to reach a large audience of farmers and via the promotion of suitable management practices. The review of current policy was supplemented by interviews with those responsible for providing advice to farmers and farmers themselves. The interviewed farmers and advisors were relatively engaged with the subject of SOC although the results demonstrated that there was scope to improve current levels of understanding and practice. The currently policy environment at the national level, was not, in general, creating changes in management practices with those interviewed, so any potential enhancement of SOC that the policy mechanisms had the ability to create, were being missed.

A review of the scientific literature regarding SOC and data gathered from subsequent soil sampling under a range of farming practices has allowed for the exploration of the potential and realisation to increase SOC levels through various management approaches. Practices which promote an increased use of organic matter amendments, reduced tillage systems and organic farming systems were of particular focus; with all three demonstrating the potential in improve SOC levels.

Combining the social and natural science aspects of the issue of SOC has allowed for an exploration of the potential approaches to improve SOC within English agriculture. Critically, research and development of the subject needs to be improved to further the scientific understanding of SOC in relation to farming practices and land use. Development is also required of current national policy, in particular agri-environment schemes (AES), which despite reaching a wide farming audience, would appear to create minimal management changes and therefore has minimal impact on improving SOC levels.

The two sides of this issue, the social and the natural sciences, must be addressed together otherwise a full understanding and an appropriate approach forward cannot be reached. This is why an interdisciplinary approach has been viewed as a suitable research framework for this thesis. The concluding aim of this work is to present a 'best practice approach' in terms of physically improving SOC levels by enhancing current advisory pathways and developing an effective policy environment.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DEFINITIONS AND ACRONYMS

AES – Agri-Environmental Scheme

C – Carbon

CO_2 - Carbon Dioxide

CSF – Catchment Sensitive Farming

CSS – Countryside Stewardship Scheme

Defra – Department for Food and Rural Affairs

EA – Environment Agency

EC – European Commission

ELS – Entry Level Stewardship

ES – Environmental Stewardship

ESA – Environmentally Sensitive Area

EU – European Union

FA – Farm Advisor

FWAG – Farming and Wildlife Group

FYM – Farm Yard Manure

GHG – Greenhouse Gasses

HLS – Higher Level Stewardship

IPCC – Intergovernmental Panel on Climate Change

NE – Natural England

NFU – National Farmers Union

NVZ – Nitrate Vulnerable Zone

OC – Organic Carbon

OELS – Organic Entry Level Stewardship

SOC - Soil Organic Carbon

SOM - Soil Organic Matter

SOLAW – The State of the World's Land Water Resources for Food and Agriculture

SPR – Soil Protection Review

SW – South West

TC – Total Carbon

UN – United Nations

UNCCD – United Nations Convention to Combat Desertification

UNCED – United Nations Conference on Environment and Development

UNEP – United Nations Environment Programme

UNFCCC – United Nations Framework Convention on Climate Change

CHAPTER 1: INTRODUCTION AND BACKGROUND RATIONAL

1.1 Soil Carbon at the Global Scale

The global carbon (C) stock is vast, and has the potential to be increased by careful management of C stores, particularly the terrestrial C pool[1] which includes soil. The global soil C pool is estimated at 2500 Pg (Peta grams) to 1m depth. Of this pool, soil organic carbon (SOC) is estimated to be 1500 Pg and soil inorganic C at 950 Pg (FAO, 2011b). Whilst the soil pool is not the largest of the C pools, it accounts for almost double that of the atmospheric pool and it is also potentially the most responsive to modification, with even small changes influencing atmospheric Carbon Dioxide (CO_2) levels (Tan *et al*., 2014). This is why there has been a growing interest in the potential of soils to be used as a C sink[2] in order to mitigate rising atmospheric CO_2 levels (Baker *et al*., 2007). Agricultural soil has a huge potential to play in meeting this goal with an estimated global capacity for C sequestration[3] at around 20 to 30 Pg of C over the next 50 to 100 years if correct land management practises are applied (Paustian *et al*., 2000).

1.2 Why Soil Organic Carbon?

SOC is the generic term referring to the organic fraction of C held within soil. Interest in using soil as a C sink has increased; however, higher or improved soil C levels will have numerous positive effects, not limited to reducing atmospheric CO_2 levels. It is widely accepted that organic C levels influence soil quality by improving soil fertility, soil structure and water holding capacity and by generally improving soil biodiversity and associated ecosystem services (Lal, 2004a; Lal, 2004b; Janzen, 2006; Trombore and Czimczik, 2008; Wang *et al*., 2011). The food needs of a growing global population, estimated to reach nine to ten billion by 2050 (UN, 2013), and increasing concern over environmental degradation have prompted calls for 'sustainable intensification' whereby agriculture increases production and output without damaging the natural resources it is dependent on (Kibblewhite *et al*., 2010; Smith, 2013). It is without doubt, a global challenge to meet the demands of a growing population whilst achieving efficient and productive agriculture (Tscharntke *et al*., 2012). The enhancement of

[1] A carbon pool is a system with the capacity to accumulate or release carbon (Penman *et al*., 2003).
[2] A carbon sink is anything that absorbs more carbon that it releases (Matthews *et al*., 2003).
[3] Carbon sequestration is the natural or artificial process of removing CO_2 from the atmosphere and held in a solid or liquid form long term (Matthews *et al*., 2003).

SOC will assist in aiding this goal. Increasing soil C stocks[4] can reduce the vulnerability of soil to climate change, which in turn allows for improvements in sustainable farming, as well as reducing atmospheric CO_2 levels creating a win-win-win scenario (Smith *et al*., 2008; Wang *et al*., 2011). It is thought that current agricultural practices contribute up to 30% of the anthropogenic Green House Gas (GHG) emissions that drive climate change (Smith and Gregory, 2013). However, increasing soil C stocks and sequestering C offers the greatest mitigation contribution from agriculture due to the low C concentrations in croplands (Smith and Gregory, 2013), as highlighted previously by the projections made by Paustian *et al.* (2000).

1.3 The Soil Policy Environment

To capitalise on SOC, which is both a valuable resource and a public good, a robust policy and legislative environment is required. Approaching SOC in this manner provides an added dimension to the resource and will ensure that the associated benefits (e.g. reduced atmospheric CO_2 concentrations) have the best possibility to be achieved.

To understand how SOC is currently portrayed in the policy environment, it is necessary to trace the emergence of SOC as an issue as the global, European and national level. At present SOC is very infrequently directly mentioned in policy and legislation. However, by mapping the emergence of associated subjects, such as climate change, CO_2 and GHG emissions, and C sequestration, it is possible to see the development of soil carbon as a global political issue and the potential role it could play in mitigating many issues, particularly climate change.

The turning point of international concern over the global environment came with the publication of the Bruntland Report in 1987, also known as ‘Our Common Future’ (UN, 1987) which paved the way for future debates and actions, as predicted by Burton (1987) in his review of the report. Although the report did not focus on soil C *per se*, it introduced the issue of GHG and CO_2 emissions as well as soil degradation and desertification (UN, 1987). Other global organisations and events such as the Rio Summits, the Food and Agriculture Organisation (FAO) of the United Nations and the Intergovernmental Panel on Climate Change (IPCC) have internationalised environmental problems and concerns, including, to some extent, C and soil management (Yang and Percival, 2009).

[4] A carbon stock is the amount of carbon stored in a ‘pool’ (Matthews *et al*., 2003).

The focus of the majority of the contribution made at the global scale has, however has been on dryland regions, which does lead to the question as to whether SOC is a genuine policy issue at the European and National level (national level being England). The Common Agricultural Policy (CAP) is the European Union's (EU) agricultural policy with which all Member States must comply. Since its inception in the early 1960s, the CAP has gone through a number of reforms, at times, rapidly changing its position on the need to produce versus the need to protect the environment. The impact that these reforms have had on SOC levels, is not fully understood (Defra, 2006; SAC and AEA technology, 2011). However, it is still critical to review how SOC can be potentially influenced by changes in policy at the European level as this will have an impact at the farm level.

At the national level, policies and agri-environmental schemes (AESs) are implemented based upon the European CAP. To date, soil and SOC have yet to be at the forefront of these policies, unlike water (e.g. Water Framework Directive). However, the imposed legislation and AESs, which influence agricultural practices on the farm level, are likely to have had an impact on SOC levels in England, particularly following the removal of compulsory set-aside (Freibauer *et al*.,2004; Boatman *et al*., 2006; Defra, 2006; Bell *et al*., 2011; SAC and AEA technology, 2011) . A review of SOC set within the national policy environment is required in order to synthesise the current impact policy measures are having at the farm level.

1.4. Farmers and Farm Advisors

In addition to having a robust policy and legislative environment in place to capitalise on SOC as a valuable resource, it is necessary to have an effective advisory pathway and to understand how on-farm decisions are made. To achieve this, it is essential to review the key players in implementing policy, advice and management decisions. The key actors in this case are farmers and farm advisors (FAs).

Farmers and FAs are critical in translating agricultural policy and legislation into practical actions at the farm level. Farmers are expected to produce food, comply with legislation as well as to ensure their businesses remain healthy and profitable. Due to changes in policy and public perceptions over the recent decades, farmers are no longer just the providers of subsistence, but are now required to look after the environment in which they farm (Howley *et al*., 2014), as well as taking greater responsibility for the on and off-farm impacts their practices have on the wider environment, (Howley *et al*., 2014). It is therefore essential that FAs and the advisory systems are able to support farmers in making effective decisions (Klerkx and Proctor, 2013). Understanding how farmers negotiate the advisory framework, with the aid of FAs, is critical. In addition to this, the knowledge base of FAs is as important as that of the farmers' so that they are successful and effective in the implementation of policy measures and aiding farmers (Ingram and Morris, 2007). This is especially the case concerning SOC, which is not a mainstream managerial issue at the farm level.

If policy makers wish to put greater emphasis on C sequestration, then it is down to the farmers and FAs to respond to the information given and employ it in a practical manner. If farmers and FAs do not think that SOC is important, either in terms of how productive it makes the soil or in a wider environmental context, then such attempts to increase soil C will not work effectively. Policy makers need to understand what farmers and FAs think about SOC to make any changes to policy and legislation practical and effective.

1.5 The Problem

At present, SOC and its functions do not feature heavily within agri-environmental policy, particularly in Europe, but there are signs that this is changing. With increased concern over climate change, soil has been presented as a potential sink to store C. In addition to this, growing populations and the need for more food, is putting increased pressure on the land and farmers to produce more, whilst keeping negative environmental impacts to an absolute minimum. In order to make this achievable, a better understanding of the impact of global and national policies on SOC levels is required, as well as a thorough understanding and appreciation of how farmers negotiate these. In scientific literature, there is a lack of consensus regarding the impact of different farming methods on improved SOC levels. A far better understanding of practices which promote improved SOC levels and the farming decisions and the policy contexts that frame them is required in order to push this issue forward.

1.6 Research Aims, Questions and Objectives

The research aims, questions and objectives have all been designed based on the initial research problem.

1.6.1 Research Aim

The research aim for this thesis is as follows;

To assess and evaluate the practises for managing agricultural land to enhance and/or maintain SOC levels.

1.6.2 Research Questions and Objectives

The research questions and objectives can be broken down as:

Research Question 1: What are the optimum management approaches for the maintenance and enhancement of SOC levels in order to uphold a balance between farmer satisfaction and minimal environmental degradation?

> **Objective 1a:** Conduct a thorough review of related science literature to synthesise best knowledge of the impact of different farming practices (ranging from conventional, high carbon input/organic and no-till regimes) upon SOC levels and their rate of change.
> **Objective 1b:** Construct a sample of farms from two contrasting regions of England representing a range of farming practices.
> **Objective 1c:** Measure SOC levels in soil samples for paired sites, representing different farming practices, comparing and contrasting variations between management approaches.

Research Question 2: What are the mechanisms of policy measures and farm management advice regarding SOC management and what is the level of adoption of the advice?

> **Objective 2a:** Identify and evaluate current information, policy and farm management advice regarding SOC, tracing the agricultural advisory pathway.
> **Objective 2b:** Assess current policy and farm management advice regarding SOC and the practical impact it has on farm management decisions by conducting interviews with farm advisors.
> **Objective 2c:** Analyse farmers receptiveness to SOC related policy and advice through conducting interviews.

Research Question 3: What mechanisms or factors inhibit or promote the adoption of farm level advice, relating to SOC maintenance or improvement?

> **Objective 3a:** Drawing on outcomes from objectives 1 and 2, identify on-farm management strategies for maximising SOC levels.

Objective 3b: Through interviews; explore the responses of farmers and farm advisors, to the policies and management strategies identified, evaluating if current policy measures and advice pathways are effective.

Research Question 4: What current levels of SOC are found under different farming practices and systems, and what is the scope for improving these levels, when using different management and policy approaches?

Objective 4a: Analyse SOC levels in soil samples for paired sites representing different farming practices (ranging from conventional, high carbon input/organic and no-till regimes) in England.

Objective 4b: Draw conclusions based on the farmer and farm advisor interviews, and their responses to SOC management and current policy and advice.

Objective 4c: Create recommendations based on the outcomes of objective 2a and the analysis of the farmer and farm advisor interviews, to form a policy environment that is conducive to increasing/maintaining SOC levels through effective farm management practices.

1.7 Addressing these Problems

This PhD will address the above issues by conducting a series of investigations into current on-farm practices for managing SOC, the current policy and legislation structure, the quality and extent of farm-facing SOC related advice, and the scope for improving SOC levels through farm management practices to encourage C sequestration. The investigation will be carried out at the English national level. It will combine a social science driven enquiry into farming policy and practice as well as soil science aspects of current SOC levels under various farming managements, in order to provide a complete review of SOC as an issue in English agriculture. To fully address the issue of SOC, an interdisciplinary approach is required so that a holistic view can be taken of the issue.

The issue, as highlighted in section 1.5, encompasses both social science and soil science. The social science side addresses the policy framework, the advisory network and the personal views, understanding and implementation at the farm level conducted by FAs and farmers. The soil science addresses the lack of consensus regarding various farming practices and their impact on SOC, as well as the practical feasibility of undertaking certain practices at the local scale and the visible impact they have on soil quality at the farm level.

Both the social and soil sciences feed into each other so viewing them in isolation would be not effective. The two sides of the issue must be addressed together otherwise a full understanding and an appropriate approach forward cannot be reached. This is why an interdisciplinary approach has been viewed as a suitable research framework for this thesis. An Interdisciplinary approach in research, particularly within the sciences, has been repeatedly highlighted to be integral to solve and address many global and environmental problems (Mettzger and Zare, 1999; Steele and Stier, 2000; Miller 2013). Steel and Stier (2000) state that the drive for this interdisciplinary approach to research comes from the recognition of the complexity of natural environments and the intricate linkage among ecological, economic and social systems. This is particularly true for agriculture, due to its reliance on the natural environment, the negotiation with political and economic environments and the social situation of the farmer. For example, Defra (2008) highlighted the need for an interdisciplinary approach in understanding and influencing farmers' behaviours through policy. Interdisciplinary research is increasingly being promoted to enhance the understanding of the environment, identify holistic policy solutions and assist in their implementation, which is the overall aim of this thesis (Fazey *et al.,* 2014).

Figure 1.1 demonstrates the structure this PhD will take. To begin with, literature reviews will be conducted concerning both the soil and social sides addressing objectives 1a and 2a (Chapters 2 and 3). Following the reviews, a methodology (Chapter 4) will be designed based on the outcomes of the findings. There will be two methodologies. Firstly the social science methodology, addressing objectives 1b, 2b and 2c, whereby appropriate farmers and farm advisors will be identified for interview and suitable interview schedules constructed. The second methodology will address objectives 1b, 1c and 4a. SOC levels from a range of paired farms practicing different system and management approaches will be measured to assess their effectiveness in maintaining and improving SOC levels. To link the two methodologies together, farmers that have taken part in the interviewing will be assessed for their suitability to take part in the soil sampling. This will provide a case study approach.

The following two chapters, 5 and 6, will present the findings from the data collection. Chapter 5 will present the key findings from the interviews conducted with the farmers and farm advisors relating to SOC, addressing objectives 3b and 4b. An evaluation of the effectiveness of policy measures and advice pathways will be conducted, as will a summary of their responses to SOC management. Chapter 6 will present the investigation of the paired farms practising different system and management approaches. An evaluation of these practices will be conducted regarding their effectiveness at improving or maintaining SOC levels, addressing objective 4a. Chapter 7 will form a recommendations chapter, drawing on the conclusions made in the previous chapters, as well as exploring the recommendations made by the interviewed farmers and FAs in terms of improving SOC levels via management and policy strategies. This will address objectives 3a and 4c. The final chapter (Chapter 8) will be a concluding chapter, summarising the findings of the study and commenting on the difficulties and challenges of taking an interdisciplinary approach, as well as areas which could be addressed with further research.

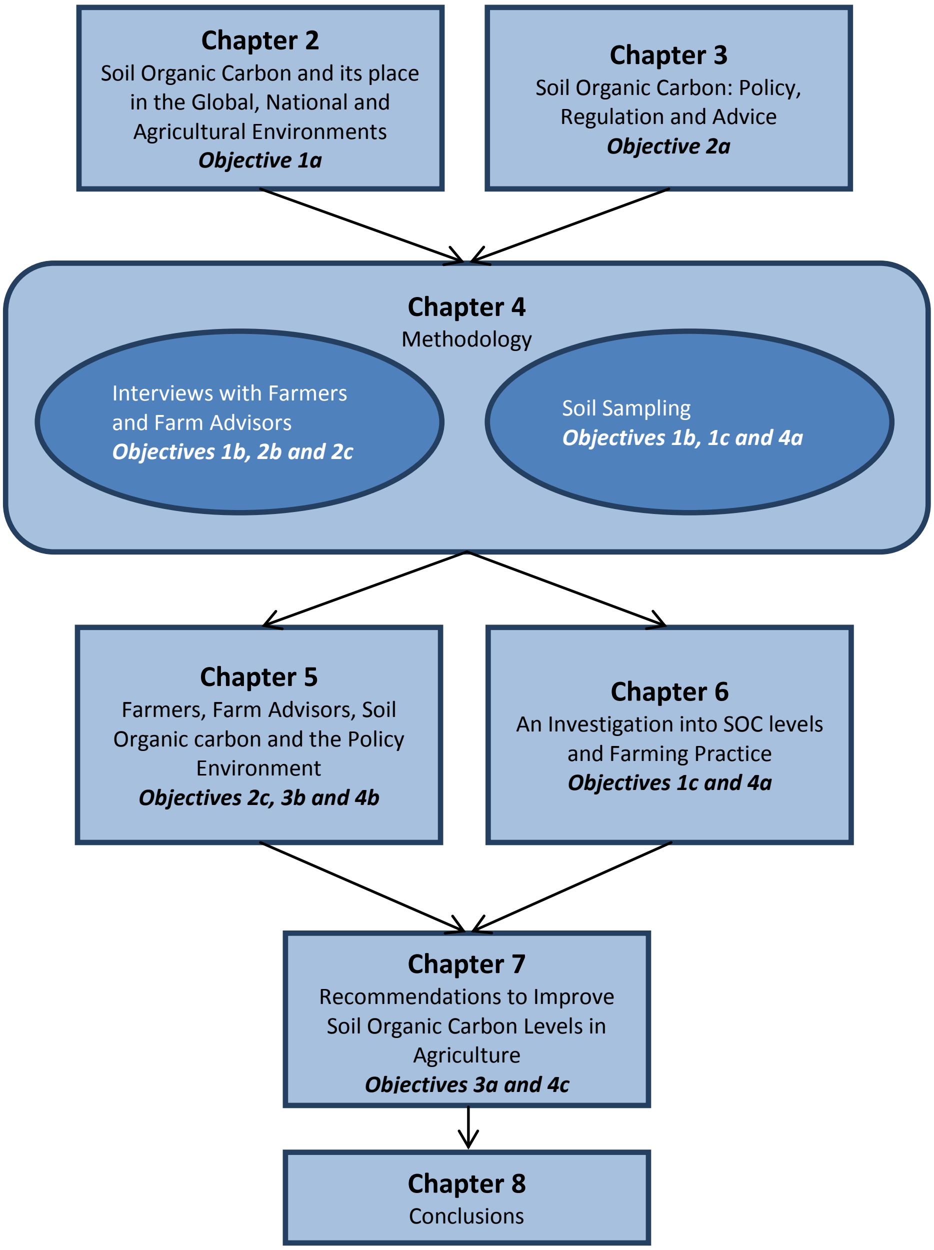


Figure 1.1: A diagram outlining the conceptual framework this study will follow.

CHAPTER 2: SOIL ORGANIC CARBON AND ITS PLACE IN THE GLOBAL, NATIONAL AND AGRICULTURAL ENVIRONMENTS

The following chapter will present scientific literature on soil organic carbon (SOC). In order to address the original objectives of this thesis, the following subject areas will be presented and discussed; the global carbon (C) cycle, changes in SOC levels, SOC and climate change, and best management practices in agriculture to increase and/or maintain SOC levels. In particular, it addresses the following objective:

Objective 1a: *Conduct a thorough review of related science literature to synthesise best knowledge of the impact of different farming practices (ranging from conventional, high carbon input/organic and no-till regimes)*

It is necessary to further this study by researching SOC at the global level and in conjunction with climate change, to provide the background context for which this research is based on. By conducting a thorough review of the scientific literature surrounding SOC, it is possible to place this thesis within a wider academic context and assess the gaps in knowledge that this research will address.

2.1. Why Soil Organic Carbon?

2.1.1 An Introduction to Soil Organic Carbon

There are five global C pools, which in descending order of size are:

- The oceanic pool at 38000 Peta grams (Pg)[5] of C.
- The geological C pool, comprising of fossil fuels with 4130 Pg of C (85% of which is coal, 5.5% oil and 3.3% gas).
- The soil pool is estimated at 2500 Pg to 1m depth. Of this pool, SOC is estimated to be 1500 Pg and soil inorganic carbon at 950 Pg.
- The atmospheric pool at 800 Pg of CO_2 and C.
- The biotic pool at 620 Pg (FAO, 2011b).

Together the soil and biotic C pools account for the terrestrial C pool (FAO, 2011b). The terrestrial C pool is one of three C pools within the biosphere, the other two being the atmospheric and oceanic pools. Figure 2.1 presents the C cycle within the

[5] Pg = 1000,000,000,000,000g ($g10^{15}$)

biosphere, and the amount of C stored in Pg within the different pools. The atmospheric pool, as shown in figure 2.1, is fed via vegetation, gaseous exchanges at the ocean surface and human practices and contains approximately 800 Pg of C. C is found in the atmosphere as carbon dioxide (CO_2) and methane (CH_4). CO_2 leaves the atmosphere via photosynthesis, dissolving into water bodies and precipitation.

The oceanic pool contains 3800 Pg of C. C is found in the oceans as dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) of which a fraction is exchanged rapidly with the atmosphere. C enters the oceans via dissolution of atmospheric CO_2, and can be converted by organisms into organic C via photosynthesis which is then exchanged throughout the food chain or precipitated as dead soft tissue or shells (calcium carbonate, $CaCO_3$). DOC and DIC also enter the oceans via input from rivers. More C is found at greater depths in the ocean due to the thermohaline circulation of the oceans, transferring dense surface waters to deeper depths, transporting the C along with it. A higher concentration of DIC (carbonate and bicarbonate ions) is also found at greater depths compared to the oceanic surface.

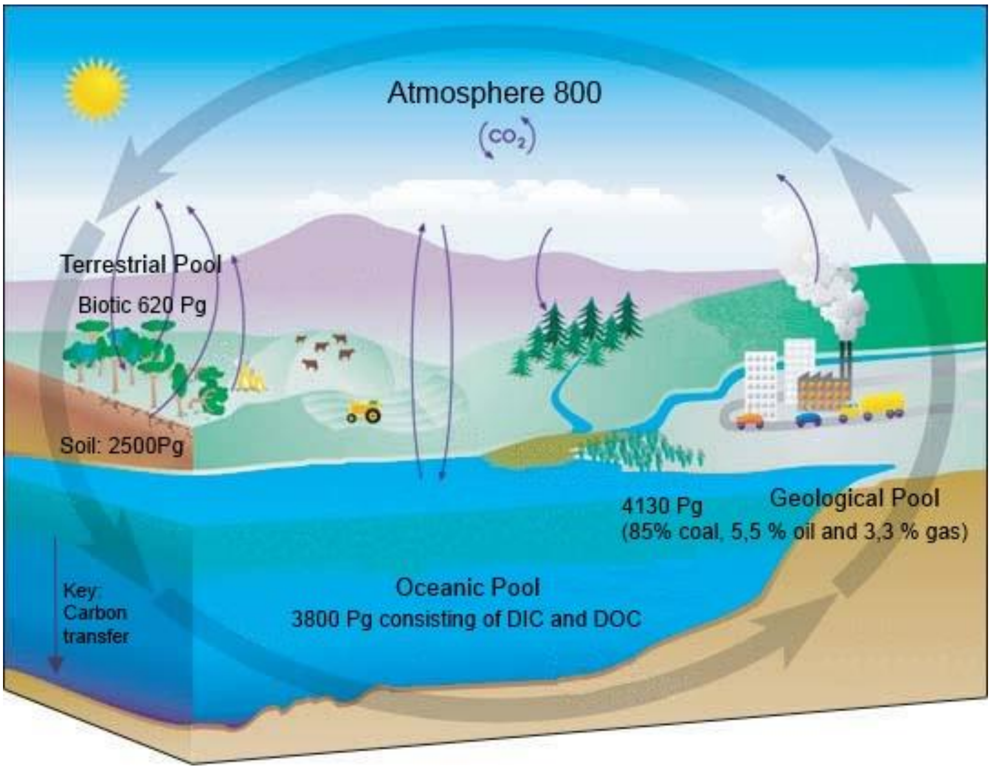


Figure 2.1: Diagram of the Soil Carbon Cycle between the three carbon pools in the biosphere (atmospheric, terrestrial and oceanic) and the amount of carbon stored in each pool (Pg of C) and exchanges. Figure based on FAO (2011b).

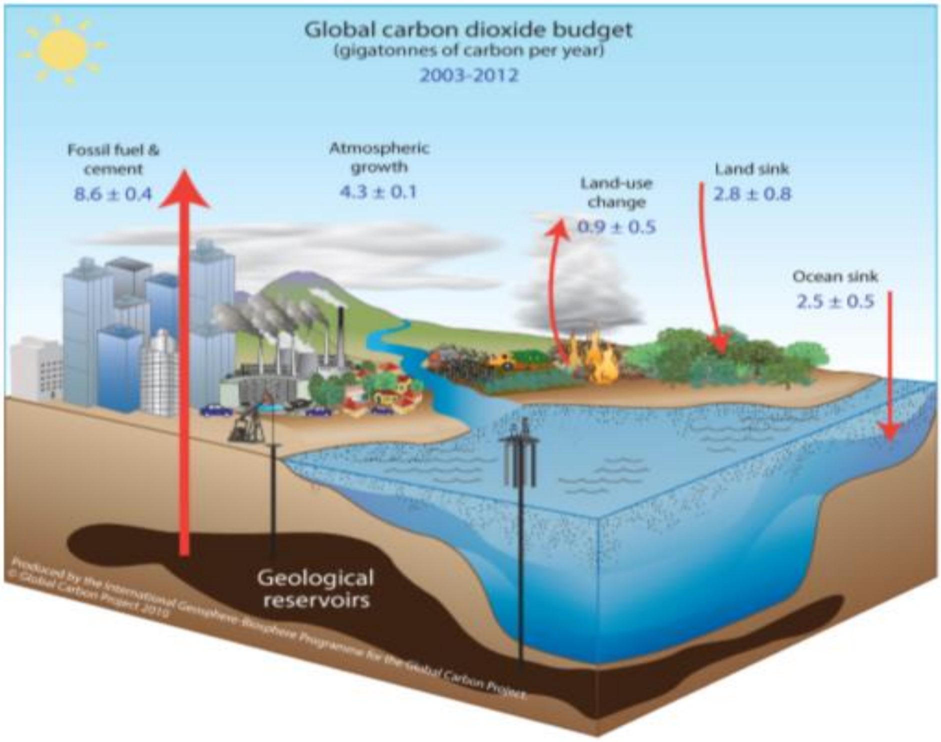


Figure 2.2: Diagram presenting the perturbations of the global carbon cycle caused by anthropogenic activities. Figures are global averages for the decade 2003 – 2012. All fluxes are in units of $PgCyr^{-1}$, with uncertainties reported as ±1σ (68% confidence that the real value lies within the given interval). The arrows represent emissions from fossil-fuel burning and cement production; emissions from deforestation and other land-use change; the growth of carbon in the atmosphere and the uptake of carbon by the sinks in the ocean and land reservoirs (Le Quéré *et al.,* 2014).

Human activity can have a significant impact on the global C cycle as figure 2.2 demonstrates, displaying the CO_2 emissions from 2003 to 2012 caused by anthropogenic activities (Le Quéré *et al.,* 2014). Fossil fuel use decreases the amount of C stored within the terrestrial pool as well as increases the amount of CO_2 released into the atmosphere from its burning. According to Le Quéré *et al*. (2014) between 2003 and 2012, an average of 8.6 $PgCyr^{-1}$ was released into the atmosphere from fossil fuel burning. A change of land use also has an impact as it can lead to the release of C from ecosystems into the atmosphere. For example, deforestation removes large quantities of C stored within the terrestrial pool, including both above and below ground stores. Land use change, has, on average released 0.9 $PgCyr^{-1}$ between 2003 and 2012 (figure 2.2). Land use change includes action such as deforestation and cultivating previously untouched land. Soil C stocks are smaller now than they were before human intervention, with historically, soils losing between 40 and 90 Pg C, globally through cultivation and land disturbance (Smith, 2012). These losses have contributed to an increase of 4.4 $PgCyr^{-1}$ into the atmosphere (figure 2.2).

Whilst the soil pool is not the largest pool, it does account for almost double that of the atmospheric and it is also potentially the most responsive to modification, with even small changes having an effect, influencing atmospheric CO_2 levels (Tan *et al*., 2014). To put it into perspective, to a depth of 1m globally, soils contain twice as much C as that in the atmosphere, and about three times of that found in vegetation (Smith, 2012). This is why there has been growing interest in the potential of soils to be used a C sink to mitigate rising atmospheric CO_2 levels (Baker *et al*., 2007). It has been suggested that agricultural soil has great potential to contribute in this quest with an estimated global capacity for C sequestration at around 20 to 30 Pg carbon over the next 50 to 100 years if appropriate practices are employed (Paustian *et al*., 2000). C found in soils originates from the atmosphere, in organic form via photosynthesis and decomposition of plant and inorganically from parent materials by bicarbonate weathering of silicate minerals, largely found as $CaCO_3$ (Dawson and Smith, 2007). Approximately two thirds of soil C is organic with the remaining third being inorganic C (Foth, 1990). SOC accumulation is dependent on biotic factors and so follows a diurnal and seasonal cycle, producing C fluxes. The photosynthetic processes, which control the gross consumption of CO_2, dominate during daylight hours as sunlight is the primary source of energy. These seasonal and diurnal fluctuations occur at all levels of the ecosystem (Dawson and Smith, 2007). C can also enter the soil system via precipitation. Rainfall in the temperate zone contains DOC concentrations in the range of 0.82-2.00 mg CL^{-1} on a mean annual basis (Dawson and Smith (2007). DOC concentrations can be three times higher in throughfall and ten times higher in stemflow, than in the original precipitation from leaching of plant-derived organic acid (Dawson and Smith, 2007). However, the exact amounts can vary depending upon vegetation species. Therefore the amount of organic C in precipitation is increased before reaching the soil surface.

Globally, crop based agriculture occupies approximately 1.7 billion ha with an estimated soil C stock of 170 Pg (Paustian *et al*., 2000). Few studies have estimated agricultural soil C sequestration potentials for Europe (Freibauer *et al*., 2004); however, Dawson and Smith (2007) estimated that the soil C stock of Great Britain was 9.833± 2.463 Pg (6.948 Pg in Scotland and 2.89 Pg in England and Wales combined). In comparison to soil, live vegetation only accounts for 5% of the UK's terrestrial C stock (Ostle *et al*., 2009). For Great Britain, the estimated vegetation C stock is approximately 0.01138±0.00256 Pg, (Ostle *et al*., 2009). Forests and woodlands account for the majority of the UK vegetation C stocks, with heath and bog vegetation making up 14% (approximately 2 tonnes per ha) and arable and horticulture crops and grasslands making up 6% (approximately one tonne per ha) (Ostle *et al*., 2009). The C stored in the arable and horticulture crops contribute to maintaining the C stock in soil via inputs of organic matter (OM) from litter and crop residue and preventing/limiting surface erosion of the soil. The C stored in agriculture vegetation is temporary as crops are harvested and some C will be lost or transformed into a food or fuel product. Whilst the crops are replaced, it is not always done on a like for like basis, so any C stock estimates of agricultural vegetation cannot be considered as permanent.

The global C stock is vast, but has the potential to be increased by careful management of C pools, particularly in the terrestrial C pool. Soil C is the biggest contributor to the terrestrial C pool (1580 Pg of C) and therefore holds the most potential to increase the global C stock further.

2.1.2 Soil Organic Carbon and Soil Organic Matter

Soil organic matter (SOM) refers to the organic fraction of the soil and is derived from plant and animal residues at various stages of decomposition, cells and tissue of microbes and substances synthesized by the soil population (Campbell, 1978; Hodgeson, 1978). SOC is found in SOM, and constitutes approximately half of SOM (55%) (Persson and Kirchmann, 1994). SOC is the generic term referring to the organic fraction of C held within soil. It excludes inorganic C which is largely made up of calcium carbonate ($CaCO_3$). In calcareous soils with neutral to basic pH, inorganic C can make up a significant fraction of the total C, whereas in acidic soils it is generally absent (Jandl *et al.,* 2014).

The amount of SOC in a soil depends upon a number of environmental factors. Different soil types will have varying amounts of C. Due to their structure, clay soils will accumulate more soil C when compared to sandy soils (Freibauer *et al*., 2004). Soil C stocks are determined by the balance of C inputs (such as OM) to the soil and losses from the soil (such as CO_2, DOC and other losses through erosion) (Smith *et al.,* 2008). Inputs and losses are largely determined by land use but climatic factors and geological factors also have an impact. For example, in colder climates, decomposition is slower and so C may accumulate more rapidly than for soils in warmer climates, where C is more likely to be lost due to rapid decomposition (Freibauer *et al*., 2004). This also creates seasonal patterns in decomposition rates (Dawson and Smith, 2007).

Within an agricultural system, the input of C to the soil is determined by the net primary production and the fraction of crop remaining in the field, as well as any other form of OM input by the farmer or land manager, through the addition of materials such as farm yard manure (FYM). The loss of C is determined by heterotrophic respiration, decomposition rates and loss of topsoil by erosion, usually by tilling practices. In general, low crop yields, a high soil C content and high SOM decomposition rates enhance the loss of C from agricultural soils (Freibauer *et al*., 2004).

It was thought that the type of the C found in the soil will determine how long the C can be stored for (Freibauer *et al*., 2004), however new research has demonstrated that this may not be case (Schmidt *et al*., 2011). The original school of thought was that active or labile C was likely to not stay in the soil system long. This is because the OM the C is derived from is readily degradable. Recalcitrant or passive C on the other hand, which is derived from more stable forms of OM, is likely to contribute to soil C sequestration. Schmidt *et al*. (2011) however attempted to answer the question as to why, when SOM is thermodynamically unstable, as demonstrated in the above paragraph, does it persist in soils, sometimes for thousands of years? The authors state that a new view of SOC-dynamics has emerged from this question, resulting in the conclusion that SOM persists not because of the properties of the OM itself, but because of the physio-chemical and biological influences of the surrounding environment. Rather it persists as it is primarily an ecosystem property and not a molecular property. Freibauer *et al*. (2004) also attributed the form of stabilisation of the OM, whether chemical or physical, and the physical location of the C (inter or intra-aggregate vs. free) to have an impact on how much and how long C is likely to remain in the soil system.

In their 2007 paper, Dawson and Smith propose three methods of SOC stabilisation. These are the micro-aggregation (53 to 250 µm) formation within macro-aggregates; physically binding with clay and silt particles; and biochemically by formation of recalcitrant soil OM compounds. The first two methods of SOC stabilisation correspond with the new hypothesis noted by Schmidt *et al*. (2011). However, with reference to the importance of recalcitrance OM, whereby the molecular structure alone can create stable OM, Schmidt *et al*. (2011) state that new research (see Marschner *et al*., 2008; Kleber and Johnson, 2010), has shown this to not be of great importance of OM cycling.

As the C cycle operates over a long period, any changes to the SOC stock from land use or management changes can take some time to appear. For example, if there is a management change leading to greater concentrations of soil C, it can take decades for the full impact to become apparent. On the other hand, C losses resulting from land use changes that accelerate biotic (decomposition) and abiotic (disturbance, erosion) C cycling can occur rapidly, within years (Ostle *et al*., 2009). Either way, a long term monitoring approach is needed to assess SOC concentrations and the response to land use and management changes (Jandl *et al*., 2014).

Soil Organic Carbon and Soil Organic Matter as Ecosystem Services

As will be highlighted and discussed within this review, SOM and SOC both have a major impact on soil fertility, both directly and indirectly. Directly, SOM provides plant nutrients via the processes of decomposition and mineralisation. Indirectly, SOM has an impact on the physiochemical properties of the soil (Hodgson, 1978).

Ecosystem services is the term applied when humans receive a benefit from ecosystems (MEA, 2005). Broadly, these benefits fall into the following four categories; supporting, provisioning, regulating and cultural services. It is also a term being used by governments and policy makers to categorise and apply monetary value to the functions provided by the environment from which humans. Whilst not mentioned directly, a similar approach has been employed in the Common Agricultural Policy (CAP) 2013 reform, whereby farmers are to be paid for 'greening' activities, effectively putting a price on environmental process and habitats. SOC is influenced by and contributes towards ecosystem services. Ecosystem services influence the dynamics of SOC, including the input of plant litter (provisioning), microbial decomposition nutrient processes (regulating), faunal activities(regulating) and soil moisture (supporting) (DeBaets *et al*., 2013). Figure 2.3 below presents the ecosystem services which soil interactions and processes influence.

Provision of Ecosystem Service and Functions by Soils

Life Support Services

- The soil renews, retains, and delivers plant nutrients and provides physical support to plants.
- It sustains biological activity, diversity and productivity.
- The soil ecosystem provides habitat for the dispersion and dissemination of seeds, which ensures the continued evolution of the gene pool.

Provision Services

- Soil is the basis for the provision of food, fibre, fuel and medicinal products that sustain life.
- It holds and releases water for plant growth and water supply.

Cultural Services

- Soil provides the foundation for urban settlement and infrastructure.
- Soils and their wider ecosystems provide spiritual or heritage value.
- Soils are the basis for landscapes that provide recreation

Regulating Services

- The soil plays a central role in buffering, filtering and moderating the hydrological cycle.
- Soils regulate the carbon, oxygen and plant nutrient cycles (e.g. nitrogen, potassium, phosphorus, calcium, magnesium and sulphur) that affect plant production and the climate.
- Soil biodiversity contributes to regulating soil pests and diseases. Soil micro-organisms process and break down wastes and dead organic matter (e.g. manure, remains of plants, fertilizers and pesticides) preventing them from building up to toxic levels and entering the water supply as pollutants.

Figure 2.3: Provision of ecosystem services and functions by soils, adapted from Climate Smart Agriculture (FAO, 2013).

Soil supports life by providing nutrients and physical habitat and support for plants, seeds, soil life, such as nematodes and microbial communities. SOM is the material which provides the vast majority of the nutrients as well as supporting the soil structure. In terms of provisioning services, soil provides the fuel, food and fibre for life, with SOM providing a high proportion of the nutrients to make this possible. It also holds and releases water for plant growth and water supply.

Soil plays a huge part on the hydrological cycle, acting as a buffer, filter and moderator. Soils regulate the C, O_2 and plant nutrient cycles (N, K, P, Mg and S), all of which affect plant production and climate. SOC plays a huge role in the C cycle, acting as a store and source of C. The biodiversity of soil life contributes to the regulation of soil pests and diseases. Soil micro-organisms process and break down wastes and dead OM, preventing these materials from building up to toxic levels, and potentially entering the water supply as pollutants. SOC and SOM play various roles in the ecosystem services that soil as whole provides and act as vital resources.

2.2. Changes in Soil Organic Carbon Levels

SOC levels change over time due to various environmental changes, including both natural and anthropogenic. The type of soil and the environment (climate and land use) are the main controlling factors. In agricultural soils the main loss of C from soils is caused by cultivation and losses from topsoil through erosion, causing the release of CO_2 from OM mineralisation (Dawson and Smith, 2007). Ostle *et al*. (2009) looked at the Countryside Survey and presented a summary of the 2007 report for soils. The Countryside Survey is scientific study which was first undertaken in 1978. The data gathered is used to inform decision makers and the public on the status of the managed and natural UK environment, including soil C stocks and vegetation composition. Soil samples were only taken to a depth of 15 cm. Whilst this is the part of the soil profile which is most susceptible to land use change and disturbances, significant quantities of C are held below these depths, so measuring at this depth provides a limited snapshot of soil C of the UK's soils. The data from the 2007 survey found that the UK soil C storage for the top 15 cm (0 to 50 cm for bogs) was approximately 1.7 billion tonnes of C, or 6.8 billion tonnes of CO_2 equivalent (Ostle *et al*., 2009). Analysis of land use change showed that the area of UK occupied by arable/horticultural cropland reduced significantly between 1998 and 2007, by between 300,000 and 650,000 ha. At the same time there were gains in improved, neutral and acid grassland and broadleaved woodland that would be beneficial to C sequestration. The observed changes in land use were most likely attributable to the increase in set-aside and conversion of arable land to improved grassland supported through the CAP and agri-environmental schemes (AESs) (Ostle *et al*., 2009).

An earlier paper by Bellamy *et al*. (2005) studied the changes in SOC between 1978 and 2003 in soils across England and Wales. Results from the study show that between 1978 and 2003, soil from across England and Wales lost 0.6% per year of C. It was also found that soils with C contents greater than 100g $kg^{-1}$of C had relative rates of loss of more than 2% per year over the survey period. The authors note that this statistic is a cause for concern as most of the soil in England and Wales is organic with C levels greater than 100g kg^{-1} (Bellamy *et al*., 2005). The authors look towards climate change as a means for explanation of the observed changes as no significant relationship was found with SOC content and land use change, which is contrary to the results later found by Ostle *et al*. (2009). However, it is stated that changing land use will have an effect upon soil C losses, but at present there is not enough data to explore these effects at a large scale (Bellamy *et al*., 2005).

The report by Bellamy *et al*. (2005) has come under some criticism. Smith *et al*. (2007) state that the observed mean loss of SOC of 0.6% per year contradicts strong evidence that the UK and Europe are net CO_2 sinks and not sources. Smith *et al*. (2007) conducted research looking at the possible relationships between climate change and SOC. They found that climate change could potentially only be responsible for around 10% of the overall SOC loss reported by Bellamy *et al*. (2005). Overall it is suggested that there is no single mechanism for the observed loss, but localised changes in land use and management are likely to have a greater influence. Dawson and Smith (2007) and Smith *et al*. (2007) suggest that substantial changes to land use and management that occurred over the data period may have caused the observed losses. The input of OM into the soil system has decreased due to a reduction in the spreading of animal manure. Instances of manure being spread on soil has reduced, due to a steady decline in livestock numbers over this period, and intensification of their production leading to increased liquid slurry from animal excreta at the expense of dry FYM. The agricultural crop yields increased over the period by about 1.45% per year, largely due to improvements in the harvest index (the amount of grain produced relative to the straw and stubble). This means that less residue is left on the field as more of the crop is valuable. Improvements in machinery may also have led to increased residue removal (Dawson and Smith, 2007). An additional factor is deeper ploughing depths, which increase C mineralisation rates, resulting in C leaving the system faster. There is also the issue of legacy effects of land use change which occurred before 1978, the start of the survey period. C turnover is a slow process and so SOC may continue to decrease many years after a land management change (Smith *et al*., 2007). In addition to this, the original paper only described data from the top 15 cm of soil, ignoring C stocks and processes at greater depths (Dawson and Smith, 2007).

2.3. Factors that Contribute Towards Soil Organic Carbon Depletion

Agriculture is both a protector and a destroyer of the environment. One of the main contributors towards SOC depletion is the conversion of land into agricultural land, which removes and disturbs natural ecosystems and associated ecosystem services (Pretty, 2008). For example; current soil C stocks are the smallest they have been since before human intervention, historically having lost between 40 and 90 $PgCyr^{-1}$ through cultivation and disturbance (Smith *et al*., 2008). The subsequent agricultural practices increase the rates of erosion and accelerate decomposition through actions such as ploughing which increases the rate of oxidation of SOM, therefore further reducing SOC (Manies *et al*., 2010). On average, agricultural practices cause 0.47 to 0.61 Pg of C per year to move laterally over the Earth's surface (Van Oost *et al*., 2007). The movement of soil, from detachment, transport and deposition, removing SOC from the site of its formation, can have profound impacts on SOC dynamics (Berhe *et al*., 2014). However, in agriculture, the majority of erosion and deposition occurs within the same field, particularly in arable farming (Van Oost *et al*., 2007). During the erosion process the disruption of soil aggregates during detachment and transport exposes OM that had been physically protected inside aggregates is loss by decomposition and transport in dissolved or particulate forms (Berhe *et al*., 2014). The overall effect erosion has upon SOC depends on the rate of detachment and transport, the method of transportation and the rate at which SOC is replaced at the site of erosion (Van Oost *et al*., 2007). If erosion rates are high and/or mineralisation rates are increased then the soil may become a CO_2 source rather than a sink (Manies *et al*., 2001). However, the depletion in SOC after land conversion to agricultural land is partly mitigated through crop production which puts C back into the system (Manies *et al*., 2001). Given the influence that the conversion of agricultural land can have upon SOC, it is critical that appropriate land management takes place.

2.4 Soil Organic Carbon and Climate Change

As the previous section has highlighted, loss of SOC usually results in the release of CO_2 into the atmosphere, which is largely recognised as the driving force behind anthropogenic induced climate change (see IPCC Assessment Reports). For example, it is estimated that atmospheric CO_2 concentrations increased from 277 parts per million (ppm) in 1750 (Joos and Spahni, 2008), the beginning of the industrial era, to 396.33 ppm in 2014 (Dlugokencky and Tans, 2014). As well as being a source of CO_2, soil, including SOC is expected to alter in response to climate change. Changes in temperature and soil moisture are likely to affect decomposition and mineralisation rates. There is already evidence to suggest that continued warming may lead to strong climate-induced SOC loss (Jandl *et al*., 2014). This would further increase atmospheric CO_2 levels whilst also degrading the soil and reducing its fertility. At present, the information on SOC is geographically unbalanced, so a harmonisation of already existing regional databases and soil monitoring programmes is needed (Jandl *et al*., 2014). This is of particular importance as, given the size of soil C stocks and the impact changes to soil can have on atmospheric CO_2 concentrations, understanding the response of SOC to climate change will be critical to map its effects (Smith *et al*., 2008; Smith, 2012). As previously stated, soil contains a large amount of the terrestrial C stock. Due to concern over global CO_2 emissions and climate change, soil has been promoted as a potential resource to sequester a proportion of the carbon released into the atmosphere. An increase in C storage may help to reduce atmospheric CO_2 levels by removing carbon from the atmosphere (Ingram and Fernandes, 2001; Lal 2004a).

There have been several studies looking at how much of an impact soil C sequestration would have upon lowering, or at least slowing the rise in atmospheric CO_2. Soil C sequestration can potentially account for around 90% of the total global mitigation potential available in agriculture by 2030 (Smith *et al*., 2008b). Although it has been described as being at best a stop-gap measure (Janzen, 2006), a stop-gap measure might be enough for the next 50 years, while technology and scientific understanding improves.

It is widely accepted that organic C levels influence soil quality. Rich concentrations of SOC enhance soil quality by improving soil fertility, soil structure, water holding capacity, and generally improving soil biodiversity and their associated ecosystem services (Lal 2004a; Lal, 2004b; Janzen, 2006; Trumbore and Czimczik, 2008). If these characteristics are further enhanced by improved SOC levels, it may lead to improved agricultural sustainability, which is key with an uncertain climactic future (Lal, 2004a). Unfortunately however, employing C sequestration to mitigate climate change may prove to be a potentially risky option. Soil can become saturated with SOC, meaning that CO_2 from the atmosphere is only stored in the soil until it reaches saturation. Research has shown that the SOC equilibrium level does not increase linearly without any limit (Freibauer *et al*., 2004; Smith, 2012; Tan *et al*, 2014).

Increases in soil C are often greatest soon after a land use or management change, and as the soil reaches a new equilibrium, the rate of increase in soil C will slow (Freibauer *et al*., 2004). The majority of the benefits occur in the first 20 years after a land management change (after which the rate of C sequestration has been shown to dramatically reduce) (Freibauer *et al*., 2004).

Another issue is that SOC is not a permanent store. Any C that has previously been sequestered can be released back into the atmosphere by poor soil management or soil disturbance. If the management or land use is reverted, the accumulated C will be lost (Freibauer *et al*., 2004; Smith, 2008). Increasing soil C stocks in one area can lead to soil C losses in another, especially if the SOC is being increased by OM amendments (due to leakage or displacement). Additionally, the climate mitigation potential of some C sequestration could potentially be lost when increased emissions of other greenhouse gases (GHG) are included (nitrous oxide (N_2O) and methane (CH_4)) as some practices that benefit SOC may not be beneficial when all GHG are considered (Smith, 2008).

C stocks are difficult to measure so there will be problem verifying any effectiveness from C sequestration resulting from a specifically designed land management (Smith, 2012). Each soil has a limited capacity for C storage, depending upon the vegetation type, climate, hydrology, topography and the nutrient environment (Ostle *et al*., 2009); therefore global estimates are hard to reach with confidence. Due to the small-scale variability of soil, a large number of replicates are often needed to assess SOC levels to an acceptable level of accuracy (Jandl *et al*., 2014). Standardisation in how SOC levels are measured is required, for example a standardised approach to the soil depth at which SOC is measured, which is often a disputed subject. SOC can be unevenly distributed throughout the soil depths, and so SOC measurements may not accurately reflect the SOC level of a certain soil. According to Jandl *et al*. (2014) most soils are sampled to a depth of 30 cm or less. SOC predominantly accumulates near the surface or at the rooting zone which this depth would cover. However, when quantifying the SOC stock, subsoil horizons should be sampled too, especially as root zones for trees go beyond the depth of 30cm, as well as the role of soil micro-organisms, moving C through the soil profile (Jandl *et al*., 2014).

2.5. Farming and the Enhancement of Soil Organic Carbon

By applying and optimising best management practices, soil C stocks can be increased and managed within agriculture. Increased C can reduce the vulnerability of managed soils to future global warming by improving soil fertility, workability, water holding capacity and reducing erosion risk (Smith *et al*, 2008; Wang *et al*., 2011). Increasing soil C stocks can both improve atmospheric CO_2 levels as well as reducing the vulnerability of soil to climate change and potentially improving sustainable farming, creating a win-win-win scenario (Smith *et al*., 2008; Wang *et al*., 2011). It is estimated that currently, agricultural practices contribute up to 30% of the anthropogenic GHG emissions that drive climate change (Smith and Gregory, 2013). However, increasing soil C stocks in agriculture offers a significant mitigation contribution due to the low C concentrations in croplands (Smith and Gregory, 2013), as highlighted previously by the projections made by Paustian *et al.* (2000) (20 to 30 Pg C sequestered over the next 50 to 100 years).

Management practices which have been shown to promote increases in SOC include; improved plant productivity (better nutrient management, rotations and agronomy), reduced or conservation tillage with residue management (reduced residue removal), effective use of OM amendments (manure management), set aside, optimal livestock densities and the use of legumes and optimal species mix. Land-use changes such as the conversion of arable to permanent grassland have also shown to increase SOC as well as farming systems such as agro-forestry and organic farming (Smith, 2008; Smith *et al*., 2008).

At the global level, the FAO, in their publication ‘Soil Carbon Sequestration: SOLAW Background Thematic Report’, listed a number of agricultural practices that could sequester CO_2 or C from the source of the pollution of the atmosphere (FAO, 2011a). These generally echoed those listed by Smith (2008) and Smith *et al*. (2008) and included the following;

- Reduction of use in the plough and movement towards minimum or zero-till.
- Incorporating crop residues (or another type of OM) in conjunction with cover crops introduced into the crop rotation cycle.
- Taking up measures to minimise soil and water losses by surface run off and erosion.

- The enhancement of soil fertility by integrated nutrient management combining OM additions, and enhancing biological processes and synthetic fertilisers.
- Improve water holding capacity around the root zone by reducing losses through run off and evaporation, and increase the efficiency of irrigation techniques.
- Better use and instigation of complex farming systems such as mixed farming (livestock and arable) and agro-forestry techniques (FAO, 2011a).

At the national level, Bhogal *et al*. (2009) highlighted two main drivers for the management of OM in UK agriculture. Firstly, as the maintenance of existing SOC levels for their soil quality and fertility benefits, and secondly, the enhancement of SOC levels for soil C storage. Focus on OM management in UK agriculture is poignant as approximately 55% of SOM is comprised of organic C, meaning that the management and measurement of OM is a good indicator for levels of SOC (Persson and Kirchmann, 1994). In an earlier report, Bhogal *et al*. (2007) stated that farming methods used to enhance or maintain SOM could be largely divided into three main categories; methods that enhance SOM, methods that maintain existing SOM and methods that maintain existing SOM levels and potentially enhance C storage. Following a change in practice, SOC levels will increase or decrease to an equilibrium that is characteristic of the soil type, land use and climate (Bhogal *et al*., 2007). The challenge is then to maintain the SOC at the new equilibrium by continuing the new management practice indefinitely (Bhogal *et al*., 2007).

Bhogal *et al.* (2009) conducted a project commissioned by the Department for Environment, Food and Rural Affairs (Defra), looking at best practices of managing SOM in agriculture. The project complements the Defra publication ‘A Soil Strategy for England’ (2009) in which protecting and enhancing SOM is the key objective. The final report gives practical advice of best practices for soil management, on lowland and upland agriculture. An extensive table was produced highlighting the relative benefits and drawbacks of best practice methods. Table 2.1 demonstrates a brief summary of this information, divided into the three methods of maintaining and improving SOM previously highlighted by Bhogal *et al*. (2007). In some cases there are examples of ‘pollution swapping’. For example, reduced tillage has the potential to decrease soil erosion and diffuse nutrient pollution, but could potentially increase nitrous oxide emissions (Bhogal *et al*., 2009). Many of the methods listed in table 2.1 are employed in the Environmental Stewardship voluntary schemes delivered by Natural England. Bhogal *et al*. (2009) envisage that methods used to enhance SOM would be incentivised via Environmental Stewardship. Methods that protect and maintain existing SOM levels would most likely be delivered by cross-compliance and incorporated into the requirement to maintain soils under the Good Agriculture and Environment Conditions (GAEC). These factors will be discussed in Chapter 3, where their effectiveness will be evaluated.

Table 2.1: Summary of the best practice methods highlighted by Bhogal *et al*. (2009) to be used on lowland agriculture for managing SOM. Many of the methods listed are used by current Environmental Stewardship schemes delivered by Natural England and under cross-compliance as part of the Single Payment Scheme.

Methods that enhance SOM **(Land use change)**	**Methods that maintain existing SOM** **(Reduce soil erosion)**	**Methods that maintain existing SOM levels and potentially enhance C storage** **(Changes in tillage practices/Increase in OM additions/returns)**
Convert tillage land to permanent grassland	Cultivate compacted tillage soil	Reduced/zero tillage
Buffer strips	Leave autumn seedbeds rough	Establish cover crops/green manures
Establish permanent woodlands	Cultivate across the slope	Straw/crop residue incorporation
Hedges, shelter belts	Manage over-winter tramlines	Encourage use of livestock manures
Grow biomass crops	Early establishment of winter crops	Import high OC materials
Introduce rotational grass	Fence off rivers and streams from livestock	
Water table management	Move feed/water troughs at regular intervals	
	Loosen compacted soil layers in grasslands	
	Reduce stocking density	

A number of the practices listed in table 2.1 will be examined below in further detail, including tillage practices and OM amendments as they relate to the particular aims of this thesis as the following text demonstrates. Tillage practices are being investigated as they cover a range of practices, varying from minimum tillage, direct drilling and

Controlled Traffic Farming, encompassing a range of techniques. OM inputs will be discussed, as again, this topic covers a range of practices including the use of FYM, sewage sludge, and crop incorporation. Organic farming, whilst not mentioned by Bhogal *et al*., (2009), is often promoted as a farming system which increases SOC and sequesters C (Smith, 2008; Smith *et al*., 2008). It is for this reason that organic farming will be discussed. Other methods highlighted by Bhogal *et al*. (2009) will not be addressed in detail in this review. Instead many of the practices outlined are covered in agri-environmental voluntary schemes in England, of which the impact on SOC will be addressed in Chapter 3. The decision to focus on the three topics was done based on the information by Bhogal *et al*. (2009) and the managements listed by the FAO in the publication 'Soil Carbon Sequestration: SOLAW Background Thematic Report' (FAO, 2011b) and by Smith (2008) and Smith *et al*. (2008), mentioned previously. The three approaches; tillage practices, OM amendments and organic farming, are not directly addressed in agri-environmental schemes, and are more likely to be undertaken by a farmer driven through a management or business decision, rather than by taking part in a voluntary scheme for which they would receive a payment.

2.5.1 Tillage practices

Tilling is the preparation of soil by ploughing, ripping or turning, with the aim to aerate the soil, prevent compaction and mix crop residues. Cultivated, or tilled soils, are viewed by many as a depleted C reservoir that can be refilled (Baker *et al*., 2007). Conservation tillage is defined as any tillage method that leaves sufficient crop residue in place to cover at least 30% of the soil surface after planting (Baker *et al*., 2007). Conservation tillage is the term applied to a number of tillage practices, including minimum tillage (<100 mm without inversion), direct drilling (no cultivation prior to drilling) and zero tillage (Davies and Finney, 2002). Conservation tillage statistics have been projected globally to estimate that if all croplands were to convert to conservation tillage, 25 Pg of C over the next 50 years could be sequestered (Baker *et al*., 2007). Conservation tillage practices fall under the third approach highlighted by Bhogal *et al*. (2009) of methods that maintain existing SOC and potentially enhance C storage.

Tilling the soil affects soil aggregation directly by the physical disruption of the macro-aggregates, and indirectly through alteration of biological and chemical factors (Choudhury *et al*., 2014), causing OM to become oxidised and lost to the atmosphere as CO_2. Soil aggregates play an important role in retaining SOC. The quantity and quality of the SOC fractions impact upon soil aggregation, which in turn physically protects the C from degradation, and increases the residence time of C (Choudhury *et al*., 2014). In addition to this, the practice of tilling encourages soil erosion due to the vast amount of soil which is loosened and moved resulting in tillage erosion being recognised as a global soil degradation process (Van Oost *et al*., 2006). Quine and Zhang (2002) describe tillage erosion as a 'conveyor-belt', transferring soil from erosion to depositional areas, creating high within field variability. For example, erosion areas will be nutrient depleted, whilst depositional areas will be enriched (Van Oost *et al*., 2006). It has been shown that sediment loss from arable farming can be reduced by 68% under minimum tillage when compared to conventional ploughing (Stoate *et al*., 2001). Lal (2004a) argues for conservation tillage agriculture due to the benefits it brings to the SOC content. Lal (2004a) states that by leaving crop residues in the field after the harvest, the C content increases as OM is not mineralised. Additionally, it prevents essential nutrients that adhere to SOC from leaving the system as the C is mineralised, potentially saving fertiliser and pesticide use (Lal, 2004a). The article by Lal (2004a) has come under some criticism, however. Van Oost *et al*. (2004) highlight that with regards to SOC maintenance and improvement, Lal (2004a) did not consider that C sequestration may occur as a result from the natural cycle of soil erosion and deposition, or simply from soil redistribution caused by tilling.

The Stern Report (2006) promoted conservation tillage practices as a means of enhancing C storage in agricultural soils (Bhogal *et al*., 2007). Bhogal *et al*. (2007) conducted a Defra project into how conservation tillage practices could increase the organic carbon content of arable soils. At present there is approximately 4.5 million ha of tilled land in England and Wales, and so Bhogal *et al*. (2007) hypothesises that even small increases in SOC per ha could lead to an increase in C storage at a national level. However the uptake of reduced tillage is limited. In 2005 in England and Wales, 50% of tilling was conventional tillage, 43% used conservation tillage and 7% used zero-till systems (Bhogal *et al*., 2007; Powlson *et al*., 2012).

There are some negative aspects of conservation tillage practices. Minimally tilled systems have demonstrated heightened N_2O emissions due to increases in topsoil wetness and/or a decrease in aeration as a result of reduced soil disturbance (Bhogal *et al*., 2007; Paul *et al*., 2009). The same issue may cause a drop in yield due to water logged soils (Lal, 2004a). In their paper Baker *et al*. (2007) reviewed studies on conservation tilled systems and the evidence of increased soil C. The authors note that the increased C reported in the studies reviewed could be due to sampling bias rather than actual increase in C. In studies which found minimum tillage to sequester C, soils were sampled to a depth of only 30 cm, or less. Crop roots often extend deeper than 30 cm, and roots contain a proportion of C too. In the studies which sampled deeper than 30 cm, minimum tillage demonstrated no consistent sequestration of C, but instead a difference in the distribution of C, with higher concentration near the surface in minimum tillage and higher concentrations in the deeper layers under conventional tillage. Similarly, Palm *et al.* (2014) commented that conservation tillage systems are likely to increase C at near-surface (<10cm) only. Despite their findings, Baker *et al*. (2007) note that there are many reasons to continue with conservation tillage methods. The reasons include; reduced erosion, reduced production costs, and a decrease in the use of fossil fuels, which is often very important to farmers. Similarly, Bhogal *et al*. (2007) found that there is limited scope for additional C storage and accumulation from reduced tillage practices, over and above present day normal farming practices. However, that is not to say a reduced tillage system is worthless, but that the emphasis should be placed upon maintaining a healthy soil and protection of existing SOC levels, rather than C storage for climate change mitigation (Bhogal *et al*., 2007).

Direct Drilling

Direct drilling (zero tillage) is a conservation tillage practice whereby the seed is drilled directly into the soil, in the stubble of the previous crop, without any prior soil cultivation, causing minimal soil disturbance (Polwson *et al*., 2012). It is a practice which is most common in dry regions such as the Americas and Australia; therefore UK and Northern Europe based research on this technique and its ability to increase SOC is limited (Powlson *et al*., 2012). A limiting factor contributing to the lack of uptake of zero-till in the UK (7% of applicable land was under zero-tillage in 2005) when compared to the Americas and Australia, is that it is likely to cause a build-up of grass weeds, crop disease problems and soil compaction, all of which decrease crop yields. These issues appear to be more prevalent in a moister climate, such as that found in the UK and elsewhere in Northern Europe (Powlson *et al*., 2012). However, direct drilling is still utilised by some UK farmers. As the soil surface is not disturbed, OM accumulates in the top layers from the remains of crops residues (Giobergia *et al*., 2013). The accumulated OM increases the availability of nutrients available for the crops and they are released into the rhizosphere at a faster rate than with conventionally tilled soils. As a result, soils under direct drilling tend to have a higher fertility rate (Ferandez *et al*., 2007).

Soils that are directly drilled continuously may create stratified soil layers, with C and other nutrients unequally distributed throughout the soil profile. This is likely a result of the absence of mixing mechanisms and the natural composition of the soil (Ferandez *et al*., 2007). In cooler, moister climates, away from dry regions where direct drilling is more prominent, Munkhom *et al*. (2003) found that soil compaction is more of an issue.

In these situations, it is likely, that periodic soil loosening will be required (Munkholm *et al*., 2003). This may however, displace the accumulated OM and the soil disturbance could result in the release of CO_2 into the atmosphere, losing the benefit of such a system.

Controlled traffic farming

Controlled Traffic Farming (CTF) is where all tillage operations are performed in fixed paths, so that re-compaction of soil by traffic does not occur outside the selected paths. The compacted soil in the tram lines has little effect on crop yields (Foth, 1990). CTF permanently separates crop areas and farm traffic, with permanent lanes for machinery and crop growth on non-trafficked, wide beds (Qingjie *et al*., 2009; Vermeulen and Mosquere, 2009). The main objective of CTF is to provide optimal soil conditions for crop growth and tyre traction (Vermeulen and Mosquere, 2009). Optimal soil conditions are achieved through reducing soil compaction, which in turn improves nutrient efficiency, decreases nitrogen leaching and minimises soil disturbances (Vermeulen and Mosquere, 2009). Similar to reduced tillage, the benefits to SOC comes from a reduction in soil disturbances and reduced erosion. Currently, it is not a wide spread practice due to the initial cost involved in modifying machinery to fit the permanent traffic lanes. The company Unilever started a CTF project in 2004 at their Colworth estate near Bedford, England. Results from the project have been encouraging with the project now forming part of their 'Encouraging Biodiversity at Colworth Estate' initiative (Unilvever, 2010).

2.5.2 Organic Matter Amendments

The application of OM materials is an important mechanism by which SOC levels can be increased, as well as improving soil fertility. OM should be applied to soils with low SOC to sequester more C. This practice, combined with other methods which promote SOC, may help to maximise the soil C sequestration at regional scale (Tan *et al*., 2014). The application of OM must be in conjunction with other appropriate methods, otherwise, the material may be readily decomposed and released as CO_2 if disturbed. The application of OM is of particular importance in arable systems, where incorporating FYM or legume-based leys, create higher OM levels than those arable systems which do not (Stoate *et al*., 2001).

The addition of OM has other benefits, beside that of increased SOC levels. These include improved water holding capacity porosity, infiltration capacity, decreased bulk density and surface crusting (Haynes and Naidu, 1998), as well as improved availability of nutrients. Due to soil variability, and climatic conditions, the amount of OM that can accumulate per tonne of OM applied can vary greatly, as it largely depends upon decomposition rates. Therefore, no simple relationship exists between C application rates and net increases in SOC levels, as it needs to be assessed at the local scale (Haynes and Naidu, 1998). It has also been shown that the increase in SOC per tonne of OM added is greater in composted material compared to fresh material. This is because decomposition has already occurred in the manures, meaning that the easily decomposable OM has already gone. When applied to the soil, the composted material is more resistant to further breakdown than the fresh material (Haynes and Naidu, 1998).

OM amendments can take the form of several types of material. These include FYM, sewage sludge, crop residues and green composts, amongst others. FYM is often a readily available material in many regions, and available in large quantities, with an estimated 90 Mt produced in the UK (Powlson *et al*., 2012). However, the majority of this material is already applied to the soil, meaning that the potential to increase the SOC stock of the UK as a whole is limited as the material is already largely being used (Powlson *et al*., 2012). It is also likely that FYM being applied to grasslands, already high in SOC, will decompose to CO_2 leaving little residue in the soil (Powlson *et at*., 2012). This could also potentially transform a soil from a C sink to C source. Ideally FYM applied to grasslands could be re-directed to areas of the country with low numbers of livestock farmers and instead, applied to arable-only systems. As Freibauer *et al*. (2004) stated, the lack of OM available is often a limiting factor in the potential for C sequestration.

Sewage sludge and biosolids are both waste products from the water industry. Sewage sludge is a semi-solid material produced as by-product from the treatment of domestic sewage water. Biosolids are formed from sewage sludge, having undergone further recycling processes. Both materials are nutrient rich and can be applied to non-combinable arable crops. In 1991, about 60% of sewage sludge produced in the UK was applied to agricultural soils, amounting to around 111 Mt annually (Chander and Brooks, 1991). Sewage sludge contains plant nutrients, particularly N and Phosphorus (P), as well as OM (Chander and Brooks, 1991). In comparison, in 2010 it was estimated that the UK produced 1.4 Mt of biosolids, of which 77% (1 Mt) was applied to agricultural land (Powlson *et al*., 2012). Again, with such large amounts of the materials already being applied to agricultural land, there is perhaps limited scope to improve SOC levels via this method.

Another waste material which can be applied to agricultural land is green manure. Green manure is composed of composting grass cuttings, tree prunings ands leaves from gardens and parks (Powlson *et al*., 2012). Green manure has increased over recent years due to local authorities seeking to minimise the amount of organic material sent to land-fill sites. For example, in 2003-2004 it was estimated that 480,000 t of green manure was applied to agricultural land in the UK. This amount rose to 1.3 Mt in 2007-2008 (Powlson *et al*., 2012). This is an area where there is scope to improve SOC levels in UK soils. As more waste is recycled in UK households, the amount of green manure which can be utilised will rise, as well as an increase in the uptake by farmers.

The retention of crop residues is essential in increasing or maintaining soil C. In their study, Zhao *et al*. (2009) found that the incorporation of crop residues positively impacted soil respiration aggregation, porosity, microbial C, bulk-density and soil water retention. In terms of SOC, the authors found that the incorporation of crop residues had the same impact as applying FYM. This may provide an alternative to those farms which lack access to livestock waste. It is estimated that annual straw (derived from crop residue) production in England and Wales is at 11.4 Mt, of which 50 % is incorporated back into the soil (Powlson *et al*., 2012). The remainder of this is already used from animal bedding and subsequently in the production of FYM, and therefore returned to the soil at a later stage (Powlson *et al*., 2012). There is therefore, little scope for using this material to improve SOC levels nationally. However, factors that increase crop yields will ultimately increase the amount of residue available and potential soil C storage (Palm *et al*., 2014). Soil fertility management is the most important factor to increase residues and soil C storage (Palm *et al*., 2014).

2.5.3 Organic Farming Systems

Organic farming is a specific farming system which encompasses a set of practices. It is thought that organic farming could increase soil C or at least reduce C losses. Crop production in organic farming relies largely on closed nutrient cycles by returning plant residues and manure from livestock back to the land and/or by integrating perennial plants, into the system (Gattinger *et al.,* 2012).

Gattinger *et al.* (2012) conducted a study into the potential of organic farming to sequester soil C. The study compared datasets from 74 studies of organic versus non-organic farming systems. Meta-analysis of SOC levels, concentrations and C sequestration rates were conducted on the data sets from the chosen studies. The results indicated that all measures of SOC and C were higher in organically managed soils compared with non-organic managed soils. However, when OM inputs, clay concentrations of the soil and climatic differences were considered, significant results were found for SOC concentrations and stocks but not for C sequestration. It was found that these factors influenced the differences between SOC concentrations and stocks.

Organic farming practices led to SOC levels in the top 20 cm of soil, over a period of 14 years, that are 3.50±0.08 mg of C per ha higher in organic than in nonorganic systems (Gattinger *et al.,* 2012). The authors note that the difference in SOC concentrations, C stocks and C sequestration, between organic and non-organic farming systems, does not indicate whether the change is due to a net C gain, due to the conversion from conventional to organic, or whether it reflects a reduced C loss compared to non-organic farming (Gattinger *et al.,* 2012).

The Soil Association conducted their own review into the relationship between organic farming and soil C (Soil Association, 2009). The data was gathered from a review of 39 comparative studies of organic and non-organic farming from around the world. They found that on average, organic farming in Northern Europe produced 28% higher soil C levels than non-organic farming. The Soil Association look towards several organic practices for this observed difference. These include:

- A dedicated soil fertility building stage in crop production with 1 to 4 years of grass and legumes in a rotation to build SOM
- A reliance upon the activity of soil organisms to provide nutrients from SOM
- Growing legumes to fix N in organic form instead of using inorganic and water soluble fertilisers
- Frequently adding OM from farmyard manure or ploughing in 'green manure' crops.

However, the Soil Association (2009) do stress that it appears the basic approach of organic farming is the most important for soil C benefits, as different locations around the world use various organic methods but still maintain higher soil C levels compared to conventional farming. They also claim that an increase in the uptake of organic farming would substantially reduce the emission of GHGs, including CO_2 (Soil Association, 2009). A potential criticism of the Soil Association study is that it drew its evidence from previously conducted research; with the 39 comparative studies coming from a number of different countries. Therefore, the review was conducted on a large scale covering many different environments and climates. Having only 39 studies on such a scale will not accurately reflect the true picture of organic farming. The report was also not peer-reviewed, and given the ethos of the Soil Association[6], it cannot be considered unbiased in its interpretation.

In comparison with the Soil Association study, an earlier study by Gosling and Shepherd (2002) found no significant difference in levels of SOM between soil managed organically and those managed conventionally. The authors suggest several reasons for their observed findings. Firstly that many experiments looking at the effects of manure on soil use unrealistically high application rates and often compare manure application with zero application, where in fact many conventional farms do add manure. Secondly, the influence of grass leys, often grown as part of the rotation in organic farming, may be overestimated. This is because when grass leys are cut, large amounts of OM are removed from the system. Also when leys are incorporated into the system, OM that is added may break down very rapidly, having little long term effect on SOM levels. Thirdly, organic farming produces lower yields therefore reducing the amount of crop residues that are returned to the soil system (Gosling and Shepherd, 2002). Gosling and Shepherd (2002) argue that the balance of C inputs and outputs are more important for SOM than whether the soil is managed organically or not. Gosling and Shepherd (2002) reached the conclusion that it would appear only when conversion to organic production leads to a significant increase in manure use and OM input, compensating for reduced crop residue inputs, will SOM levels increase

2.6 Conclusion

The pursuit of maintaining and improving SOC levels has numerous positive consequences. Whilst the soil C pool is not the largest, it is potentially the most responsive to modification, even small changes, influencing atmospheric CO_2 levels. This is why there has been growing interest in the potential of soils to be used a C sink in order to mitigate rising atmospheric CO_2 levels. Agricultural soil has a huge potential to play in this quest with an estimated global capacity for C sequestration at a 20 to 30 Pg of C over the next 50 to 100 years (Paustian *et al*., 2000).

It is widely accepted that high SOC levels improve soil fertility, soil structure, water holding capacity , soil biodiversity and associated ecosystem services (Lal, 2004a; Lal, 2004b; Janzen, 2006; Trumbore and Czimczik; 2008). Increasing soil C stocks can reduce the vulnerability of soil to climate change, potentially improving sustainable farming as well as reducing atmospheric CO_2 levels creating a win-win-win scenario (Smith *et al*., 2008). However, using soil C sequestration as a means to mitigate against climate change has been described as ‘stop-gap’ measure (Janzen, 2006).

[6] The Soil Association is the UK’s leading membership charity who campaign for organic farming and food.

Employing C sequestration as a climate change mitigation option can also be a risky option. Soil can become saturated, meaning that CO_2 from the atmosphere is only stored in the soil until it reaches saturation acting as a limited store. The second issue is that SOC is not a permanent store, and the soil will only remain a C store for as long at the SOC friendly practices are being employed.

Changes in SOC levels are largely caused by changes in land use and poor land management. In agricultural soils the main loss of C from soils is caused by cultivation and losses from topsoil through erosion, causing release of CO_2 from OM mineralisation (Dawson and Smith, 2007). Studies at the UK level by Ostle *et al*. (2009) and Bellamy *et al*., (2005) highlighted the estimated changes in UK SOC levels, which are likely to be a result of change of land use. In order to maintain and improve SOC levels in agricultural soil, best practices managements need to be applied. Management practices which promote increases in SOC are looked at in detail in this review, including; conservation tillage routine, organic farming and effective OM amendments. All three have their merits as well as negative components, and it is recommended that practices aimed at maintaining or improving SOC levels are applied based on local conditions and situations.

Approaches aimed at sequestering C need to be considered within a political framework. An increasing demand for limited land resources, and increasing costs of inputs, means that soil C sequestration cannot be viewed in isolation from other environmental and social needs (Smith, 2008). If policy makers wish to increase the global and national SOC levels, effective policy measures are required that not only work for the environment but also for the farmers who are employing them. Whilst there is a vast amount of research of the effect on SOC levels of various environments and management strategies, there is little in comparison in regards the impact that environmental policies have. Chapter 3 will investigate the associated policies and their potential impact on the environment regarding SOC levels in an attempt to address this knowledge gap. Many of the approaches mentioned in this review will be highlighted again in Chapter 3, as they are presented within an agri-environmental framework. As with this review, Chapter 3 will present those methods promoted by policy and voluntary schemes, many of which are the same as those highlighted by the scientific community as being beneficial in the improvement of SOC or SOM.

To achieve and address the original research problem highlighted in sections 1.5 and 1.7, the issue of SOC levels in agriculture and the maintenance or improvement therefore of, must not be viewed in isolation. The purpose of this review was to address objective 1a; to synthesise best knowledge of the impact of different farming practices on SOC levels. This was achieved whilst providing a background of the understanding of SOC and its place within the global aim to mitigate against climate change. The outcomes from this review will feed into Chapter 4, the Methodology, where knowledge of certain practices will be applied to the data collection.

CHAPTER 3: SOIL ORGANIC CARBON: POLICY, REGULATION AND ADVICE

The aim of this chapter is to present soil organic carbon (SOC) as a policy issue, tracing its emergence within agri-environmental policy and farming advice at the global, European and national level. Concern over the environment, natural resources and climate change has increased dramatically over recent decades, resulting in an increased awareness of SOC and its potential mitigation[7] role in acting as a carbon (C) sink to alleviate anthropogenic driven climate change. As previously mentioned, SOC cannot be addressed in isolation. To achieve the best outcome for maintaining and improving SOC levels, it must be viewed as a policy issue in agriculture, with a review of the advisory pathways in place, and the consideration of how farmers utilise this advice. The aim of this chapter is therefore to address objective 2a;

Objective 2a: *Identify and evaluate current information, policy and farm management advice regarding SOC, tracing the agricultural advisory pathway.*

This review will begin by tracing the emergence of SOC as a policy issue at the global, European and National level, highlighting the key players and the significant agreements, legislation and policy. At the national scale, as this chapter will demonstrate, SOC can be potentially influenced by agri-environmental policy which is largely driven by support mechanisms associated with the Common Agricultural Policy (CAP) of the European Union (EU). Therefore, the EU, CAP and agri-environmental policy mechanisms are significant in the following chapter.

The review will also present literature regarding how farmers respond to this policy and legislation, and take on-board advice regarding SOC at the farm level. Agri-environmental policy has, over the years, attracted considerable scholarship as it has challenged the traditional assumptions of the role of agriculture within contemporary society (Buller et al., 2000) , as well as its general dependency on the voluntary adherence of participating farmers. Consequently, substantial literature has grown up around issues of farmer participation and engagement in these voluntary schemes (Klerkx and Procter, 2013). This literature will be reviewed in the latter section of this chapter.

[7] Mitigation refers to the action of reducing the probability, severity, seriousness or painfulness of some action, occurrence or consequence (Oxford Dictionaries, 2015a).

3.1 Introduction

Whilst SOC has yet to be at the forefront of any policy, there are several key players at the global scale who promote issues interrelated to SOC. Organisations under the United Nations (UN) have contributed a vast amount of information into the global community on SOC. A review of the organisations and reports from the UN will be examined in this chapter. These include the Brundtland Report, the Rio Summits, the Intergovernmental Panel on Climate Change (IPCC), and the Food and Agricultural Organisation (FAO). The materialisation of summits and treaties and the activities of these organisations will be presented and discussed in relation to SOC and how it has developed at the international scale.

At the European level, it is the European Union (EU) that draws up much of policy that potentially impacts SOC. The Common Agricultural Policy (CAP) is the agricultural policy of the EU and therefore impacts significantly upon the management of agricultural land. The CAP has been reformed several times since its inception in 1962, reflecting the changing agricultural concerns of the EU over this time. In the UK, agri-environmental policy is regionally devolved; hence the focus of this thesis will be on the agri-environmental policy environment of England. To date, agri-environmental policies and Agri-Environmental Schemes (AESs) in England have been dominated by issues of landscape, biodiversity and of agricultural pollution (for example, run off and nitrogen (N) levels in water). The CAP and national approaches in England will be presented and analysed in terms of the impact on SOC and its promotion.

Having discussed SOC and policy at the global, European and national scale, the final section of the chapter will consider how farmers and farm advisors (FAs) respond to and employ policy instruments and advisory channels, and the degree to which these actors perceive SOC to be a significant issue. Both farmers and FAs are key participants or actors in determining the effect agriculture has upon the wider landscape. Due to the growing concern over the environment, natural resources and climate change, farmers are having greater responsibility placed upon them in terms of how they practice agriculture. They are also having to take greater responsibility for both the on and off farm impacts their practices have on the wider environment. FAs (including agronomists, AESs representatives and consultants) are quite often the link between legislation and farmers, translating the policy into practical outcomes. Farming is very knowledge intensive, making it essential that FAs and the advisory systems are able to support farmers in making decisions and be effective in solving their problems (Klerkx and Proctor, 2013).

The chapter will begin at the broad scale, narrowing down to the individual farm level as it demonstrates the linkage between larger political and scientific movements, and the practical decisions made on the ground. The absence and gradual emergence of SOC in legislation, policy and advice will be traced at the global, national and individual scale.

3.2 The Emergence of Soil Organic Carbon as an Issue at the Global Scale

The global awareness of SOC as an environmental concern, coincides with, and is part of, the emergence of 'sustainable development' at the global scale. The Brundtland Report, published in 1987 by the Brundtland Commission, established by the UN, was the first to use and define the term 'sustainable development':

> *'Development which meets the needs of the present without compromising the ability of future generations to meet their own needs' (UN, 1987).*

Figure 3.1 presents a timeline of summits, conventions and publications that have been key in the global environment and the subsequent emergence of SOC. As figure 3.1 demonstrates, the mainstream global movement on environmental concern began in 1987. Since this time, issues surrounding the environment including climate change, CO_2 emissions and resource protection have become globalised, crossing political and geographical boundaries. This in part, has been caused by the recognition that environmental problems transcend national boundaries, leading to collaboration between governments and non-governmental organisations (NGOs), as the following section demonstrates (Yang and Percival, 2009). Corporate responses to climate change have also improved since the late 1980's with multinationals influencing the development of a large amount of environmental legislation (Kolk *et al*., 2008; Yang and Percival, 2009). Whilst the role of multinationals in managing and influencing C in terms of emissions and sequestration are an important consideration at the global scale, they fall beyond the remit of this thesis, which is concerned primarily with the on-farm influences concerning SOC.

Nevertheless, despite the globalisation of environmental concern since the late 1980's, many consider the progress so far to be insufficient in terms of global impacts, particularly in regards to climate change (Zaccai, 2012). Policy responses with respect to soil remain under-developed, and are considered not to be meeting policy objectives (Zaccai, 2012). As the following section will demonstrate, whilst there has been an emergence in global treaties and an increase in concern over the environment, the measurable impact of these has been mixed.

There are a number of organisations and treaties at the global scale concerning the environment, natural resources, climate and the well-being of those who manage the land. The organisations and treaties examined in the following section of this review are all devolved from the UN, all of whom have produced reports and/or have conducted research into environmental concerns at the global scale.

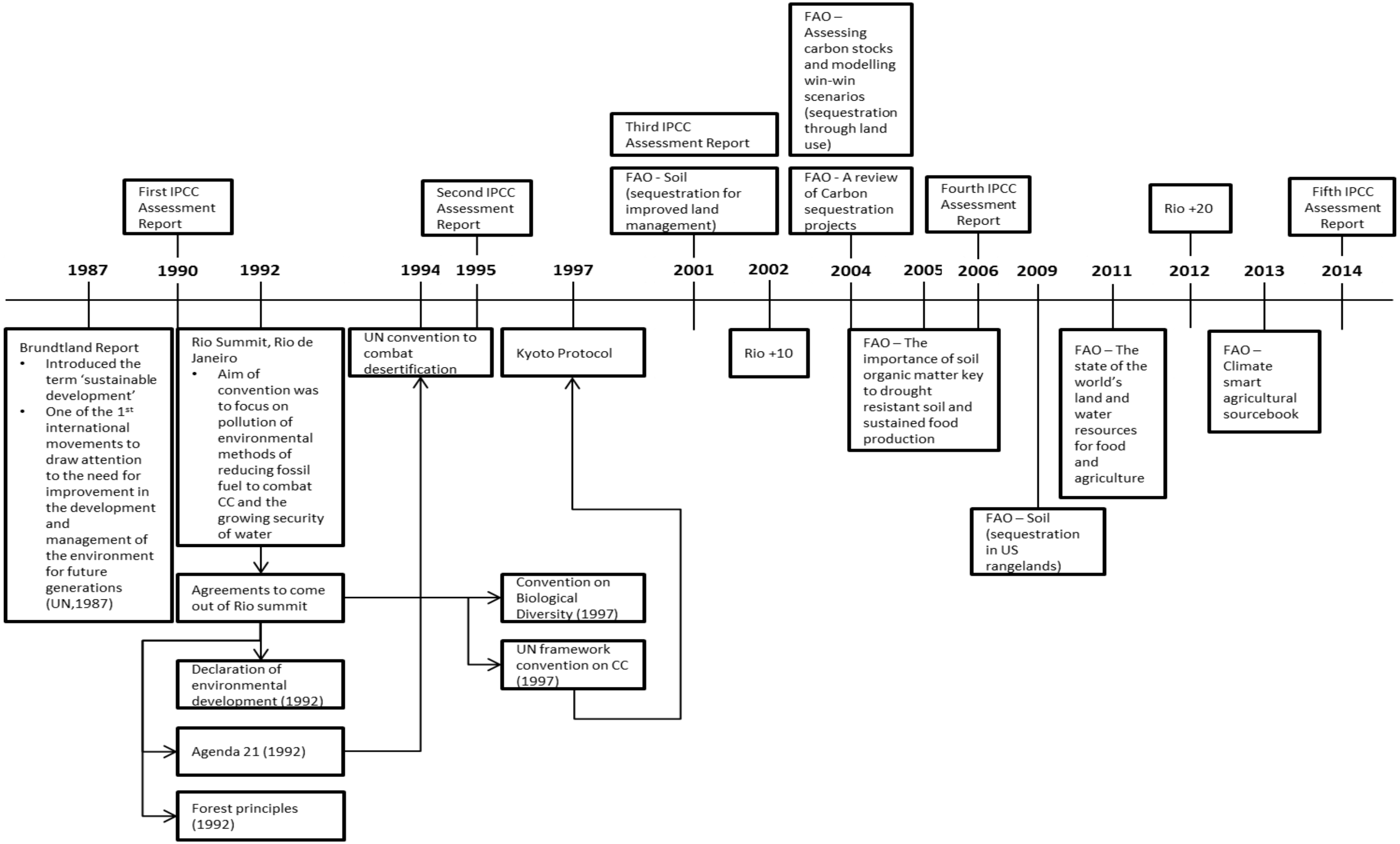


Figure 3.1: A timeline depicting the reports, publications, treaties and summits of the UN concerning the global environment with the potential to impact global policy on SOC, from 1987 to 2013

3.2.1 The Brundtland Report

The purpose of the Brundtland Report was to address the issue of poverty in the developing world by paving the way for economic growth based on policies, which sustain and expand environmental resources (UN, 1987). Whilst not directly mentioning SOC or soil C sequestration, the importance of soil was highlighted, paving the way for future research. Being the first report of its kind to bring the concern of the global environment to an international level, it paved the way for future debates and actions, as predicted by Burton (1987) in his review of the report. The report sparked a succession of treaties and summits concerned with the global environment and climate. It also internationalised environmental policy and made the environment a global issue, crossing political and geographical boundaries (Sneddon *et al*., 2006)

3.2.2 Rio Summits

The Rio summit, also known as the United Nations Conference on Environment and Development (UNCED) (UN, 1992a), was held in Rio de Janeiro from 3rd to 14th June 1992, five years after the Brundtland Report. Since the first event, a Summit has occurred every 10 years; 2002 in Johannesburg, South Africa and 2012 in Rio de Janeiro. The Agenda 21, the United Nations Framework Convention on Climate Change (UNFCCC), United Nations Convention to Combat Desertification (UNCCD) and the Kyoto Protocol are the more pertinent international initiatives for SOC to have emerged from the Rio Summits. Table 3.1 summarises their specific contribution.

Table 3.1: A summary of the treaties and conventions spawned from the Rio Summits which have a potential impact on SOC and related subjects.

Treaty/ Action Plan	**Purpose**	**Mention of Soil, SOC, C and Sequestration.**	**The Emergence of SOC**
Agenda 21 (written in 1992)	A voluntary action plan on sustainable development.	Soil is mentioned throughout regarding soil conservation[8], fertility, pollution, and erosion (UN, 1992b). Soil as a carbon (C) sink is not directly mentioned, however, the following statement comes under section 11.15 (Chapter on Combating Deforestation) of the agreement with regards to actions that should be taken at the international level to support national efforts of combating deforestation: *'b. Coordinating regional and sub-regional research on carbon sequestration, air pollution and other environmental issues*'. Both oceans and forests are mentioned as potential C reserves, but soil is not directly linked to *C* sequestration, and as the above quote demonstrates, further research on C sequestration was recommended (UN, 1992b).	Whilst it is a step forward following the Brundtland report, with greater emphasis on C sequestration, it remains inapplicable to the UK environment.
UNFCC (came into force in 1994)	A treaty with the objective to 'stabilise greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system' (UNFCCC, 2013a).	Soils are once again mentioned as a C sink, as well as a C source from agriculture practices (UNFCCC, 2006).	Little development from Agenda 21, but continuing focus on soil as a C sink and the agriculture as a C source contributing to increases in GHG emissions. SOC is not directly mentioned.
UNCCD (Entered into force in 1996)	National action programmes to combat desertification and mitigate the effects of drought (UNEP, 2013).	Original agreement states that affected countries should promote the conservation of soil resources, as well as improving information of soil resources.	The UNCCD focuses on soil conservation rather than the use of soil as a C sink (UN, 1994). SOC is not mentioned either which is noteworthy as good SOC management can play a large part in soil conservation.
Kyoto Protocol (Adopted on 11th December 1997 and entered into force on the 16th February 2005).	An international agreement developed from the UNFCC, and sets binding obligations on industrialised countries to reduce emissions of GHG (UNFCCC, 2013b)	Agricultural soil is mentioned as a source of CO_2 rather than a sink, although forests are mentioned as C sinks (UN, 1998).	Out of the agreements to come from the Rio summits, the Kyoto protocol is perhaps the most applicable for the UK. However, it only mentions soil as a source or a sink of C in relation to atmospheric concentrations. Whilst related, SOC is not directly mentioned or addressed.

[8] Soil conservation refers to the combination of factors used to protect soil from degradation (Matthews *et al.*, 2003).

The impact of the Rio summits has been mixed. Whilst the many agreements and action plans developed from Rio Summits were, and are, a positive sign that governments from around the world are taking an interest in the environment and climate change, the summits' success has been variable in terms of creating positive changes and implementing greater sustainability (see Drexhage and Murphy, 2010; Tollefson and Gilbert, 2012). This is partly due to the lack of quality data to quantify the measures undertaken (Hsu *et al*., 2013). The Kyoto Protocol (table 3.1), which came into force in early 2005, has also had its criticisms, similar to that of the Rio Summits. The original aim of the Kyoto Protocol was to produce a global political consensus over climate change, but the economic and political means to meet this challenge have been questioned (Kythreotis, 2012). Most poignantly though, across these various summits, documents and initiatives, soil was mostly cited as a resource which needed to be conserved in order to increase fertility and prevent erosion, or as a source of CO_2 from agricultural practices, rather than its potential as a C sink despite the growing climate change agenda globally.

3.2.3 The Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is a scientific body established in 1988 by the World Meteorological Organisation and the United Nations Environment Programme (UNEP). The specific aims of the IPCC are to assess scientific information relevant to:

- Human-induced climate change
- The impacts of human-induced climate change
- Options for adaptation[9] and mitigation.

Therefore the IPCC's focus has been on climate change, and so soil and SOC do not feature heavily in the five comprehensive climate change science assessment reports published in 1990, 1995, 2001, 2007 and 2014. Nevertheless, soil and increasingly SOC do feature in the various assessment sub-categories. Table 3.2 highlights the emergence of SOC within the assessments.

[9] Adaptation refers to the process or action of adapting or being adapted to something (Matthews *et al*., 2003).

Table 3.2: A summary of the mention of soil, SOC, C and sequestration within all five IPCC Assessment Reports.

IPCC Report	**Mention of Soil, SOC, C and Sequestration.**	**Emergence of SOC**
IPCC 1st Assessment (1990)	Soil referred to largely with respect to changes in soil moisture and the impact on ecosystems (IPCC, 1990a). Soil erosion, largely caused by increased run-off and its impacts were discussed. Impacts largely found to be an increase in soil erosion and changes in soil moisture (IPCC, 1990a). Under short-term actions to limit net CO_2 emissions from agriculture, cover crops and perennial crops were suggested as a way to increase the C storage in both plants (as above ground biomass) and soil (IPCC, 1990b). Loss of SOM was recognised as a significant contributor of atmospheric C (IPCC, 1990b). The use of min-tillage was suggested as a way to increase SOM levels (IPCC, 1990b).	SOM was highlighted as an issue and recognised as a contributor to CO_2 levels, as well as the recommendation of the use of min-tillage practices to increase SOM levels. This is a key step forward in terms of the emergence of SOC as a recognised issue.
IPCC 2nd Assessment (1995)	Changes in soil moisture continued to be mentioned in the context of climate change (IPCC, 1995). Soil C sequestration in forestry was mentioned as a mechanisms to lower CO_2 emissions (IPCC, 1995)	The emergence of SOC is halted as the same themes are discussed as in the first report with the addition of C sequestration in forestry.
IPCC 3rd Assessment (2001)	Soil moisture continues to be mentioned (IPCC, 2001). Greater emphasis on the impacts soil could face if climate were to change (IPCC, 2001). Alterations in decomposition rates were highlighted (SOM) (IPCC, 2001).	Focus changes slightly to review how soil characteristics could change in the face of climate change. This included the decomposition rates of OM, which in turn will impact SOC elves. However, SOC has still not been mentioned directly.
IPCC 4th Assessment (2007)	C trading and C tax were introduced as possible mechanism to reduce CO_2 emissions (IPCC, 2007). Bio-energy and the practice of planting crops for biofuels were mentioned as practices which could retain soil C, as well as restoring degraded land and improving water run-off (IPCC, 2007).	Economic measures to mitigate against climate change emerged, again, related to SOC, however, SOC has still not been directly mentioned.
IPCC 5th Assessment (2013)	SOC is recognised as a contributor to CO_2 emissions resulting from land use change and the associated soil disturbance that causes C to be lost from the soil (Stocker *et al*., 2013). Increasing the size of existing C pools via C sequestration was highlighted as a climate change mitigator (IPCC, 2013). C pricing highlighted as an option for climate change mitigation (IPCC, 2013).	SOC is recognised as a source of CO_2 emissions following land use change. Increasing C sequestration was also mentioned.

The IPCC reports have increased in volume and technical and scientific understanding since the first assessment report in 1990. C as a commodity that could be traded, or have a value applied to, has increased in prominence throughout the reports. This is particularly true in the case of the fourth Assessment published in 2007; two years after the Kyoto Protocol came into effect. It suggested limits on the amount of GHG emissions countries could emit (UNFCCC, 2013b). By the fifth report, soil has shifted from being seen as source of C and atmospheric CO_2, to a material that could also act as a sink to mitigate against climate change. This indicates that SOC has risen in prominence in terms of scientific understanding and recognition; however, this is yet to be fully mirrored within policy measures.

3.2.4 The Food and Agriculture Organisation of the United Nations

Finally, in this review of the emergence of SOC at the global scale of environmental policy, is the impact of the Food and Agriculture Organisation (FAO) of the UN. The FAO is a UN organisation that leads international efforts to defeat hunger, serving both developed and developing nations. The FAO regularly posts a number of bulletins, publications and reviews on, or related to soil, C sequestration and climate change on their website. The FAO is a major source of information and advice on soil and SOC, unlike the other bodies reviewed above, and can be considered as a global resource of soil information. The following eight key publications produced by the FAO have reference to soil and C;

- Soil Carbon Sequestration for Improved Land Management (2001) (FAO, 2001)
- Assessing Carbon Stocks and Modelling Win-Win Scenarios of Carbon Sequestration through Land Use (2004) (Ponce-Hernandez, 2004)
- A Review of Carbon Sequestration Projects (2004) (FAO, 2004)
- Soil Carbon Sequestration in U.S Rangelands (2009) (Flynn *et al*., 2009)
- The State of the World’s Land and Water Resources for Food and Agriculture (2011) (FAO, 2011a)
- Climate Smart Agriculture Sourcebook (2013) (FAO, 2013)

A full review of these publications can be found in Appendix I. The FAO hold a vast amount of information on soil and soil C, ranging from policy, practical management, to soil science. Much of this information is readily available online and, as can be seen from the dates above, is recent, demonstrating that soil C has become of increasing interest in recent years. This is in stark contrast to the previous UN organisations and reports reviewed here, which have only recently begun to recognise soil and soil C as a policy issue. Improved land management of SOC, SOM and soil C sequestration are presented by many FAO publications as something that could be of benefit in developing countries, particularly in dryland environments. However, there is still very little information available that is more specific to environments or agricultural systems found in Europe, and much of the developed world. At first glance, this might appear problematic. Yet most countries in the Western world can afford, and do, produce their own research into agricultural systems outside of the FAO. Developing countries, on the other hand, may not have the resources to conduct or publish their own research. In addition, many have harsh, dry climates, and a greater amount of degraded land which could be utilised and improved. Such improvement would not only benefit local livelihoods but may also have an impact on the global environment too.

3.2.5 Review of the Emergence of Soil Organic Carbon as a Global Issue

The treaties, summits, reports and agreements related to the UN map the development in global environmental awareness since the Brundtland report in 1987. The term sustainable development is now in common usage and has marked a change in environmental management approaches across the world. However, sustainable development does not necessarily, nor explicitly implicate SOC management directly but does generally cover the issue of soil degradation and desertification, both of which are essentially dryland issues.

The fact that SOC was not mentioned explicitly in the raft of reports that emerged in the late 1980's to late 1990's demonstrates that at the time it was not high on the agenda of environmental policy. Agenda 21 introduced the idea of C sinks but even this did not directly link to soil and soil management. Both Agenda 21 and UNCCD, both formed in 1994, focus on issues found in dryland environments such as desertification, soil conservation, fertility, pollution and erosion, but critically SOC remained omitted. The UNFCCC, formed in 1997, identified soil as both a source and a sink of C, whilst the Kyoto Protocol critically identified agricultural soil as source of CO_2 and therefore C. Between 1994 and 1997, soil became at last recognised as a source and a sink of C, highlighting the first major jump forward for SOC being seen as a significant policy issue, since the Brundtland report in 1987. Whilst this shows development in the emergence of SOC as a policy issue, the focus has nevertheless remained largely on dryland environments and therefore not directly applicable to the UK. Even with this gradual growth in references and policy initiatives with respect to SOC and C sequestration, it is not easy to identify the real impact on agricultural land management. Research is clearly very much needed at the level of both the sub-national policy environment and at the level of the farm.

The IPCC reports have had a huge impact on global policy and awareness with regards to climate change understanding, mitigation and projections. Soil moisture was a reoccurring issue throughout all five reports with respect as to how it has or may alter in response to a changing climate. From the first report in 1990, to the most recent in 2013, soil has shifted from being seen as source of C and atmospheric CO_2 to a material that could act as a sink as well with strong evidence to suggest that it could have large impact in reducing CO_2 emissions from agriculture through good management. Unlike many treaties and reports, the IPCC has a truly global perspective, reporting on all areas and environments, and not just dryland environments in developing countries. This global reach has led to a large increase in the global awareness of the environmental issues, even developing a shared desire to solve them.

Lastly, the FAO, who in recent years have published several reports on soil and C, although soil and SOM have been a reoccurring topic in FAO publications since the mid-1960s. It is encouraging that such issues have come more to the forefront of the global conscience. From analysing the literature from these organisations, it is possible to see that soil as a C sink has only become popular relatively recently (past 10 years or so). There is, therefore, still plenty of research remaining to be conducted in regards the global soil C sink and its potential to mitigate against climate change, and its role in sustainable agriculture, as well as to extend research into temperate environments.

Even where targets or objectives are set for the management of soil and soil C there is a lack of data for the effect of those targets globally, meaning that it is difficult to ensure compliance or measure the effect of the objective. As can be seen from the discussion above, the addressing of SOC at a global level is difficult as different countries, political systems and climates will have their own particular views and special conditions, as has been highlighted with climate change. The final concern over the policy towards SOC and C sequestration is that the policies and schemes created are prone to the development of bureaucracy and process at the expense of measureable impacts to SOC.

3.3 European Policy and Strategy on Soil Organic Carbon

Having presented the emergence of SOC as an issue at the global scale, the following section will now review SOC and its portrayal at the European level, via the European Union (EU). There are several reasons why the EU and its policies and strategies related to SOC are being reviewed here. Firstly, the EU developed and proposed the Soil Framework Directive in 2006, which will be examined below. Secondly, agricultural policy in all the Member States of the EU is largely integrated into the EU's Common Agricultural Policy (CAP). The CAP operates as the *de facto* national policy framework in all Member States including the UK and its devolved administrations. All local and national regulatory and financially supporting initiatives regarding agriculture and soil management are required to fit into the broad regulatory framework of the CAP with individual farm management decisions also operating within this framework. Thirdly, specific elements of the two pillars of the CAP which have the potential to impact SOC. For example, the 'first pillar' outlines cross compliance and certain elements of the 'second pillar', which provide financial support for the provision of public goods through agricultural activities, facilitate the positive management of SOC at the farm scale through voluntary actions. It is these actions under the agri-environmental schemes (AESs) of the CAP that offer the potential for improved SOC levels. As they are voluntary, such measures require the additional role of advisors to encourage and assist in their uptake. The following section of this chapter will outline the mechanisms presented by the EU's regulatory approach and CAP that impact SOC levels, followed by the national measures undertaken within this framework.

3.3.1 The Common Agricultural Policy

The Common Agricultural Policy (CAP) is the EU's agricultural policy for which all Member States must comply. British agriculture is entirely subsumed into the CAP in terms of funding and regulation, which is an important consideration as national approaches to agriculture and SOC will be discussed further on in the review.

The CAP articulates with the issue of SOC in three important ways. Firstly, successive CAP policies and incentives in support of productivity and increased yields in EU agriculture, since it began in 1962 (EC, 2013a), have undoubtedly had significant consequences for SOC levels in many European agricultural soils (figure 3.2 presents these reforms). However, there is inefficient firm evidence to support this hypothesis due to a lack of studies measuring SOC levels over time, with Bellamy *et al*. (2005) and Bell *et al*., (2011) being the only ones of note.

Secondly, the CAP provides a framework and substantial financial support, for a series of agricultural measures and management practices under the ‘agri-environmental’ programme (within the ‘second pillar’) that individual Member States can use to support the provision of environmental public goods on agricultural land or as a result of agricultural activities. The third way is via cross-compliance within pillar 1 which sets out a number of good practice management requirements that must be adhered to.

EU Member States have varied degrees of freedom in choosing how to respond and implement CAP rules as necessary for their own requirements. Whilst the original aims of the CAP in supporting European agricultural production are still fundamental today, emphasis has moved, through a series of reforms, away from increasing production to maintaining and improving the environment, as well as encouraging the production of high quality produce demanded by the market, maintaining and improving food security and animal welfare standards, and to support farmers’ incomes (Europa, 2007).

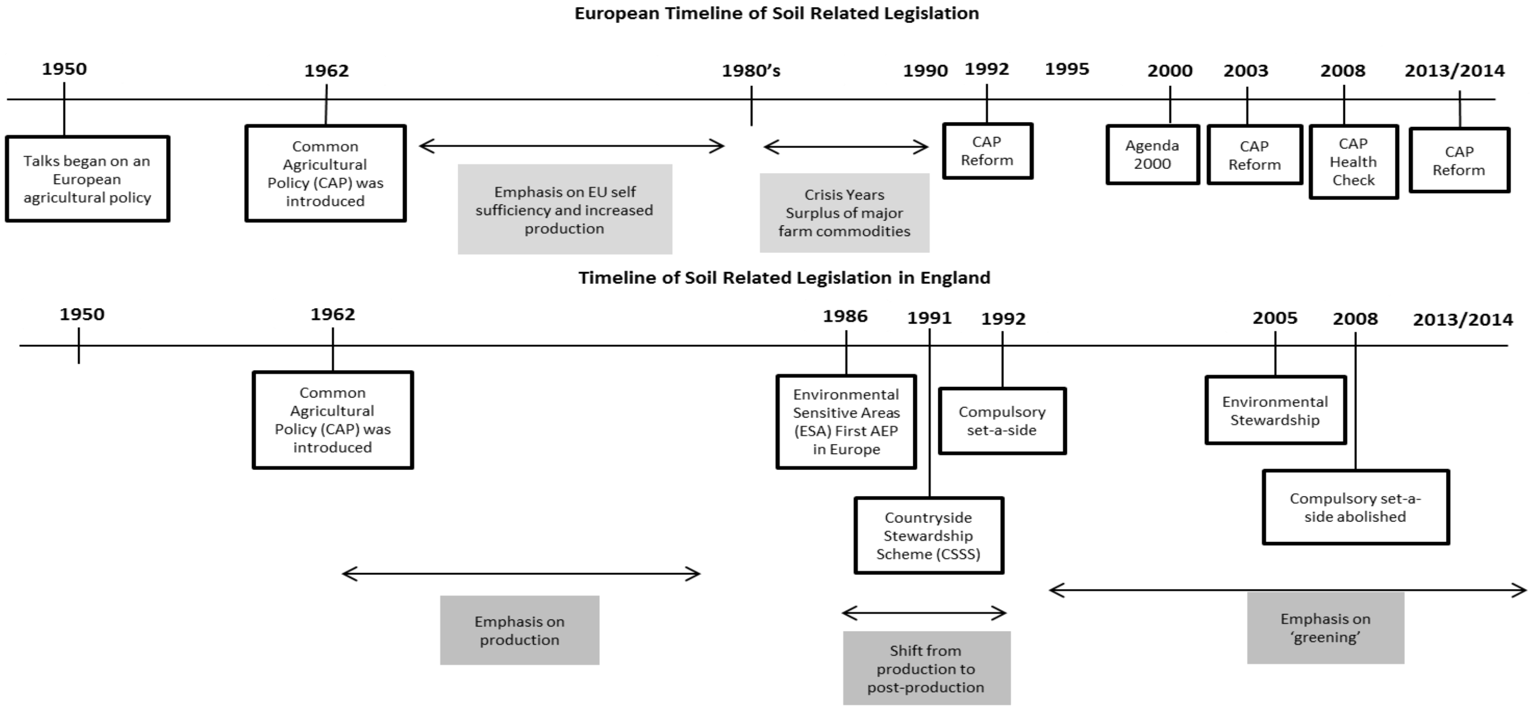


Figure 3.2: The two timelines in the diagram represent the changes and developments in agricultural soil related policy in Europe and England from the introduction of the CAP to the present.

1992 CAP Reform

The first major reform of the CAP occurred in 1992 (Figure 3.2). A shift was made from product support (through prices) to producer support (through the support of incomes and activities) (Walford, 2002). In response to the surplus of commodities and growing concern over the environment, a policy of compulsory set-aside was introduced in an attempt to slow down intensification rates and help deliver environmental benefits - 'greening' the CAP (Dobbs and Pretty, 2008). Set-aside is one of the few land use changes which is a direct consequence of policy. It is also likely to have had the biggest influence on SOC levels, given the increase in land that was no longer being cultivated[10]. In 2006 the Department for the Environment, Food and Rural Affairs (Defra) produced a report looking at the impacts of set-aside in England on the environment (Defra, 2006). Whilst the report looked in detail at many positive environmental benefits, the authors noted that there were a number of potential benefits that could not be quantified due to a lack of suitable data (Defra, 2006). These included reduced C emissions from fewer field operations, and the impacts of soil structure and fertility, i.e. those benefits linked to improved SOC levels. Other authors (Freibauer *et al*.,2004; Boatman *et al*., 2006) suggested that the lack of soil disturbance associated with an increase in set-aside land could have had the potential for C sequestration. Freibauer *et al*. (2004) also highlighted the potential for sequestration via the fossil fuel off-setting using biofuels planted on the set-aside land. In their modelling study, Bell *et al*. (2011) associated the gain in SOC seen in 1993 to be attributed to the introduction of set-aside. However, whilst their study, which aimed to measure the flux in UK SOC from 1925 to 2007, produced interesting results, the authors note that much of the data was based on estimates, or from the 20 previous studies measuring SOC that were examined. The authors also note, that due to the nature of SOC concentration change and long transition times following land use change, would mean that a lengthy field trial would be required to be created, but such data would validate the model (Bell *et al*., 2011).

[10] NB The compulsory set-aside in 1992 followed an unsuccessful voluntary approach implemented in 1988. The area of land which had to be submitted was reduced from 20% to 15% in 1992, followed by further reductions in 1995 and 1996 to 10% and then 5%, respectively (HMRC, 2014).

Agenda 2000, 2003 Reform and 2008 CAP Health Check

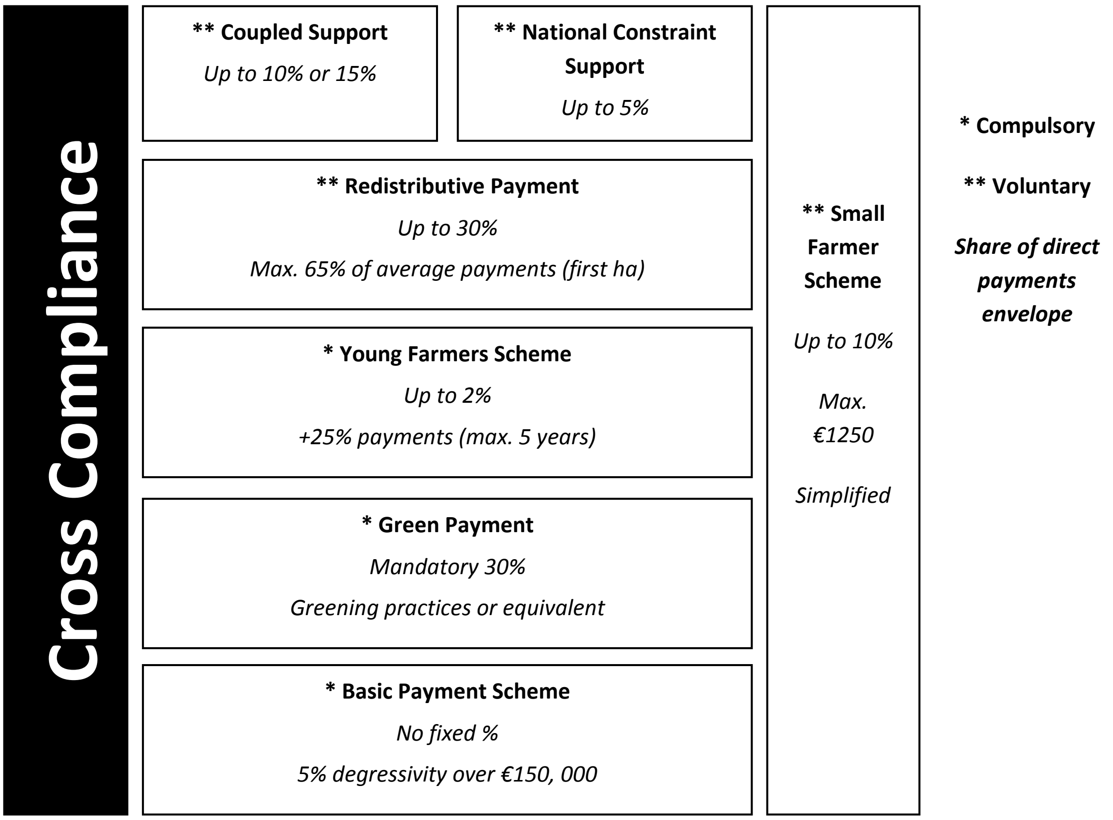
Subsequent changes to the CAP in the first decade of the 21st Century saw the continued greening of the CAP, with the introduction of the second pillar which was concerned with rural development, with the first pillar remaining concerned with production (Agenda 2000). This was later followed with payments to farmers being decoupled from the pillar one (production) and more funds being shifted to pillar two (rural development and environment) (Dobbs and Pretty, 2002) (2003 Reform). This shift meant that there was increased emphasis for farmers to provide and deliver more environmental goods and services, and conduct conservation behaviours on their farm land. This can be seen as a potentially advantageous move for SOC levels as the pressure was alleviated to intensively farm, potentially leading to improved soil husbandry and therefore increased SOC levels. Cross compliance was also introduced and enforced in 2005, linking direct payments to compliance by farmers with basic standards towards the environment, food safety, animal welfare, and animal and plant health.

In 2008, due to a need for greater productivity in EU agriculture, the compulsory set aside was abolished (HMRC, 2014) (CAP Health Check). Ultimately, these reversals of legislation, may well have undone much of the work in building up SOC levels, as C would have been released far quicker than it would have been sequestered. A report by SAC and AEA Technology (2011) highlighted that there may have been an increase in SOC levels in arable soils previously submitted in set-aside, it is likely that this increase may have been lost as land was returned to cultivation (SAC and AEA Technology, 2011). However, the report stated that this could not be quantified due to a lack of comprehensive monitoring.

The CAP Post-2013

In the most recent CAP reform, increasing emphasis is once again being placed upon encouraging farmers to provide environmental and other services in return for financial support mechanisms (EC, 2013b). A new policy instrument in Pillar 1 is directed to the provision of these environmental goods, marking a major change in the policy framework (figure 3.3) (EC, 2013b). The payment for providing environmental goods creates a large potential for improving SOC levels, if C sequestration is encouraged through the new policy instrument, either via reducing vulnerability to climate change or through the encouragement of creating permanent grassland. There will also be focus on bridging the gap between the science and common practice via the Farming Advisory System, aimed to help the industry to adapt to new trends, technologies and challenges (EC, 2013b). This will hopefully improve the knowledge base regarding soil science, in particular SOC. It seems likely that under the new CAP, awareness of SOC and C sequestration will continue to increase. However, as has been previously highlighted, a comprehensive monitoring of SOC is required to quantify any physical changes in levels, something which has not yet occurred.

A. The new design of direct payments under the CAP post-2013. Figure adapted from EC (2013b)



B – Target actions under Pillar 1 and Pillar 2, CAP post 2013, adapted from EC (2013b).

Pillar 1	Targeted Action	Pillar 2
Green payment	**Environment**	Agri-environment-climate Organic, Natura 2000
Top-up payment	**Young Farmer**	Business development grants. Higher investment aid.
Top-up payment	**Areas With Natural Constraint**	Area payments
Alternative simplified scheme	**Small Farmer**	Business development grants
Improved legal framework	**Producer Cooperation**	Aid for setting up producer groups. Cooperation and supply chain.

Figure 3.3: Diagrams A and B present some of the changes to the CAP post-2013. (A) pictures the new design of the direct payments, whether compulsory or voluntary, and their percentage share of the direct payments envelope. All of the direct payments fall under cross compliance. (B) demonstrates the target actions of the CAP post-2013 and the measures to support them under Pillar 1 (production) and Pillar 2 (environment). Figure adapted from EC (2013b)

3.3.2 The EU Soil Framework Directive

The Soil Framework Directive (SFD), introduced by the European Union in draft form in 2006, marks a more regulatory, as opposed to voluntary, approach to the management of soil quality within the EU. The complicated history of this initiative, as detailed below, demonstrates the significant difficulties of approaching the issue of soil quality from a regulatory perspective.

'The Thematic Strategy for Soil Protection' (EC, 2006) presented the draft proposals for the SFD. The proposals emphasised the importance of soil as a resource and its potential as a C sink (EC, 2006) and would have been the first piece of policy directly related to, and concerned with, the maintenance and protection of soil. The proposal identified the key threats facing soil as:

- Erosion
- Decline in OM
- Local and diffuse contamination
- Soil sealing
- Compaction
- Decline in soil biodiversity
- Salinisation
- Floods
- Landslides (EC, 2006)

At the national level, a stakeholder workshop on the proposed SFD, held in London in May 2007 highlighted several potential issues (Defra, 2007). Overall it was agreed that the intent of the proposals were good, but that the content needed revising.

On the 13th February 2012, five years after the Thematic Strategy was released, the EC published a report on the implementation of the strategy and the ongoing activities. In the report, it was noted that the preservation of SOM was a current and upcoming challenge. It was stated that in 2009 European cropland emitted an average of 0.5 tonnes of CO_2 per hectare, most of which resulted from land conversion (EC, 2012). As well as seeking to ensure that less 'natural' land, (particularly peatlands) was converted to cultivated land, the report suggested that attention should be paid to the preservation of permanent pastures and the management of forest soils in order to keep C stocks and thereby help in the present and future reduction of emissions (EC, 2012).

In 2014, due to continuous blocking of the SFD and the failure for all parties to agree on its conditions, the EC made the decision to withdraw the framework (EC, 2014). While it is certainly true that farmers are completely dependent on their land to be in good condition in order for their businesses to succeed, and that having good, fertile soil is of the upmost importance, the increasing pressure to produce more to feed a growing population will inevitably put strains on their ability to retain or improve on existing SOC levels. Whilst it is encouraging that soil and therefore SOC eventually became a subject of European legislation and policy proposals, it is also frustrating that they were blocked by what was a minority of Member States (UK, Germany, Austria and the Netherlands, (EC, 2012)), ultimately forcing them to be removed. With an ever increasing population, agriculture must produce more food and unless it is done in a sustainable way, soil will continue to be degraded. The EC recognises this and states that it is important that the EU improves the way in which it deals with soil and related issues, particular in the absence of formal legislation. There is still no systematic monitoring or protection of soil across Europe, meaning that knowledge of the state of European soil is fragmented and soil protection is not undertaken in an effective and coherent way by all Member States (EC, 2012). This has also meant a lack of monitoring of SOC levels.

The SFD was likely blocked as soil and its management and conservation, was simply not regarded as a priority issue, deserving of an additional raft of agricultural legislation, for many of the Member States concerned. However, increasing SOC levels is not just about creating better soils, but also the positive role it could have in mitigating against climate change, by acting as a sink for CO_2. What is needed is a shift in the focus and discourse associated with the need for soil legislation; from the management and improved productivity of dryland soils for agricultural purposes to the future role SOC may play in mitigating climate change. This is certainly the direction the EU needs to take to bring SOC back to the policy-making table. As Bouma and Drooger (2007) state in their report on implementing the SFD in the Netherlands, such policies should be driven by societal concern and citizen engagement, supported by forward-looking science rather than by producer interests and scientific considerations. In this case the withdrawal of the SFD was driven by the Member States who were blocking the proposals, rather than a lack of scientific evidence proving that European soils were becoming degraded. As they go on to say, science may lead to results or evidence that is unattractive to politicians and producer interests (Bouma and Drooger, 2007) and therefore has little chance of being formally adopted into policy and legislation. Given the size of the EU and the number of different economies and environments it covers, it is a challenge to develop a piece of environmental legislation that would fit well with all Member States. However, soil has proved to be an important part of the global challenge towards a more sustainable future and lessening the impacts of climate change, so the EU cannot really afford not to do something about the state of its soils.

3.4 National Policy and Strategy on Soil Organic Carbon

At the national level, EU regulations and the CAP have much of an influence on how farm land is managed as Member States are required to operate within this framework. There are two areas where the UK implementation of the CAP, managed by Defra, articulates directly with the issue of SOC. These are cross-compliance and AESs, both of which influence decision making and stipulate the undertaking of certain management practices that have the potential to impact SOC levels. Hence, these will be examined in the following section. This is not exhaustive review of all policy instruments emerging at the national level. Others, such as private retailer schemes, though significant in influencing agricultural practice are not considered as it falls beyond the remit of this thesis. Figure 3.4 demonstrates the hierarchy of legislation from EU to the national level, correct at the end of 2013. The legislation and voluntary schemes in figure 3.4 are an amalgamation of those discussed in the previous and current section.

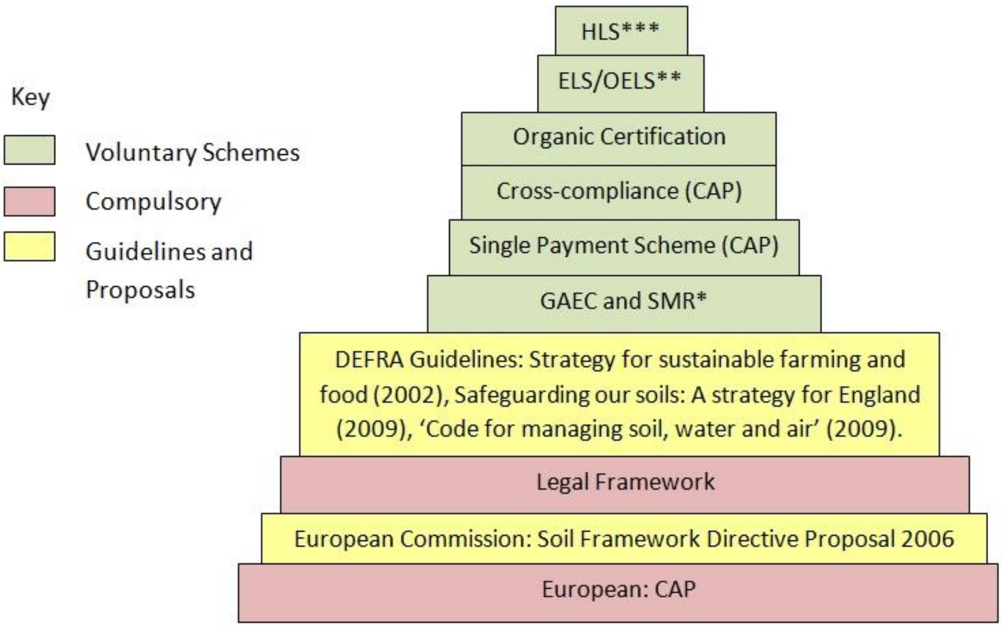


Figure 3.4: Hierarchy of environmental policies and national agri-schemes within England.*Good Agricultural and Environmental Condition and Statutory Mandatory Requirements ** Entry Level Stewardship/Organic Entry Level Stewardship ***Higher Level Stewardship.

Defra have produced several policy documents relating to soil, which identify the UK government's position on the protection and management on the nation's soil. The 'Strategy for Sustainable Food and Farming' (2002) addresses the challenging issue of sustainability and the implications for the farming industry as a whole. Although it does not focus on soil directly it does cover important aspects of conserving vital resources including soil, water and biodiversity and the importance of C storage (Defra, 2002). 'Protecting our Water, Soil and Air' by Defra (2009a) sets out a number of Codes of Good Agricultural Practice (CoGAP) regarding the management of water, soil and air. With regards to soil it gives practical advice on soil fertility and plant nutrients as well as addressing the Soil Protection Review 'SPR' required as part of cross compliance.

'Safe guarding our Soils: A Strategy for England' (2009b) complements the aims of the proposed SFD. However, in the Strategy's forward, Hilary Benn, Defra's Secretary at the time of publication, notes that the harmonised EU approach set out in the draft SFD is not suitable for England and a more localised approach should be adopted (Defra, 2009b). This is reflected within the document by addressing national issues with localised approaches, for example, specific guidance for different soil types. Defra's vision is that by 2030, all of England's soils will be managed sustainably with degradation threats tackled successfully, improving soil quality and sustainability. The Strategy highlights those areas that Defra will prioritise. Areas of focus include better protection for agricultural soils, protecting and enhancing stores of soil C, building the resilience of soils to a changing climate, preventing soil pollution, effective soil protection during construction and development and dealing with the legacy of contaminated land. The Strategy will be delivered through improving the evidence base, providing information and guidance to those that manage soils, and using regulation and incentives where necessary to drive further action. An improved evidence base, if combined with a monitoring programme would address the gap in quality data highlighted previously.

3.4.1 Cross Compliance

Cross compliance has defined Good Agricultural Environmental Conditions (GAECs) and Statutory Management Requirements (SMRs) (table 3.3). It is important to note that the GAECs and SMRS referred to here are pre the CAP reform in 2013, as they have been updated and altered following the reform. Table 3.3 highlights the GAECs and SMRs which have a potential impact on SOC. The information in the table was derived from original documents outlining the GAECs and SMRs, assessing what was involved for each one and relating back to original scientific literature to determine their potential impact on SOC. The SMRs are concerned with areas of public, animal and plant health, environment and animal welfare. The GAEC standards relate to issues of soil erosion, SOM, soil structure, ensuring a minimum level of maintenance, avoiding the deterioration of habitats and the protection and management of water (RPA, 2014). GAEC 1, specifically concerns the protection of soil; the Soil Protection Review (Defra and RPA, 2005; Defra, 2009a). Of the SMRs, SMR 4 is the Nitrate Vulnerable Zone (NVZ) regulation which has significant implications for soil management. If farmers comply with cross compliance, they are then entitled to receive payments from the Single Payment Scheme (SPS). This is a voluntary measure and farmers are not necessarily obliged to be part of the scheme if they receive a high enough income from their produce alone. However, in 2009, it was recorded that 93% of agricultural land eligible for SPS in England was ‘activated’ and receiving payment (Defra, 2010). With such a high uptake, it validates the reasoning for assessing cross-compliance in terms of its impact on soil management and SOC.

Table 3.3: Good Agricultural and Environmental Conditions and Statutory Management Requirements under Cross compliance that impact SOC levels. Information adapted from Defra and RPA (2005) and Defra (2009).

GAEC	Potential Impact on SOC
Soil Protection Review (SPR) (GAEC 1)	Improves management of OM input and erosion sites by documenting associated information.
Environmental Impact Assessment (EIA) (GAEC 5)	May prevent degradation to soil via the assessment of the environmental impact of a planned activity, providing alternatives.
Sites of special Scientific Interest (SSSI) (GAEC 6)	Area will be protected from harmful or environmentally degrading activities, preventing SOC from being lost from the ecosystem.
Overgrazing and Unsuitable Supplementary Feeding (GAEC 9)	Overgrazing can lead to soil erosion and therefore SOC loss. The prevention of overgrazing will reduce the amount of SOC being lost.
Heather and Grass Burning (GAEC 10)	Increases soil C input.
Agricultural Land which is not in Agricultural Production (GAEC 12)	Encourages good management of land not in production, including the use of cover crops. OM input will be increased, as will erosion.
Protection of Hedgerows and Watercourses (GAEC 14)	Prevents erosion and therefore SOC, from leaving the soil system.
Hedgerows (GAEC 15)	Prevents erosion and therefore SOC, from leaving the soil system.
No Spread Zones (GAEC 19)	Limits the area of land where OM can be applied.
SMRs	**Direct Impact on SOC**
Sewage Sludge (SMR 3)	Increases OM input into the soil.
Nitrate Vulnerable Zones (NVZs) (SMR 4)	Regulates the amount and timings of OM applications to the soil, influencing SOC levels.

3.4.2 Agri-Environmental Schemes

Although agri-environmental schemes (AESs) form part of the CAP, Member States have the freedom to decide how they are set up, their aims and objectives and the rationales under which they are promoted. AESs, whilst designed and enforced through Defra and associated organisations, are regionally devolved, so England, Scotland, Wales and Northern Ireland all have different schemes. AESs are being presented here due to the large area of land in England that is under AES agreements. AESs were introduced during the 1992 CAP reform; however England already had an AES in the form of the Environmentally Sensitive Area (ESA) scheme, introduced in 1986, followed by the Countryside Stewardship Scheme (CSS), in 1991 (A review of these schemes can be found in Appendix II). The AESs of England have changed accordingly with the CAP reforms but they have all involved some form of ‘Payment for Environmental Services’ since their implementation in the mid 1980’s (Dobbs and Pretty, 2008), although payment was primarily designed to cover the farmers loss of income and the concept of ecosystem services was not used then.

What follows is a discussion of the most recent AESs in England. Whilst AESs have been an important pieces of legislation, SOC has rarely been mentioned, due to the fact that AESs have so far always been firstly about landscape, secondly, nature, and thirdly pollution. However, certain practices which have been promoted via AESs will have likely had an impact on SOC levels in agricultural soil. Whilst they have so far not focused on SOC as an issue, AESs are still a key mechanism to influence farming practice reaching a wide audience and therefore hold a huge amount of potential. For example in 2012, approximately 79% (four out of five farmers) were members of an AES (Mills *et al*., 2013). It is therefore pertinent that their impact on changes on farming practice and land management as well as their ability to engage with farmers is assessed. In terms of advice, the farm business survey in May 2013, suggested that in 2011/2012, 74% of the interviewed farmers got technical advice in a manner with no direct charge, whilst another 59% and 52% got it via events and demonstrations, and discussion groups, farm walks or workshops, respectively (Defra, 2013d). These methods are associated with AESs.

Environmental Stewardship 2005 - 2013

Environmental Stewardship was introduced in 2005following the closure of new applications of CSS and ESA in 2003 (Natural England, 2010a). Building on the previous schemes, farmers were encouraged to undertake environmental actions on their farm and in return receive payment. There were three types of environmental stewardship; Entry Level stewardship (ELS), Organic Entry Level Stewardship (OELS) and Higher Level Stewardship (HLS) (Table 3.4).

Table 3.4: A summary of the key characteristics of ELS, OELS and HLS. Table adapted from Natural England, (2010a).

	Entry Level Stewardship (ELS)	Organic Entry Level Stewardship (OELS)	Higher Level Stewardship (HLS)
Eligibility	Open to all farmers	Open to all farmers with organic land, land entering conversion, or combination of organic and conventional farming.	Negotiated with farmers, using target themes.
Duration	5 years	5 years	10+ years
Payment	Standard: £30 per ha per year	Standard: £60 per ha per year.	Payment varies according to specific management. Has higher payments to reflect greater input.

As the name suggests ELS is the basic level of environmental stewardship, and OELS is the organic version. At the beginning of 2011, there was approximately 6.3 million ha in ES agreements in England, amounting to 68.6% of the utilisable agricultural area (Courtney *et al*., 2013), an increase in land compared to earlier AES schemes, ESA and CSS.

The ELS aimed to encourage large numbers of farmers and land managers across England to deliver simple environmental management that went beyond the SPS of the CAP and its requirement to maintain land in GAEC (Hodge, 2010). Whereas the HLS requires a greater input, with higher payments made to reflect this.

As mentioned previously, to date AESs have not directly targeted SOC, however, some of the practices which were encouraged will have an impact on SOC levels, as presented in table 3.5. This table was created by assessing the original documents outlining the scheme options and considering their impact on SOC levels based on academic and scientific literature.

Table 3.5: Voluntary management options under the three Environmental Stewardship schemes that maintain and protect soil, adapted from Natural England, (2010a) and using information from Bhogal *et al.* (2009) (highlighted in *italics*)

Voluntary measure (**E** – Entry Level Stewardship, **O** – Organic Entry Level Stewardship, **H** – Higher Level Stewardship)	**Impact on Soil Organic Carbon levels**
EJ2/OJ2 Management of maize crops to reduce soil erosion.	Reduced erosion will result in a decreased loss of organic carbon from the soil system.
EJ5/OJ5 In-field grass areas to prevent erosion and run-off.	Reduced erosion will result in a decreased loss of organic carbon from the soil system. *Enhance SOM.*
EJ10/OJ10 Enhanced management of maize crops to reduce soil erosion and run-off.	Reduced erosion will result in a decreased loss of organic carbon from the soil system.
EJ13/OJ13 Winter cover crops.	Covering the soil surface during winter will reduce erosion resulting in a decreased loss of organic carbon from the soil system, as well as supplying a source of OM. *Maintains SOM and may enhance C storage.*
HJ3 Arable reversion to unfertilised grassland to prevent erosion or run-off.	Reduced erosion will result in a decreased loss of organic carbon from the soil system. Will also increase the supply of OM into the soil. *Enhance SOM.*
HJ4 Arable reversion to grassland with low fertiliser input to prevent erosion or run-off.	Reduced erosion will result in a decreased loss of organic carbon from the soil system. Will also increase the supply of OM into the soil. *Enhance SOM.*
HJ6 Preventing erosion or run-off from intensively managed, improved grassland.	Reduced erosion will result in a decreased loss of organic carbon from the soil system.
HJ7 Seasonal livestock removal on grassland with no input restriction.	This will lead to reduced erosion resulting in a decreased loss of organic carbon from the soil system.

However, similar to previous issues highlighted with ESA and CSS, Hodge (2010) found that the voluntary approach coupled with the amount of management options available in environmental stewardship schemes, gave the farmers opportunities to commit to options that they would have undertaken anyway or could implement at minimal or no cost. Thus, environmental stewardship makes very little difference to the way in which farmers manage their land and perhaps even their attitudes towards the environment. It also impacts the relative success of the scheme, which can be measured by whether or not potentially environmentally improving practices are taken up beyond their extent in the absence of the scheme and the value of the environmental gains relative to the cost of their provision (Hodge, 2010).

Whilst the amount of land under the schemes has increased, the conditions under which farmers can participate remain simple, requiring very little change from them. The exception is perhaps the introduction of the HLS which may indicate policy makers have taken heed of previous evaluation studies suggesting this issue. In terms of SOC, the majority of soil related options are focused on soil erosion rather than OM or C.

Organic Farming Scheme

Under the British (and EU) rules, farmers may benefit from financial support under agri-environmental policy for conversion to organic farming methods. Although a European ‘Organic’ certification scheme exists, many organic farmers in the UK prefer to operate under the Soil Association’s Organic Farming Label. Although there are other organic schemes, it has been decided to treat Organic Farming *per se* as a component of UK agri-environmental policy as agri-environmental payments have been a key element in the success of organic farming

An organic farming system does not involve the use of artificial fertilisers or pesticides, and instead relies on crop rotations and other forms of husbandry to maintain a healthy soil and control weeds, pest and diseases. Not using artificial fertilisers or pesticides means that there is a greater reliance on a soil’s fertility to keep the farm productive. To do this, organic farmers must maintain the fertility and biological activity of the soil, increase soil quality by multi-annual crop rotation including legumes and other green manure crops, and use livestock manure or other sources of organic material (Defra, 2014b). These practices are likely to encourage high rates of SOM and therefore SOC (see Soil Association, 2009; Gattinger *et al.,* 2012). The strict regulations, with which organic farmers must comply with, specify what inputs are permitted for fertilising the soil and pest and disease control, as well information how produce must be processed, labelled, and imported and exported. The Soil Association, which is a charity, is the principal UK organic certifying body. The fact that it is a charity emphasises the close link between the 'ideology' of organic farming and the notion of good soil.

In addition to the certifying bodies, Defra helps support organic farmers in England though the OELS, which represents only a small area of AESs, being only 6% of the land area compared to ELS (Hodge, 2010). OELS provides funding for organic farmers already registered with a CB, as they are already adhering to a strict regulatory framework. Whilst organic farming is still a 'niche' in the market, its potential to increase C levels in soils needs to be investigated further with rigorous regulations to maintain the high standards of production.

Catchment Sensitive Farming 2005 to Present

Catchment Sensitive Farming (CSF) is a project run by the Environment Agency (EA) and Natural England, and funded by Defra and the Rural Development Programme for England and can be identified as another policy instrument. The CSF forms part of the delivery of the Water Framework Directive and the Nitrates Directive, both of which created regulation on farms effecting soil management, particularly the application of manures. CSF enables farmers and land managers to take voluntary measures to reduce diffuse water pollution from agriculture in priority catchments. Soil erosion contributes to diffuse pollution and so is also targeted through CSF.

CSF provides access to the Capital Grant Scheme which funds practical work to reduce diffuse water pollution, offering up to 50% funding for the improvement work. CSF also provides free specialist training and on-farm advice by CSF advisors. Workshops form part of the advice system. Similar to other AESs, CSF has the potential to impact a large area of farmed land in England, as well as providing sources of information and advice to farmers. It is for this reason it is being discussed in terms of its impact on SOC levels.

The five year evaluation report states that farmer engagement has been successful with 9,023 farm holdings receiving advice directly (EA, 2011). However this only amounts to 17% of all farm holdings within Priority Catchments (EA, 2011) indicating that there is a greater potential to be had. The report also stated that 93,360 farm-specific recommendations had been made for improving soil and land management, with an uptake rate of just over 50% (EA, 2011).

The table below (table 3.6) is a selection of diffuse water pollution measures highlighted by the report that have contributed the most to CSF during the first 5 years. This is not a comprehensive list but a selection of those measures which may potentially improve or maintain SOC. These have been selected by considering their impact on SOC levels based on research conducted using academic and scientific literature. Measures 1, 2, 3 and 5 concern a reduction of soil erosion or a soil disturbance. This would firstly stop or limit the amount of soil and therefore SOM being lost from the system through mechanical movement. A reduction in soil disturbance will also limit the amount of SOC lost to the atmosphere as soil from lower depths will be less likely to become exposed to the atmosphere. Measures 4, 6, 7 and 8, concern a greater input of OM through manures. This would increase the SOM content and, if managed correctly, also lead to an increase in SOC.

Table 3.6: A highlighted number of diffuse water pollution measures that contribute most to overall CSF benefits which also maintain or increase SOC levels, adapted from EA (2011) using information from Bhogal *et al*. (2009) (Highlighted in *italics*).

Measure	Potential impact on SOC
1. Cultivate land for crops in spring rather than autumn	Reduced erosion rates if cultivated in Spring when soil will be drier. Therefore less SOM will be lost. *Maintain SOM.*
2. Reduce field stocking rates when soils are wet	Reduce erosion rates limiting the amount of SOM being lost. Also will prevent compaction. *Maintain SOM.*
3. Reduce overall stocking rates on livestock farms	Reduce erosion rates limiting the amount of SOM being lost. Also will prevent compaction. *Maintain SOM.*
4. Integrated fertiliser and manure nutrient supply	Potential greater use of manure, adding more OM into the soil and therefore more SOC. *Maintain SOM and may enhance C storage.*
5. Adopt reduced cultivation systems	Less erosion so SOM is not lost. SOC is less likely to be lost to the atmosphere if soil is not disturbed. *Maintain SOM and may enhance C storage.*
6. Incorporate manure into the soil	This will add more SOM into the soil potentially leading to an increase in SOC. *Maintain SOM and may enhance C storage.*
7. Increase capacity of farm manure stores to improve timing of slurry applications	This will potentially allow for a greater amount of manure to be returned to the soil if the storage capacity is increased. *Maintain SOM and may enhance C storage.*
8. Transport manure to neighbouring farms	May help neighbouring farm to increase its OM input, therefore potentially leading to an increase in SOC. *Maintain SOM and may enhance C storage.*

3.4.3 Review of National Policy and Strategies for Soil Organic Carbon

Many of the mechanisms reviewed above do not address SOC directly but instead have an indirect potential to influence SOM and SOC levels. For example, AESs reach a large farming audience and many of the managements promoted in ES and CSF impact SOM and SOC, but neither are directly mentioned. However, ES does not necessarily require farmers to make any changes to their farm management, and so any potential increases in SOM and SOC may not be fully realised as no actual change in management occurs. The impact that any of these AESs may have had on SOC is difficult to ascertain, as with the impact of set-aside, there is a lack of quantifiable data and studies researching the direct impact. In terms of assessing environmental impacts on the whole, Kleijn and Sutherland (2003) found that the research designs used in most studies to assess AESs were inadequate to consider reliably the effectiveness of schemes. In addition, the SPR that forms GAEC 1 under cross compliance, whilst it shows that Defra recognises soil as an important resource, it only requires documenting certain information rather than change to management approaches. Defra's 'Safe guarding our Soils' states that there will be priority given over improved protection for agricultural soils including the protecting and enhancement of soil C. It is said that this will be achieved using information and guidance, and regulation if found to be needed, based on an improved evidence base. Improved evidence is certainly something which is required, as highlighted with regards to uncertainty over the influence of set-aside on SOC. Whilst 'Safe guarding our Soils' demonstrated that Defra recognises the importance of soil in terms of C sequestration and climate change mitigation, this has yet to be fully realises in the mechanism which reach the farm and influence management decisions. Whilst C and soil C sequestration are being discussed at the global scale (IPCC, Rio Summit, FAO), at the national level, it is still missing from policy, even towards the mid to late noughties. There are several reasons that could be considered for this. The biggest one being that SOC is simply not considered an issue within the environment and climate that is present in England, unlike drier regions such as Africa and the Mediterranean. Additionally, AESs have been, to date, concerned with landscape and biodiversity issues, rather than climate change mitigation measures such as C sequestration (which would include SOC). The detailed reasoning for both of these goes beyond the realm of this thesis but pose very important questions when considering the future of SOC as a policy issue in English agriculture.

3.5 The Advisory System and the Key Actors

Having previously presented and analysed the policy environment within which farmers in England operate, the following section will now present literature outlining how farmers and FAs negotiate this framework. This part of the review addresses objective 2a of this thesis:

Objective 2a: Identify and evaluate current information, policy and farm management advice regarding SOC, tracing the agricultural advisory pathway.

To achieve this, the literature regarding the knowledge base of farmers and FAs will be reviewed, combined with a discussion on the source of information, and the process of information transfer within the advisory system. Following this, a discussion on policy and farming decision will be presented.

In order to manage agricultural land within the constraints of the law and various voluntary programmes, farmers have an array of management decisions to make. There are a number of factors that influence these decisions which need to be considered. The individual personalities, environments and circumstances of the farmer are the central factors. It is also important to consider the information sources farmers use; the how, who and where their information comes from. By reviewing these topics, it will be possible to assess how effective they are, and the on-farm impact they have in terms of SOC maintenance or improvement.

Farm Advisors

FAs play a key role in how agricultural management is practised. FAs, including agronomists, AES representatives and consultants, are quite often the critical link between legislation and policy on the one hand and farmers on the other. FAs here are considered integral to the translation of policy and information into on-farm advice, based on survey statistics from Defra (2013d). As the survey demonstrated, 74% of farmers received advice with no direct charge, 59% via events and demonstrations, 52 % by discussion groups, farm walks or workshops, and 34% by paying a charge (Defra, 2013d). As part of the original objectives of this thesis, this research has been keen to explore the particular form and nature of advice given to farmers related to SOC and soil management. As the above sections have shown, the principal framework for SOC related initiatives in the UK have been through agri-environmental policy, a key role, it is suggested here, is played by FAs linked to the promotion and management of AESs. Hence the focus here and later in the empirical sections of this thesis is given to FAs. Farming is very knowledge intensive, making it essential that FAs and the advisory systems are able to support farmers in making decisions and be effective in solving their problems (Klerkx and Proctor, 2013). How information is presented, and what information they choose to present, can impact the farmers' decisions. The personal, and corporate beliefs, and understanding of FAs are also an important consideration. FAs from a range of backgrounds advise farmers on a number of issues. They advise on operational and strategic decisions that farmers are required to make (Klerkx and Proctor, 2013). Advisors also help farmers with regulatory compliance, aiding farmers in successfully taking part in AESs and assisting grant applications. The knowledge base of FAs is as important as that of the farmers as they too have a role in the implementation and success of AESs (Ingram and Morris, 2007). FAs are also expected to have wide knowledge base to meet the requirements of the high level of variability in farm types and practices, landscape, climate and soil type they come into contact with.

Ingram and Morris (2007) state that social scientists, who have an interest in policy, are often too quick to focus on farmers as the principal target group of new agri-environmental policies, even though other communities also have a role to play. In a later study, Ingram *et al*. (2010) notes the importance of considering the knowledge of FAs and scientists as well as the farmers in relation to soil management and knowledge.

Farmers

Farmers are also key actors in determining the effect agriculture has upon the wider landscape. Due to the shift in production, intensification, and a growing concern over the environment, natural resources and climate change, farmers are having more responsibility placed upon them in terms of how they practise agriculture. They are now required to take greater responsibility for the on and off-farm impacts their practices have on the wider environment, or in other terms, to be custodians of the rural environment (Howley *et al*., 2014). Rather than just be providers of subsistence, farmers are now required to look after the environment in which they farm, in order to meet the expectations placed upon them (Howley *et al*., 2014). Soil has always been a vital resource for farmers. With increased intensification, soil conservation has become even more important to the farmers as a tool for maintaining production. Presently, with the wider community concerned over climate change and natural resources, farmers not only have to manage the soil for their own use, but also to comply with the expectations of the wider community, including the general public and government. For this reason, farmers play a key role in translating EU and National policy in terms of strategy and environmental measures, into practical farming mechanisms.

3.5.1 Knowledge Base, Source, Transfer and Implementation in the Advisory system

Knowledge Base and Source

Knowledge in agriculture is described as the 'fourth factor of production' because of the wide range of knowledge, skills and aptitudes that farmers require (Walter *et al*., 1997). Farmers must have a broad knowledge base in order to farm successfully in a competitive market. The emergence of new policies, legislation and AESs requires more complex and demanding skills and knowledge. This means that farmers must learn new skills and knowledge in order to keep up with the changing expectations placed upon them.

Whilst there are policy orientated reports highlighting the degradation of agricultural soil (see FAO), the farming industry perceive that soil is managed sustainably and in line with environmental measures (Ingram, 2008). As a community, the knowledge farmers hold can vary a great deal, depending on the type of farm, experiences, education, and personal views of the farmer on issues such as the environment. It is for this reason why there is a range of opinions on farmers' ability to manage soil sustainably (Ingram, 2008). However, there is very little information available on the nature and extent of farmers' knowledge regarding soil as it has not been well documented. Ingram is one of a very few who have explored and published research on this topic, with particular regards to the management of soil.

Ingram (2008) conducted a study into the nature and extent of farmers' soil knowledge through conducting interviews with farmers and FAs. She found a range of competencies amongst farmers in relation to scientific knowledge, with a lack of consensus among advisors regarding farmers' knowledge of soil. Only 40% of all the interviewed advisors agreed that farmers were technically well informed about soil management. The advisors in her study saw soil management as a complicated issue which a number of farmers appeared not to fully understand. Ingram (2008) concluded that farmers did not always have sufficient knowledge to make the link between certain practices and their consequences. In a later study, Ingram *et al*. (2010) noted that although it appeared from their research that farmers' knowledge on soil degradation had increased in recent years, it was not always applied to their own farming practices, echoing the results from the previous study. Whilst farmers acknowledged that certain management practices led to increased run-off, none accepted that their individual practices were responsible, attributing the problem instead to other sources, as well as blaming extreme weather.

It is suggested that during the intensification of UK agriculture between 1950 and 1980, the local knowledge base of farmers was replaced by specialised and commoditised agricultural inputs (Ingram, 2008). Local knowledge is considered important in the execution of sustainable agricultural practices, meaning that farmers may currently not have the knowledge to practice sustainable agriculture, including good soil husbandry. This lack of specialised knowledge could be further reduced by the idea from Ingram (2008), who noted that farmers tend to place a high value on their experiences, drawing on this as a primary source of knowledge, but often feel that this source is overlooked by advisors and policy makers. In addition to this, Ingram (2008) states that farmers are in the habit of performing the same management practices year on year, or in other words *'the habit of carrying out degrading operations without thinking about the consequences*'. This may mean that farmers do not seek new advice or information as they are content to carry on as normal.

Although the research by Ingram (2008) exposes some conflicting opinions both within and between the farmer and FA communities, there is a general consensus that, although largely knowledgeable, many farmers appear to lack the in-depth scientific and tacit knowledge necessary for carrying out more complex sustainable soil management practices (Ingram, 2008). Farmers place a high value on their experiences to support their management decision and are therefore perhaps protective over this knowledge, preferring traditional, safe methods. With regards to sustainable management and good soil management, the traditional, more ecosystem orientated methods that are needed to help improve sustainable agriculture, have been partly lost due to the intensification of farming and higher reliance on modem technologies. The knowledge base of farmers will have to change in order to meet the new environmental challenges and expectations facing farmers today. However as farming is constantly developing due to population and technology requirements, farmers, as a community, are well equipped for altering their knowledge base.

As outlined in the previous section, farmers can receive information and advice from many different sources. With greater improvement in communication technologies, the available sources of information with which farmers' can increase their knowledge, have dramatically increased in recent years. Sources of information for farmers can come from the internet (for instance forums, published articles and Twitter), printed news (for example Farmers Weekly), contact with FAs, agronomists or consultants (through face-to-face briefings, by email, phone and text messaging), workshops, farm walks, published fact sheets and networking with other farmers. Despite the advancement in availability of information, face-to-face visits from advisors and practical demonstrations still remain to be the best source of information for farmers. Palmer *et al*. (2006) found that there was no substitute for genuine training in field assessment versus the provision of factsheets. Ingram and Morris (2007) state that individual farm visits by an advisor remains one of the most powerful and effective forms of communication and is most valued by the farmer. Whilst the authors recognise other information gathering mechanisms, they state that advisors remain an essential component of the agricultural knowledge system. In order to improve the sources of information available, there is a need to engage more fully with farmers to discover what processes actually have the largest impact in informing and/or changing their practices (Ingram, 2008).

Knowledge Transfer and Implementation

Knowledge transfer refers to the process of transferring knowledge from one section of an organisation or industry to another. The transfer in this case is from policy makers and legislators to the farmers. The agriculture advisory system is comprised of several components, from the business, technical and engineering, to the environmental. All three of these are necessary in the process of knowledge transfer. This division reflects the complexity and diversity both of the policy goals and the regulatory requirements within which farmers are meant to support and comply with (Garforth *et al*., 2002). FAs are the main facilitators in this knowledge transfer process. Klerkx and Proctor (2013) have stated that FAs are far more than technical experts, with the relationship between them and farmers being more of a '*coach, sparring partner, and facilitator, co-producing knowledge with the client*'.

Information and advice are important tools in the achievement of policy objectives (Garforth *et al*., 2002). It is the individual farmer or land manager that determines if the policy objectives are met via the combined effects of their management decisions and allocation of resources under their control. Garforth *et al*. (2002) conducted a study based on the 2002 Curry Report. The Curry Report concluded that '*we do not think that the current approach to farm advisory services meets the needs of the farmers now, or will it adequately prepare the industry for the challenges and opportunities of a reformed CAP*'. From their review of policy documents at the time, Garforth *et al*. (2002) highlighted three major areas in which the advisory system and therefore knowledge transfer could be improved. These were:

- Integration
- Facilitation
- High quality advice.

The need for integration reflected the fragmentation which existed both in the provision of publicly funded advice and in the extension of publicly funded research and development through knowledge and technology transfer programmes. This fragmentation can partly be attributed to the privatisation of ADAS. It also refers to the need to integrate the different agriculture industries, as mentioned previously, to provide the best and highest level of information available. Facilitation implies something more than just the provision of advice and information, but help with implementation, relating back to the important role FAs play. Without facilitation, farmers may struggle to implement advice, as practical advice is needed. Incentives such as grants also form part of the facilitation, with grants encouraging farmers to take up various schemes and enforce policy objectives. Quality advice is crucial and needs to be up to date with the most recent advancements in technology and science. It also needs to be accessible and user friendly in order to be effective.

Palmer *et al*. (2006) looked, in detail, at the potential of knowledge transfer between farmers, land managers and regulatory bodies, to achieve better soil management in the UK. Three areas were identified as gaps in regulatory body provision and therefore gaps in knowledge transfer. These were:

- Organic matter (increase through amendments, tillage and rotation (direct and indirect benefits))
- Soil structure (methods of assessment and influence of rotation and cultivation (direct and indirect benefits))
- Soil biology (the effect of soil management on incidence of pests and diseases).

In terms of the objectives of this study, these are key areas which can impact SOC. If these areas were to be improved in terms of research, available information and mechanisation of delivery, farmers would have improved circumstances under which to increase SOC levels.

Palmer *et al*. (2006) felt that there is both a need and an opportunity for regulatory bodies to fill gaps in soil management knowledge, with great potential to improve cross-sector productivity. At the time of publication, the authors felt that recently introduced legislation heightened the potential opportunities to improve soil based knowledge across the different sectors of agriculture. The authors considered that the soil management plan as part of GAEC and the continuation of environmental stewardship and the development of the SFD would allow and encourage a change in general farm management, more specifically soil management, and improve farmers' knowledge.

Palmer *et al*. (2006) proposed a soil management information gateway, similar to the Agricultural Research Forum (ARF[11]) in Ireland as a means to facilitate a central pool of resources available to all farmers. The vision was that information and contacts for organisations with the best available soil management information could be made available to farmers through such a forum. Updates on soil management training events could also be made available to farmers, informing farmers and advisors of all upcoming training opportunities. Such an action was seen by these authors as an essential short-term priority, and a cornerstone of any further activity (Palmer *et al.*, 2006).

Similarly, Garforth *et al*. (2002) highlighted the importance of horizontal communication within a social system, with the sharing and exchange of ideas among land managers and farmers. An almost universal finding is that farmers are the most frequently reported source of information and influence upon other farmers. This echoes the suggestion made by Palmer *et al*. (2006) that freely accessible forums are effective mechanisms for the exchange of ideas and information. Given the vast improvement in communication technology and the development of social media, this is a vital resource which perhaps needs to be researched to maximise the full potential that the agricultural industry could redeem from it. Such a forum as suggested by Palmer *et al*. (2006) could easily be set up and could potentially reach a wide audience if promoted by farming media.

The implementation of farming knowledge can be described as ‘the continuation of politics by other means’ (Majone and Wildavsky, 1978). The beliefs, agendas and actions of those people involved in the interpretation and application of policies and legislation is very important, as it can impact how knowledge is applied. Juntti and Potter (2002) state that policy makers, implementers and target groups, across the policy networks, form divergent interpretations of policy language, legislative intent and implementing actions. Government bodies such as Defra, Natural England and the Environment Agency, for example, are described as being concerned primarily with ‘ticking boxes’ and meeting set objectives whilst Non-Governmental Organisations (NGOs) such as FWAG, the NFU and RSPB have fundamental causes or beliefs behind their organisational aims which are consequently reflected in their advice to farmers regarding policy and legislation (Juntti and Potter, 2002). If a farmers’ knowledge is guided by contact with government bodies only, they may only implement the basics needed to fulfil an AES. However, if a farmer is inclined to seek advice from an NGO, they may implement their environmental practices beyond those which are

[11] The ARF is an online forum for farmers in Ireland.

required for compliance with minimum requirements. Additionally, if a farmer seeks advice from wider sources, their knowledge base will likely be broader, and the implementation of their knowledge may have a greater impact.

AES's are potentially one of the key mechanisms that can impact SOC levels at the farm. An effective AES should facilitate learning and build confidence and motivation. Facilitation is key, as a scheme is more likely to have long-term effects and be more successful (Garforth *et al*., 2002) in resulting in more informed farmers and improved practical implementation. Juntti and Potter (2002) claim that AESs will require advisors to act as 'extensionists', not just promoting the AES but also helping to bring about the environmental up-skilling of the farmer, if the practices are to be sustained in the long term. The most important fact to the farmer in terms of knowledge implementation of an AES is the credibility of the advisors delivering the scheme. Farmers need to believe that the advisors are credible and knowledgeable in their subject (Garforth *et al*., 2002). If the farmer perceives the advisors to be knowledgeable and there is solid communication between the two parties, then there is likely to successful knowledge implementation and a successful AES.

3.5.3 Farmer Attitudes and Decision Making

The European CAP has acknowledged the role of farmers in conserving the landscape and as protectors of natural resources since the introduction of AESs in the 1992 reform (Burton *et al*., 2008). The 2003 CAP reform bought about the changes so that the management of agricultural land and landscape (without producing any marketable output) is subject to the same level of payment as production activities. These changes re-constitute the role of farmers in maintaining the landscape. Moreover, they provide a payment for this role without a necessary requirement to produce (Gorton *et al*., 2008). AESs are a key policy instrument with the total area of land covered and expenditure increasing over the years. For example, in 2002 30.2 million hectares were covered within the EU by AESs, as well as an increase in €50 million to nearly €2,012 million between 1993 and 2004 in AES expenditure (Burton *et al*., 2008). However, even though the schemes are well implemented, it does not guarantee that the stated objectives of the schemes have actually been met (Kleijn and Sutherland, 2003).

Given the importance of the impact that the agricultural policy environment has been upon the decisions farmers make, it is surprising that there is little long-term or longitudinal research on how farmers' views of agricultural policy have shifted. Over the decades, policy orientation has changed (from production to greening), but there is little evidence that farmers' fundamental attitudes have also adjusted (Gorton *et al*., 2008). Policy makers have recommended that the way in which farmers adjust to changes in agri-environmental policy depends partly on the farmers' pre-existing attitudes and mind sets (Gorton *et al*., 2008). In a study by Wallock *et al*. (1999) based on the mind sets and behaviour of 245 Scottish farms and their farmers, it was concluded that farmers' behaviours can only be explained when attitudes are considered. Coleman *et al*. (1992) have shown how policy measures which encourage positive attitudes towards conservation are more effective than those that do not, as they will facilitate a positive change in attitudes. This sentiment was echoed by Morris and Potter in 1995 too, who stated that the aim of an AES should be to facilitate change in practice and attitudes and ensure that conservation practices are finically viable.

The farmers' perception of the environment is very important as it can influence their decision making and AES participation (Guillem and Barnes, 2013). However, the views that farmers can have of the environment are very broad as a number of factors can influence them, such as financial (e.g. Soil erosion impacts on yield), ecological (e.g. Wildlife habitats) and social aspects (e.g. Aesthetic value of the landscape) (Guillem and Barnes, 2013). Indeed, Kaljonen (2006) suggested that to evaluate the success of an AES, a relational review is needed combining both the social and natural elements, and the networks which tie the two together.

Previous researchers have observed that AESs force farmers to follow the standard rule (Kalijonen, 2006). Although certain levels of skill are involved in the setting up of AESs, once the scheme is established, the farmer's ability to demonstrate further skills through conservation work is limited. This is in addition to the fact that a conservation project becomes a static display in the landscape, which is radically different from the renewable seasonal display with cropped land uses. AESs' also prevent farmers from acting entrepreneurially or introducing innovative ideas, limiting competition between farmers. This consequently limits farmers to perform identity-enhancing behaviour in any significant way (Burton *et al*., 2008). Burton *et al*. (2008) found that by effectively taking responsibility for part of the farm, AESs allow farmers to disown personal responsibility for scheme areas while concentrating on production in the remaining areas of the farm.

Despite the practical impact, research suggests that voluntary AESs may not be effective in inducing permanent changes in farmers' attitudes and behaviour (Burton *et al*., 2008). Burton *et al*. (2008) conclude that the AESs act as a facilitator for the expression of existing attitudes rather than actually changing attitudes. As Wilson and

Hart (2000) have found, in many cases where farmers have adopted schemes, they have done so predominantly because of a combination of commercial and financial interests and that the schemes often involved very little adaptation. If the prescription of a scheme does not fit in with the current set-up of a farm, the farmer will be less inclined to participate. However, if very few changes are needed to fulfil the requirements of the AES then the farmer is more likely to sign up, in other words the ‘goodness of fit’. For example, Ingram *et al*. (2012) conclude from their study that AES participation is not a distinct development pathway but rather an additional strand that is incorporated into an existing collection of pathways. Despite AESs being around for over a quarter of century now, the issues mentioned by the authors previously, were highlighted by earlier authors when AESs were first introduced. Coleman *et al*. (1992) stated that policy measures needed to create positive attitudes towards conservation in order to create shift in attitudes, if not, AES measures may be seen as temporary bribes, shallow in operation and transitory in their effect.

AESs’ are voluntary, so farmers who are disengaged with environment protection are not required to change their practices; therefore their views are less likely to change. Guillem and Barnes (2013) found that farmer participation in an AES is strongly linked with the moral consideration for the ecological aspects of farming. Essentially, if the farmer is involved or invested in the environmental area that the AES is targeting, then they are more likely to participate in the scheme. Burton *et al*. (2008) state that AESs should encourage farmers to engage with conservation in order to understand the objective and the skills and processes which are required. At the time of publication, Burton *et* al. (2008) felt that AESs did not facilitate the level of engagement with conservation work required to produce a change in the culture of conventional farming. In order to achieve this change, Burton *et al*. (2008) suggest the possibility of mimicking symbolic capital production in conventional agriculture by setting species production targets, building on existing small-scale schemes which aim to help integrate productive farming with the conservation of biodiversity and the countryside. Enabling the comparison of results with the prospect of economic reward for production would encourage farmers to learn more about others’ management practices and learn to value the skills required for managing biodiversity (Burton *et al*., 2008). For good environmental attitudes and behaviour to become established in the culture of conventional agriculture, AESs must contribute towards the generation of cultural capital and enable farmers to enact, and display, skilled behaviour (Burton *et al*., 2008).

AES participation can be inhibited by aspects of farm structure, such as farm size, type and tenure (Wilson and Hart, 2000). Wilson and Hart (2000) found that in many regions AESs use as an income support measure, which may not benefit small family farmers most in need of green subsidies for farm survival. The authors also found that farmers on holdings larger than the regional average, who have more flexibility in decision making and are usually more financially better off, may also have larger ecologically important habitats left on their farms eligible for support under AESs. In general, holdings under an AES instigate an increased number of activities, which are more expected to maintain or improve environmental quality than those not participating (Westbury *et al*., 2011). However, research has demonstrated that participation does not guarantee the delivery of environmental protection or the improvement the scheme is intended to deliver (Kleijn and Sutherland, 2003).

The Agri-environmental Footprint Index (AFI) is a farm-level, adaptable approach that aggregates measurements of agri-environmental indicators based on multi-criteria analysis techniques. Research by Westbury *et al*. (2011), explores the use of AFI in combination with data from the Farm Accountancy Data Network (FADN). Results from the study show that AES practices had no significant influence on AFI values in lowland and upland livestock farming. However, there was a significant relationship between AES and region within arable farming. In the East and West Midlands, holdings in AES were assessed with large AFI values compared with non-participating holdings. The main driver for this is the percentage for un-cropped land, for example arable holdings in the West Midlands have an increased percentage of total farm area as un-cropped land within the participating AES. In other regions, differences were less distinct (Westbury *et al*., 2011).

At present, there are no agreed methodologies to evaluate the benefits of particular AES, or to track the environmental consequences they lead to (Westbury *et al*., 2011). Garforth *et al*. (2002) also comment that very little data exists on the effects and the impacts of information and advisory services. However, Garforth *et al*. (2002) do draw several conclusions regarding evaluation methods. Firstly, that in order to succeed, a scheme must have coherence between its design and the environment in which it operates (i.e. the ‘goodness of fit’ of a scheme to the environment it’s being applied to). Secondly, that successful implementation may also depend on the enthusiasm of the individual promoting, or implementing it. Thirdly, and probably the most key, schemes must build in provision for facilitation, such as having training, the design of user-friendly forms and self-assessment materials, and structured activities and demonstrations within a group setting (Garforth *et al*., 2002). In addition to these suggestions, Escobar and Buller (2014) highlight that currently Defra’s approach to considering farming behaviours and policy implementation focuses on factors that determine people's intention to act (e.g. attitudes, values, beliefs and knowledge), whereby behaviour is an outcome, with the wider context in which farmers make decision remaining out of scope. The authors suggest that the evidence base needs to be enhanced with social science approaches that understand behaviours not as a pre-determined outcome but as the social interaction through which, for example, farmers construct their identity, build their sense of professional community, relate to a wider set of stakeholders and to culturally embedded ideas about farming (Escobar and Buller, 2014).

3.6 Conclusion

Current policy has been reviewed with regards to SOC, and as has been demonstrated, there have been a number of treaties, policies and voluntary schemes related to soil, ranging from the global to the national scale.

The review has examined the various national, European and global policies and schemes, summarising the key points of the schemes and policies and how SOC and soil management have been affected. The most influential policy for European farmers, both now and in the future is the CAP. As a long term policy the CAP has experienced great change since its introduction. In particular, since the 1990s the CAP has demonstrated an increased concern over the environment, including soil management, especially that there is an increased recognition of SOC at the global scale in terms of climate change and carbon sequestration. The second pillar of the CAP has allowed an evolution in awareness of SOC, which has helped with the management of the environmental aspects of farming. Despite this change in the CAP in 2003, the knowledge of SOC was present in legislation at the global scale in late 80's and early 90's. This late development of policy to support the management of soil is likely due to the fact that soil is not seen a key issue in many countries within the EU. The CAP has received some negative press over the years but is constantly evolving as it is challenging to cover so many different farming practices in different countries, especially when considering a changing political environment. In terms of future development in policy that affects soil management, following the withdrawal of the SFD, it is unknown whether there will be any further policy development in terms of direct soil regulation, and whether the need for such regulation is perceived as being required.

The national policies that are in place in England have, like the CAP, developed rapidly in a relatively short period. Unfortunately this means that the various schemes outlined above have not been in place for long enough periods for proper metrics to be developed. However, they appear to be having a positive impact on farming practices in England.

What has been highlighted as part of the review of polices above is that SOC is a difficult thing to manage directly and is therefore managed as part of other schemes. This does mean that farmers might not be aware of the effects these schemes have on SOC. Despite these points the policies in place seem to encourage good SOC management, preventing the intensification of agriculture, the down side being that many of these schemes are voluntary. Their success therefore, depends upon farmers implementing the schemes and having an initial driver to do so.

There are many aspects to consider when looking at the advisory system and how farmers negotiate it. As this review has highlighted, the role and expectations of farmers has changed over the years and will likely continue to do so, as the regulatory and policy environment is updated. Farmers are therefore expected to maintain and expand their knowledge in order to keep up with the expectations of those policies. How knowledgeable farmers are in regards to environmental aspects of farming is disputed, but farmers themselves appear to feel they are very well informed. Farmers receive information from a number of sources with a high percentage of them noting that the majority of their knowledge comes from their peers. FAs have an important role in providing farmers with information and ensuring that they are able to apply their knowledge in a practical manner. FAs are also a key facilitator in the transfer of information from policy objectives to farmers, who can then develop the practical outcomes to the policy. FAs need to be seen, by the farming community, to be cognisant with the material they are outlining on to the farmers in order for the farmer to have a level of trust in the FA’s ability.

In order for SOC levels in English agricultural soil to improve, FAs and farmers must have access to information and policies which encourage good soil management and practices which promote increased SOC levels. As has been demonstrated in this review, at present, whilst SOC is indirectly influenced by pieces of legislation, there is nothing specific on this topic. SOC has not been presented as the focus of any agricultural policy or legislation and nor does it feature predominantly in AESs. This reflects that SOC has as yet to be seen as an issue which requires direct policy

The aim of this review was to address objective 2a; identify and evaluate current information, policy and farm management advice regarding SOC, tracing the agricultural advisory pathway. This has been achieved by evaluating those organisations, treaties, polices and schemes at the global, European and national level.

A review of the key actors involved in translating policy at the farm level has also been conducted, to see how effective these measures are at creating changes and improving knowledge. The outcomes of this review will feed into Chapter 4, where knowledge of polices and how farmers and FAs negotiate the advisory framework will be employed.

CHAPTER 4: METHODOLOGY

The methodology was designed with careful consideration of the original research questions and objectives, taking into account the results and conclusions drawn from the literature reviews. From the outset the overall aim of this thesis has been to understand how soil organic carbon (SOC) is accounted for, in regards its material and physical value, and also in terms of its precedence and societal importance, within agricultural practice. To achieve this, the research has sought to identify, firstly, how SOC and its protection and enhancement has been incorporated into agricultural policy and on-farm decision making, and secondly, how individual management practices have impacted levels of SOC in agricultural soil.

The focus of this thesis is the farm; the SOC content of the farmland and the decision-making and management processes that impact upon that content. The investigation and analysis of the SOC content on sampled farms was undertaken using a range of techniques which are described further on. As SOC is an emerging, yet still relatively minor area, of agri-environmental policy as previously demonstrated in Chapter 3, it was decided to include an investigation of how SOC advice was framed and communicated to farmers by interviewing farm advisors (FAs). This was conducted in addition to carrying out detailed case study interviews with farmers to investigate how they perceive SOC as a policy and management issue.

To address both the social science and soil science elements of this research, twin methodologies were designed. Farmer and FA interviews were coordinated with on-site inspections of management techniques and detailed soil analysis. In this way, discourses, practices and outcomes could be related together into a holistic understanding. The decision was made to compare two different regions to provide a wider perspective of the response of farmers and advisors to these issues. As outlined in the introduction, taking an interdisciplinary approach to environmental problems is seen by many academics (Mettzger and Zare, 1999; Steele and Stier, 2000; Miller 2013; Fazey et al., 2014) as a key step in addressing a number of global environmental issues. As highlighted by Fazey et al. (2014), interdisciplinary research is increasingly being promoted to enhance the understanding of the environment, identifying holistic policy solutions and assisting in their implementation, which is fundamentally the overall aim of this thesis. This once again justifies the approach taken here, to investigate both the social/political and scientific sides of the issue of SOC levels in agriculture.

This chapter will first set out the process by which the case study areas were selected and will then go onto provide details on the methodologies and approaches adopted for the social and the soil science components.

The objectives addressed in this section are:

***Objective 1b**: Construct a sample of farms from two contrasting regions of England representing a range of farming practices.*

***Objective 1c**: Measure SOC levels in soil samples for paired sites, representing different farming practices, comparing and contrasting variations between management approaches.*

***Objective 2b**: Assess current policy and farm management advice regarding SOC and the practical impact it has on farm management decisions by conducting interviews with farm advisors.*

***Objective 2c**: Analyse farmers receptiveness to SOC related policy and advice through conducting interviews.*

***Objective 4a**: Analyse SOC levels in soil samples for paired sites representing different farming practices (ranging from conventional, high carbon input/organic and no-till regimes) in England.*

4.1 The Case Study Sites

Although two different methodologies were employed for this research, one drawing on social science, the other on soil science, both originate from an initial common objective;

Objective 1b: Construct a sample of farmers from two contrasting regions of England representing a range of farming practices.

The case study sites are critical to this research as they provide a means to bring the social and soil science research together within distinctive but individually coherent socio-economic and natural contexts. For the soil science component of the research, it was essential to identify and work within areas of relatively similar soil type and land-use regime so that management effects on SOC could be identified and studied. For the social science component, it was essential to work in areas of coherent land-use yet variable management practice. For comparison, it was important to identify areas of contrasting soil type, landscape, meteorological regime, land use and agricultural priorities. As agricultural policy making is devolved to the constitutive countries within the UK, and accepting that the focus of this study would not include Scotland, Wales or Northern Ireland, the decision was taken that the selected study areas should lie in two different English regions.

4.1.1 Study Area Location

The research was based in the South Western (SW) and Eastern regions of England. The two regions are distinct from each with regards to climatic variations, soil types and agriculture practices. The majority of agriculture in the East is arable production with some pig farming, compared to the SW where livestock farming forms the largest component of agriculture production. For example, in 2013, the East of England produced a total crop output to the value to £2119 million, compared to £886 million in the SW. For livestock however, the SW produced a total output of the value of £2266 million, whereas in the East, it was £1248 million (Defra, 2014a). Out of the 1.4 million ha farmed in the East during 2013, most of this was given over to wheat (31%), other cereals (13%), permanent grass (13%) and oilseed rape (12%). In the SW, 1.8 million ha was farmed during 2013. Half of this was used for permanent grass (primarily used for livestock grazing), while wheat accounted for only 8% and other cereals, 11%. Another distinct contrast between the two regions is the output of milk. In the SW, the output of milk production came to the value of £975 million, whereas in the East this value was only £57 million, showing that dairy farming is more prevalent in the SW (Defra, 2014a). These figures display the differences between the two regions in terms of agricultural production, justifying the reasoning for comparing the two areas, allowing a comparison of different farming types and managements and how they relate to SOC management.

Based on the differences in land use highlighted above, it is fair to presume that soil management approaches differ between livestock and arable farmers. Having reviewed the initial research, it was assumed that soil and SOC would be of greater concern in arable farming due to the greater reliance on the soil system for crop success compared to livestock farming.

With regards to climate, as demonstrated in figures 4.1, 4.2 and 4.3, there are significant seasonal variations between the two regions for average rainfall and temperatures, along with soil temperature. The SW receives, on average, more rainfall in both the summer and winter months than the East (figure 4.1). The East has higher average summer temperatures; whilst the SW has warmer winter months (figure 4.2). This is also reflected in average soil temperatures, with the SW having warmer soil during the winter months, but cooler soil during the summer (figure 4.3). As outlined in

Chapter 2, temperature and moisture levels can impact the decomposition rates of Organic Matter (OM), influencing the SOC levels.

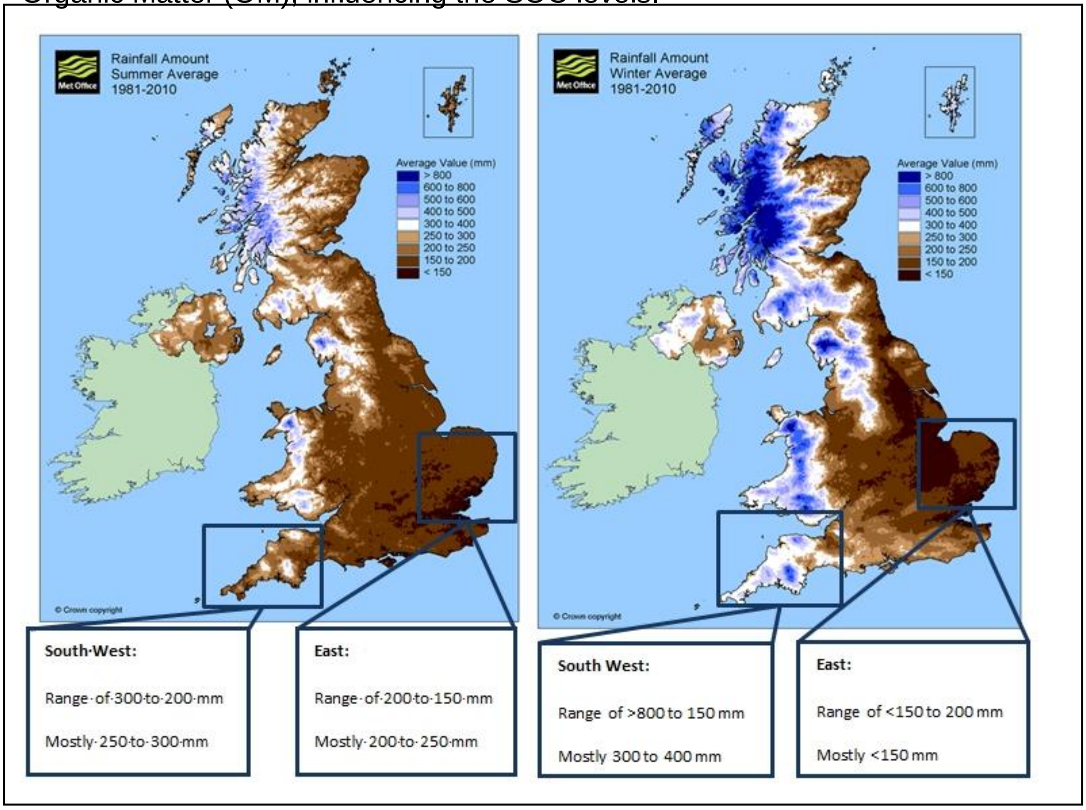


Figure 4.1: Average rainfall for the summer and winter months of the of the UK with the East and South Western regions highlighted from 1981 - 2010 (Meteorological Office, 2014)

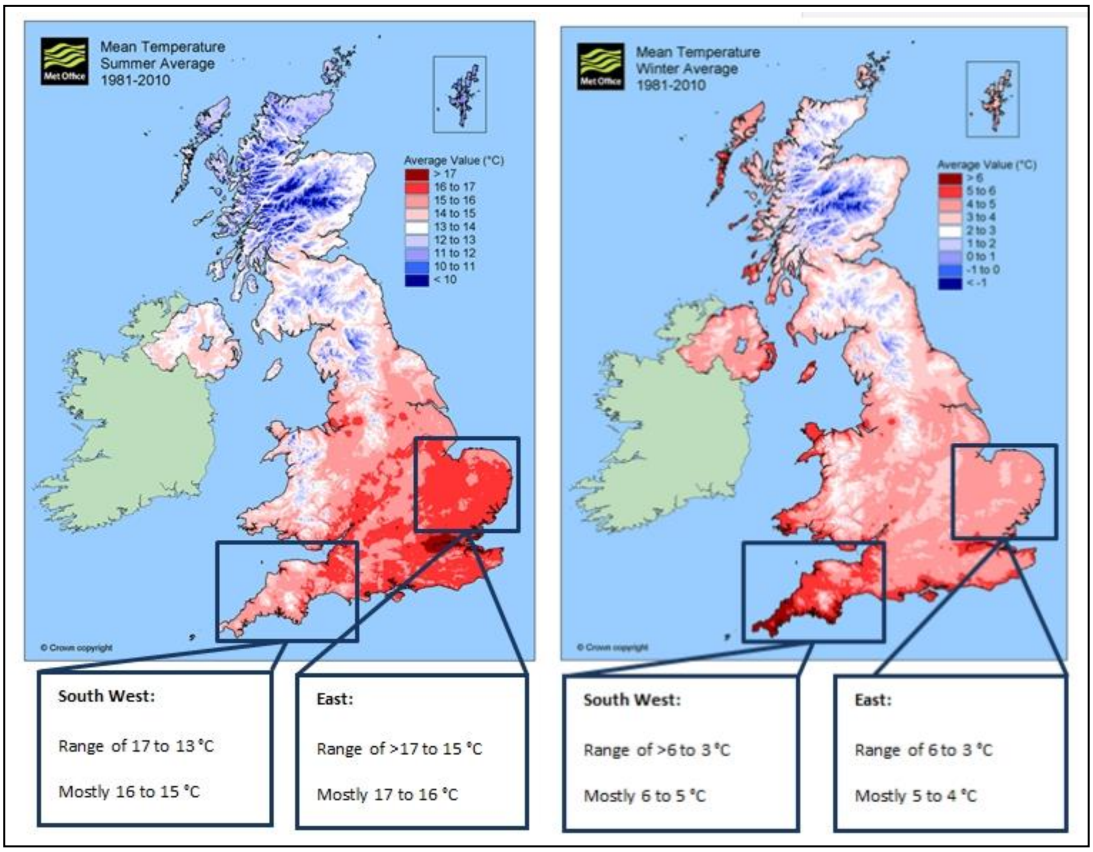


Figure 4.2: Average temperatures for the summer and winter months of the UK with the East and South Western regions highlighted from 1981 to 2010 (Meteorological Office, 2014).

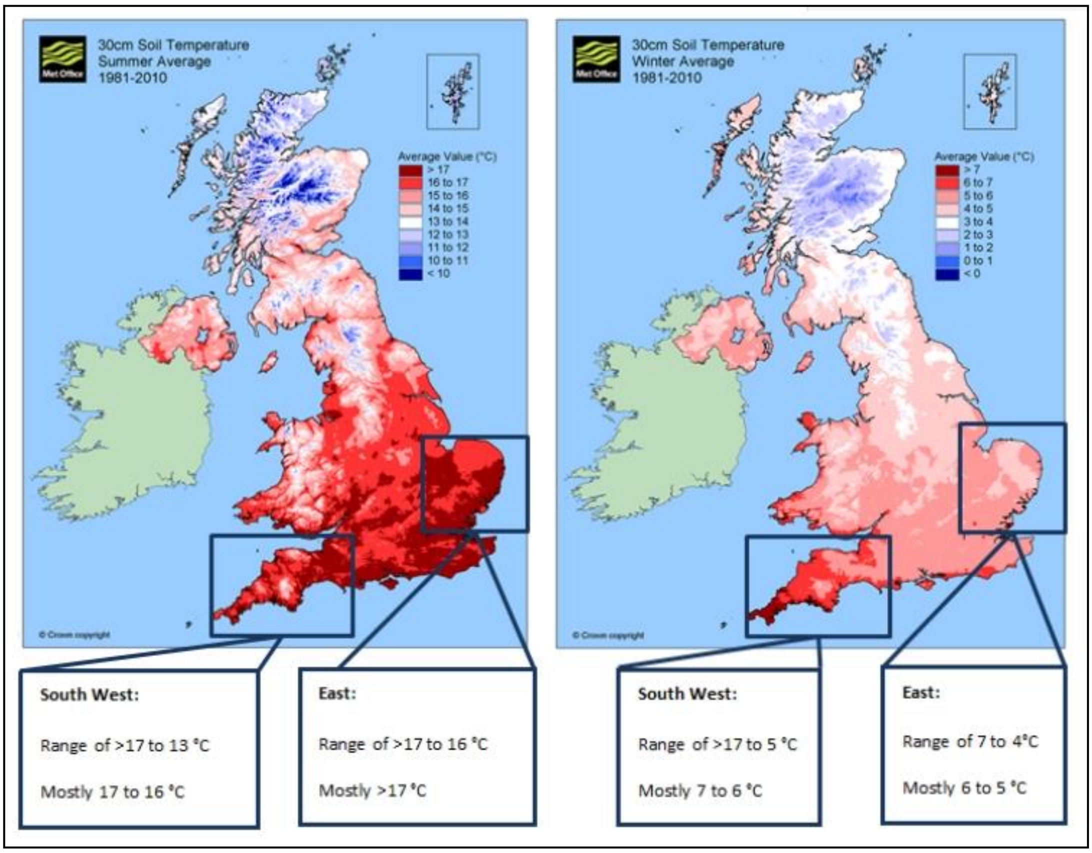


Figure 4.3: Average soil temperatures for summer and winter in the top 30 cm for the UK with the Eat and South Western regions highlighted from 1981to 2010 (Meteorological Office, 2014).

Figure 4.4 demonstrates the variations in soil types across the two regions. The SW largely has acid loamy and clay soils which are freely draining or slowly permeable (mid and light pink and light green, as per figure 4.4) with some blanket peat bog (purple). The East also has loamy and clay soils but these are slowly permeable or have impeded drainage (dark and mid green). There is also a large area of coastal flat soils (mid and dark blue) and some sandy soil (orange). The greater area of sandy soils in the East is indicative that the region may have less SOC content compared to the SW. Soils with high sand contents naturally hold less organic material than those with high clay contents and peat soils.

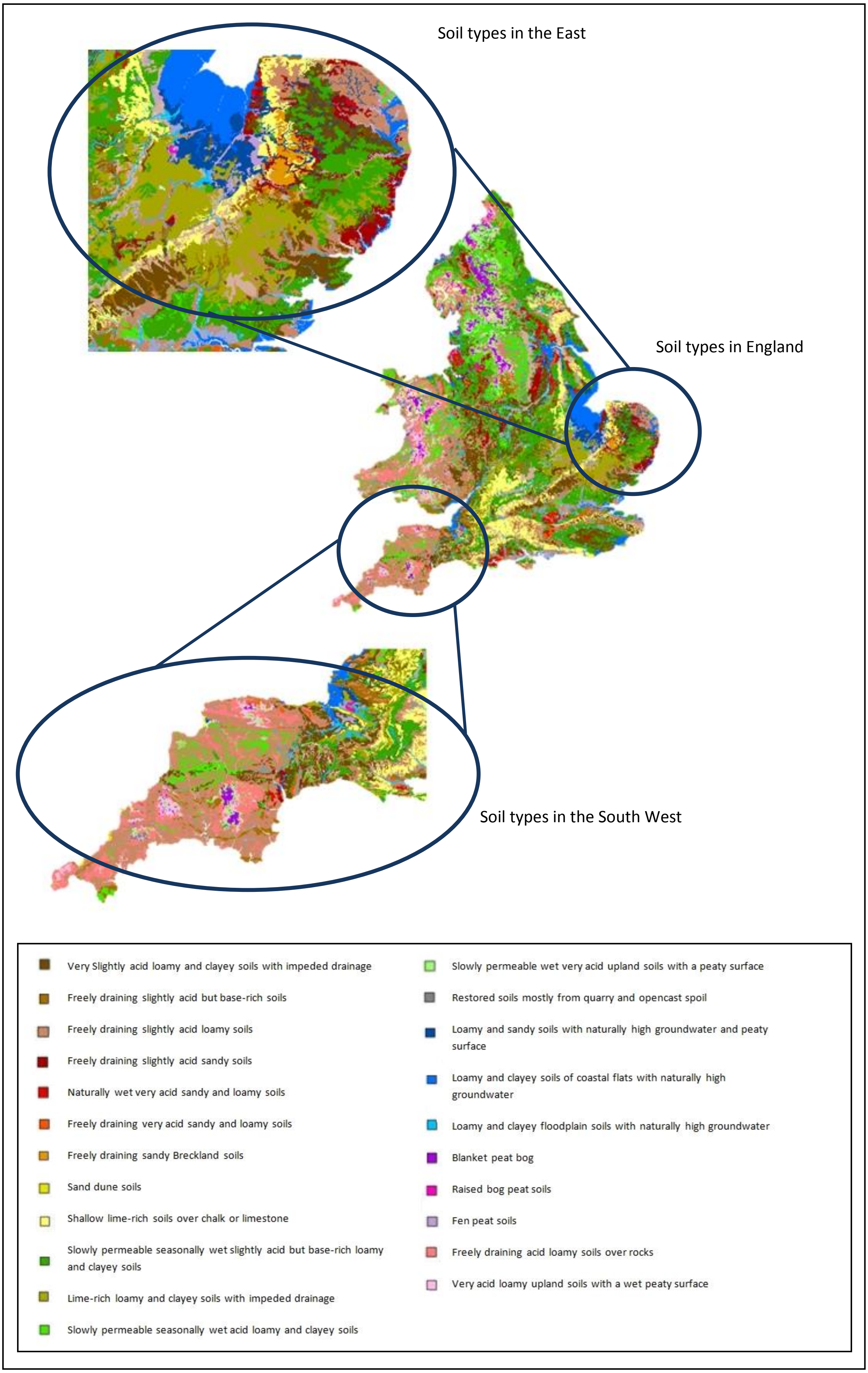


Figure 4.4: Soil maps of the South West and Eastern regions of England (NSRI, 2014)

4.2 Sampling Plan and Research Design

The following section addresses the two methodologies undertaken; the social science and the soil science. The social methodology was designed to address the following objectives;

Objective 1b: Construct a sample of farms from two contrasting regions of England representing a range of farming practices.

Objective 2b: Assess current policy and farm management advice regarding SOC and the practical impact it has on farm management decisions by conducting interviews with farm advisors.

Objective 2c: Analyse farmers receptiveness to SOC related policy and advice through conducting interviews.

The soil science methodology was designed to address objective 1c and 4a;

Objective 1c: Measure SOC levels in soil samples for paired sites, representing different farming practices, comparing and contrasting variations between management approaches.

Objective 4a: Analyse SOC levels in soil samples for paired sites representing different farming practices (ranging from conventional, high carbon input/organic and no-till regimes) in England.

As has been previously mentioned, a case study approach was chosen as the most suitable means with which to address these objectives and undertake this research. The use of case studies allows for the combination of the social and soil science methodologies. The use of case studies, defined as ‘a particular instance of something used or analysed in order to illustrate a thesis or principle’ (Oxford Dictionary, 2015b), was chosen as a suitable approach. Using illustrative case studies provides a ‘somewhat’ representative view on the situation at the time of sampling, not being representative (small numbers involved, and only two regions investigated) but not unrepresentative (reflects variations in farming practice and the regions at the time of sampling). Case studies have been identified for their potential for holistic approaches to knowledge-making (Orum *et al*., 1991),and as being suitable for the interweaving of different methodological and interdisciplinary approaches (George and Bennet, 2004), as is the case with this research. Although the ability to generalise from case studies to broader, more general contexts is sometimes offered as a criticism of the approach, Flyvbjerg (2006) has countered this by asserting that case studies provide empirically rich detail along specific lines of enquiry.

4.2.1 Introduction to the Social Science Methodology

The objectives of the social science component of this study were, firstly, to assess current policy and farm management advice regarding SOC and the practical impact it has on farm management (objective 2b) and, secondly, to analyse farmers receptiveness to SOC related policy and advice (objective 2c). For both objectives, a face-to-face semi-structured interview approach was adopted.

Interviews are a well-known, tried and tested methodological approach within the social sciences and were deemed particularly appropriate to address the aforementioned objectives. Their strengths and advantages are well documented (see Lindsay, 2003; Cloake *et al*., 2004; Kitchen and Tate, 2013). Interviews are, as Robson (1993) maintained, a relatively easy ways of obtaining information. A well-structured, carefully prepared interview, drawing upon the skills of the interviewer and a rapport between the interviewer and interviewee, is a vital tool. There is growing acknowledgement within human geography and the social sciences that interviews record ‘what people say’ and not necessarily what they might actually think or do. However, when combined with site visits, practical knowledge and parallel methodologies, they can provide the basis for a rich analysis of individual and societal actions. Certainly, in this research, the decision to undertake face-to-face interviews was based on the understanding that they would provide a more detailed and personal account on the subject of SOC, than compared to postal or internet questionnaires.

The majority of the interviews were done on location at the interviewees’ place of work or home, with only one being conducted over the telephone. Conducting interviews in such a personal manner allowed for interviewees to provide answers through more narrative stories and anecdotes, as well as off-topic conversations; that were just as valuable as the direct answers from the interview questions. Interviews are an interesting method of data collection as they are a reflection of what the interviewees think is the norm or the truth; it is their reflection of what they think is right. As Holstein and Gubrium (2006) state, during an interview, reality is continually under construction. This is both a positive and a negative factor in their use. Positive as it provides a true reflection of what the interviewee thinks is correct, but negative, if for example, the purpose of the interview was to gather factual information. There is also the risk that the interviewee may withhold information if they think it will portray them negatively. It was decided that, for the social science component, a sample size of approximately 20 farm advisors and 20 farmers (10 from the East, 10 from the SW) was appropriate. The aim of the interviews was to provide an illustrative and personal account, which meant that a large sample size would not have been feasible due to the time taken to undertake the interviews. This was especially true given the time needed to undertake the soil sampling. The small sample size is a limitation of this research but the interdisciplinary nature of this work is a critical component, so it was important that an equal balance was struck between the two methodologies.

4.2.2 Farm Advisor Interviews

Aim

The aim of the FA interviews was to generate evidence on;

- What farm-facing advice on SOC exists and how it is transmitted.
- How advisors felt this advice was taken on board in farm management decisions.
- Whether SOC is considered prominent in agri-environment policy and farm facing advice.
- Whether the current policy environment is conducive to promoting good soil and SOC management.

Identifying Farmer Advisors

When identifying FAs to interview, a number of considerations had to be taken into account. They had to work in either the SW or the East of England (the two case study regions), and work for a range of organisations, to present a true picture of the advisory system. An effort was made to ensure that the FAs identified and interview came from a range of backgrounds, those who were self-employed, who worked for small and large agri-consultancies, governmental bodies and agri-environmental schemes (AESs). This spread aimed to provide a wide picture of the current advice provided on SOC.

A number of mechanisms were used to identify the FAs. Contacts provided through the University were contacted first. Other resources included; emailing local departments of national government bodies and charities asking for advice or contacts, and contacting people whose names had been provided by previously interviewed FAs. This snowballing approach was used rather than using a directory listing advisors as this would have largely only included those who were self-employed or worked for small companies, rather than those who worked for government organisations or charities. Contact was initially made by email, if an email address was available, and then with a phone call, if required, two or three days later. The response rate from the emails was reasonably good. In total 50 emails were sent out with 30 responding. In the end, 11 FAs from the East and 10 from the SW were interviewed (21 in total). The decision whether to conduct an interview from the email responses was based on who and where they worked, ensuring a fair representation of FAs were included, as well as their availability to take part in the interview (see Appendix III for a breakdown of where and for whom the FAs worked for). The interviewed FAs ranged from those working in consultancies (three from the SW, four from the East), government bodies (three from the SW, one from the East) and charities (two from the SW, one from the East), to those who were self-employed (one from the SW, and four from the East). Based on the Defra farm practice survey of Autumn 2012, this represents a true picture of where farmers receive their advice from. In the survey, 61% of holdings had used specialist independent farm advisors and was the most popular form of advice sought, with farming press and media as the next popular choice (56%) (Defra, 2013a). Five of the interviewed FAs fell within the category of independent farm advisor with an additional two working for small consultancies. However, 45%, 44% and 36% of the surveyed holdings used organised events, literature received in the mail and Defra related websites, respectively (Defra, 2013a), which is where advisors working for government bodies, charities and the larger consultancies are most likely to come into contact with farmers. Given that these three sources of information are ranked at 4, 5, and 6 out of 11 identified sources of information, justifies the use of these advisors in this research. The experience for each FA varied from 1 to 40 plus years within their current job. The FAs not only provided advice to farmers and land managers but to additional parties also, including government funded projects in addition to their FA role. The projects were for Department for Environment, Food & Rural Affairs (Defra), Natural England and the Environment Agency (EA). Other receptors of advice included other FAs, local authorities, water companies, compost plants, mineral/gravel extractors, land restoration companies, agri-industry companies, engineers and charities.

Interview Schedules

The interview schedule for the FAs was structured around the objectives previously stated. Each interview began with a brief explanation of the project and its aims, and the format of the interview. All the interviews were recorded, although the interviewees had the freedom to pause the interview if they wished to speak off the record. It was also made clear that they would remain completely anonymous, and only an overview of their job role and location would be incorporated into the results of this project. A common question set was used for all interviews to allow for direct comparisons between the responses. These questions can be seen in Appendix IV.

The interviews were divided into sections, with each section focusing on a different topic. The first section focused on their role as an FA. The purpose of the first section of the interview was to explore their job role, what types of farmer and other persons they came into contact with as part of their role, through what mechanisms did they advise their farmers and what advice did they provide on SOC. The second section had questions which focused on the responses they had received from farmers in relation to SOC advice. These questions were aimed to highlight reasons why it was felt, that farmers either take up the advice provided, or why they do not; including highlighting any conflicts between SOC advice and other farm management practices or advice. Also, the interviews outlined as to whether or not the FA being interviewed felt that SOC was seen as a management issue by farmers. The final set of questions centred on their personal opinions and whether they felt there was room for improvement within the current advice and legislation.

4.2.3 Farmer Interviews

Aim

The aim of the farmer interviews was to generate evidence on:

- The receptiveness of farmers to treating SOC as a policy and management issue.
- What farm-facing advice on SOC exists, along with its quality and extent.
- Whether SOC is prominent in agri-policy and farm-facing advice.
- By which processes policy and advice is taken on board in farm management decisions.
- Whether the current policy environment is conducive to promoting good soil and SOC management.

Identifying Farmers

Identifying farmers to interview was an important task. The interviewees' farms were to be located in either the SW or the East of England, and there was also a need to ensure that the selected farmers managed a range of agriculture systems and practices (organic, conventional tillage, minimum tillage, those in agri-environment schemes (AESs) and those which were not). Given the nature of the study, it would have been very easy to identify largely organic farmers to interview as these would have been more likely to display high levels of engagement with the issue of SOC.

A number of mechanisms were used to identify the farmers. Firstly, initial contact lists were provided by the FAs who were interviewed prior to the farmers (the farmers being in receipt of their advice). Other resources included contacts through the University, using the Open Farm Sunday website, and contacts provided by previously interviewed farmers in a standard 'snowballing' approach.

Contact with farmers was initially made by email, if an email address was available, and then with a phone call, if required, two to three days later. The response rate from the emails was reasonably high. In total 26 emails were sent out with 21 responding resulting in 11 farmers from the East and 10 farmers from the SW being interviewed (21 in total). All the farmers in the SW had livestock; combining a range of cattle, sheep and chickens with only one being organic. Comparatively, in the East, only one farmer had livestock, the rest being solely arable farmers, two of whom were organic. This was consistent with farm business data (Defra, 2014a) and allowed appropriate decision to be made about the representativeness of the selected sample.

A full breakdown of the selected farmers can be seen in Appendix V. This sample size was chosen due to the nature of the project which is to provide in-depth examples and personal accounts by the farmers. In depth material from selected farmers was judged as more revealing than more superficial information from a larger number. A breakdown of the farmers; where they farm and what crops they grow/animals they husband can be seen in Appendix V.

It is worth noting that the farmers contacted through this work were generally pre-disposed to think about their soils and may well have been somewhat more 'forward thinking' than others amongst the farming population. This positive pre-disposition to soil management is an issue that would have been very difficult to overcome, as a farmer who is not interested in current research or their soil, would not be responsive to an interview on the subject and simply would not respond. To try and overcome this issue, the interviewed FAs were asked to speak to their farmers, whether forward thinking or not, and encourage them to take part in an interview. It was hoped that if taking part in this research was recommended by someone the farmer trusted and had a good relationship with, they would take part. On a positive note though, the research was University led and was not being sponsored by a company or government body, and therefore was without any 'hidden agendas'. This meant that I was seen as an approachable and unbiased figure. I was there to discuss the soil matters with the farmers, rather than to scrutinise their practices or to test their knowledge.

Interview Schedules

The interview schedule for the farmers was structured around the aims previously stated. Each interview began with a brief explanation of the project, its aims, and the format of the interview. All the interviews were recorded, although the interviewees had the freedom to pause the interview if they wished to speak off the record. It was also made clear that they would remain completely anonymous, and only their general location and overview of their farm would be incorporated into the results of this project. A common question set was used for all interviews to allow for direct comparisons between the responses from farmers.

All interviews began by explaining my interest and background in the subject and how the research project had come about. It was also clearly stated that I was not from a farming background, so this research was a steep learning curve. This was explained to make the interviewees feel at ease, so they did not feel as if their knowledge was being tested. This also allowed some rather basic questions to be asked, in order to get the farmers to explain what they would consider normal and self-explanatory practices, in more detail.

The interview schedule was divided into sections with questions focusing on certain themes (See Appendix VI for the interview schedule). Section one focused on their farm and basic soil management practices. The questions in section one had the overall aim of investigating as to whether or not the farmer being interviewed considered soil and SOC an integral part of their farming system, and how they managed it. Section two focused on what advice the farmer received, what they thought of it, and how they thought it could be improved.

The questions in this section highlighted where the farmer received information from, what AESs, if any, they were involved in, and their perception of how legislation and government initiatives had impacted upon their farming decisions and practice. There was also room for them to express how they felt policy and advice could be improved and where current weaknesses were.

4.2.4 Interview Analysis

Following an interview the recording was transcribed. When all interviews were completed, the answers to each question were analysed and noted (see appendix III and V). Following this, the transcriptions were read through several times to highlight the main themes and issues to come of out the interviews. Those themes which were repeatedly mentioned and which related to the original aims and objectives of this project were discussed. Having undertaken an initial scoping analysis of the interview data, the main themes to emerge from the data set were identified as the following:

- SOC and its importance: Analysing the views and receptiveness of the farmers and FAs to SOC, will highlight whether it is considered as part of farm management decisions, and the varying importance SOC may have between different regions or farming practices. This topic addresses objectives 2b, 2c and 3b.
- Agri-environmental policy, legislation and AESs: By analysing and discussing the farmers' and FAs' experiences and views of current English agri-environmental policy and AESs with particular regards to SOC, it is possible to assess the uptake and success of voluntary schemes, the suitability of schemes and policy, and whether they promote or inhibit SOC conservation in English agriculture. This topic addresses objectives 2b, 2c and 3b.
- The sourcing and application of OM: Discussing OM in terms of its benefits, the reasons why it is added, and most importantly, where it is sourced from and how it is applied addresses objectives 3a and 4b. This topic also highlights key variations between farming location and farming practices, and the difference in OM sourcing, use and application.
- Carbon (C), climate change and carbon sequestration: By assessing the views and experiences of the farmers and FAs with regards to these important topics, it is possible to evaluate some of the key obstacles in improving SOC levels. This subject address research question 3 by placing the issue of SOC into a wider context.
- Farming practices associated with enhancing SOC: The opinions and experiences of farmers and FAs with reference to SOC enhancing practices will be discussed, analysing what practices they feel work and are effective. This addresses objectives 2b, 2c, and 3a.
- Recommendations made by the farmers and FAs regarding advice and policy specifically regarding SOC.

These themes formed the basis for the discussion of the social data set which can be seen in Chapter 5, with the exception of the recommendations which are addressed in Chapter 7.

4.2.5 Soil Sampling

The soil science methodology was designed to measure and analyse SOC levels in soil samples from paired sites, representing different farming practices (objectives 1c and 4a)

Farm Selection and Locations

On selected farms, measurements were taken of SOC content. The farms selected for soil sampling were all from the East, were managed farmers who had been previously interviewed and were chosen depending upon their farm management. They were also selected in 'pairs'. For example, two farms were selected within a 10 mile radius of each other, which had similar soil types, and which were practising different types of farm managements (see table 4.1 and figure 4.5). This was done so that a comparison could be made between geographically close farms, so that a true evaluation of the effects of the farm managements could be analysed. All the farms sampled were managed by farmers that had previously been interviewed to improve the quality of the case studies and to provide additional, personal accounts of managing the farms. This has provided the study with a further integrated, interdisciplinary and holistic dimension. The sampled farms had a range of farm management practices as demonstrated in the table below. When identifying farms to sample and to pair, consideration was given to the type of practices and systems being undertaken. The decision on what specific agricultural practices and systems to focus on was based upon the initial literature and science review conducted in Chapters 2 and 3. It was therefore decided to focus specifically upon different tillage regimes and OM amendments and whether or not the farm was certified organic. For each pair, 'opposite' practices were chosen to measure, for example, organic farming system and a conventional farming system. Whilst it would have been desirable to measure farms from the SW also, time limitations prevented this.

In total six farms were chosen to sample, creating three distinct investigations. This sample size was thought suitable, as it allowed for a more detailed investigation of SOC levels and the undertaking of interviews with the farmers, which would not have been achievable with a larger sample size.

Table 4.1: A table summarising the location and management practices of the sampled farms.

Pair	Farm	Location	Farm Management Practices
Pair A	Farm 1	South Suffolk	1. Baseline Field: Permanent Pasture used for low intensity sheep grazing. 2. 3 fields which have been under organic farming for 12 years. Conventional tillage. Crop residue incorporated. 3. 3 fields which have been under organic farming for 4 years. Conventional tillage. Crop residue incorporated.
	Farm 2	South Suffolk	1. Baseline Field: Permanent grassland occasionally used for horse grazing. 2. 3 fields under 15 years of minimum tillage. Crop residues are left. 3. 3 fields which have had 9 years minimum tillage followed by 6 years of conventional ploughing. Crop residues are incorporated.
Pair B	Farm 3	North West Essex	1. Baseline Field: Permanent grassland. Not used for anything. 2. 3 fields which have been under non-inversion tillage for 7 years. Crop residues are left. 3. 3 fields which have been under non-inversion tillage for 5 years followed by 2 years conventional ploughing. Crop residues are incorporated.
	Farm 4	South Cambridgeshire	1. Baseline Field: Permanent grassland. Not used for anything. 2. 3 fields which are conventionally ploughed 1 in every 3 years. Crop resides are incorporated. 3. 3 fields which have been under non-inversion tillage for 5 years. Crop residues are left.
Pair C	Farm 5	South West Suffolk	1. Baseline Field: Unmanaged woodland. 2. 3 fields under direct drilling for 5 years. Crop residues are left. 3. 3 fields under direct drilling for 2 years. Crop residues are left.
	Farm 6	South West Suffolk	1. Baseline Field: Permanent grassland. 2. 3 fields conventionally ploughed. Chicken manure added annually. Crop residues are incorporated. 3. 3 fields direct drilled for 2 years. Crop residues are left.

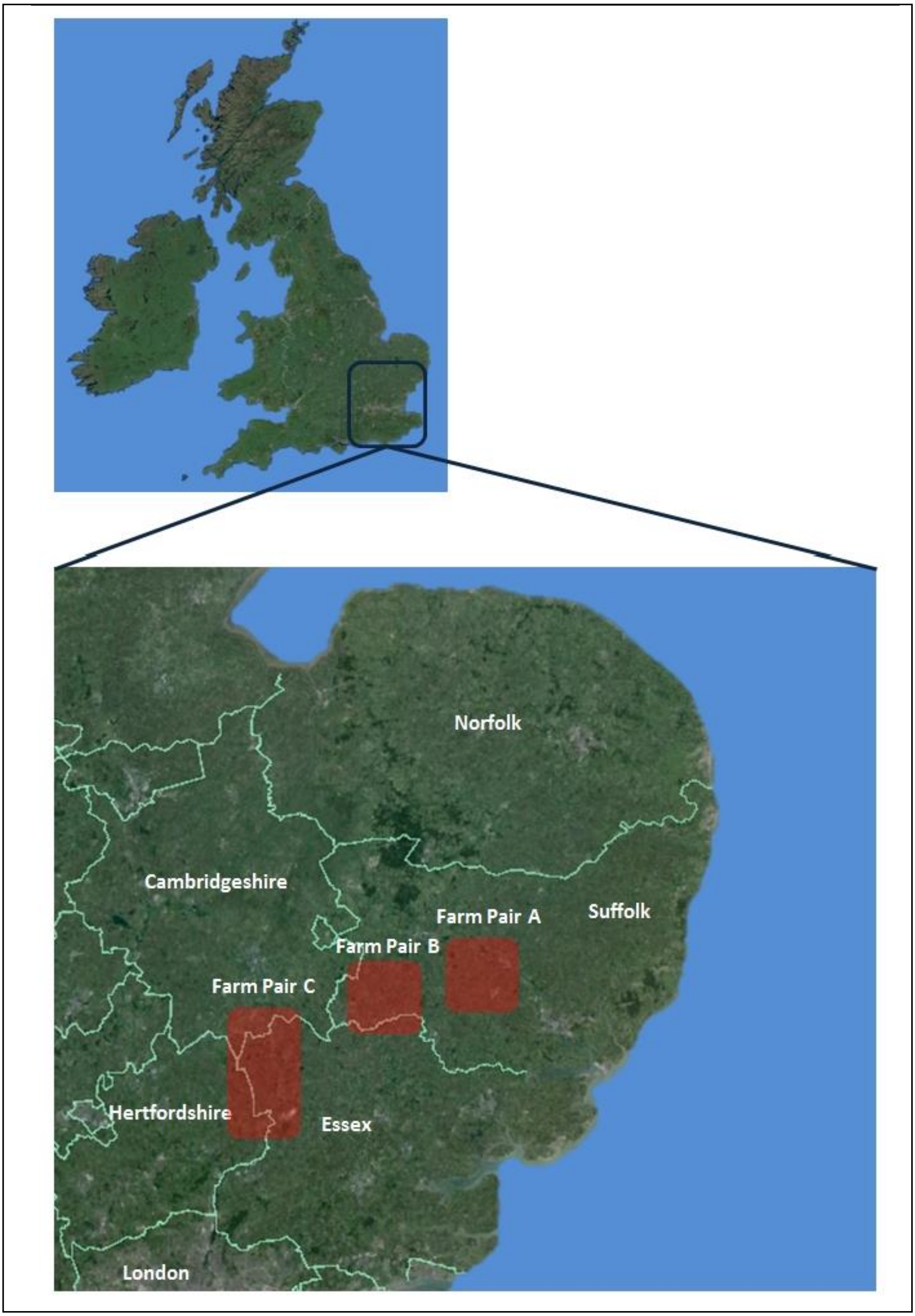


Figure 4.5: Map of the UK, highlighting the areas in the East of England where sampling took place for each of the Farm Pairs. (Map adapted from Google Earth, 2014).

Sampling Plan

An outline of the sampling plan can be seen in figure 4.6. At each farm, a baseline field was identified, where it was assumed the highest SOC content of the farm would be found. This was an area that was not in agricultural production and was usually either an area of woodland or grassland, depending upon what was available at each farm. Six fields were sampled at each farm, plus the baseline field. These fields were generally split into two categories, with three fields under one management practice and three fields under another. Figure 4.6 summarises the sampling plan for each farm. Within each field, three sampling locations were allocated. The three locations were chosen at random, using a random number table, however it was ensured samples were not taken from erosion, marginal and depositional areas of the field. The sample plan allowed for a reflection of the SOC content of each individual field. This is suitable as the research is addressing the relationship between land management and SOC, and not spatial distribution of SOC within a field. Each sample was taken using a Whacker Hammer to 50 cm in depth to allow for depth analysis. Measurements of SOC were taken from 0 to 10, 10 to 20, 20 to 30, 30 to 40 and 40 to 50 cm depth. The organic C levels measured from each field were compared to the organic C found in the baseline soil. The soil samples were taken on one occasion and there was no repeat sampling.

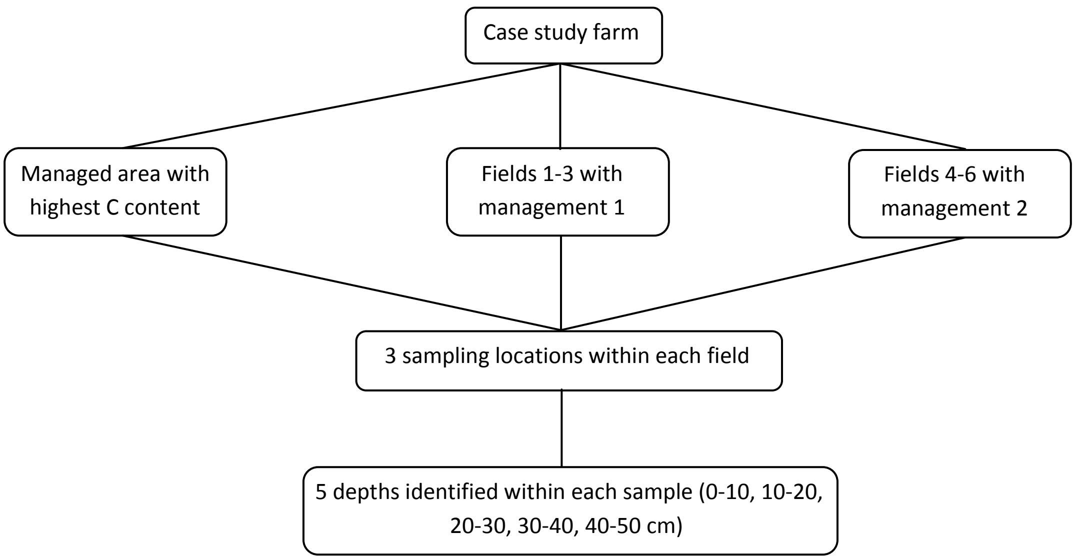


Figure 4.6: Simplified sampling plan for case study farms

4.2.6 Laboratory Analysis

To address the requirements of objectives1c and 4a, the soil's pH, soil particle size, total C, C:N ratio and SOC were measured, as demonstrated in table 4.2.

Table 4.2: Laboratory measurements taken on the soil samples from each farm, detailing which cores were used.

Measurement	Baseline	Management 1	Management 2
pH	Core 1	Core 1 of each field	Core 1 of each field
Soil Particle Size	All	All	All
Total C	Core 1	Core 1 of each field	Core 1 of each field
SOC	All	All	All
C:N Ratio	All	All	All

Soil Preparation

After taking the core samples in the field, the cores were cut into 10 cm length pieces and placed in labelled plastic bags.

Upon return to the laboratory, the samples were weighed to two decimal places and then air dried in a drying oven at 40°C in their sample bags. They remained in the oven for up to seven days until the samples were dry, although the duration varied slightly depending upon initial moisture content. Once cooled, the samples were then re-weighed on the same scales to ascertain their dry weight. The weight of the bag was deducted from both measurements.

The dried samples were then sieved to 2mm particles to separate the stone fraction from the fines fraction. It was from the sieved sample that samples for the laboratory analyses were then taken.

pH

pH was measured to characterise the soil and provide background information. It also proved important in determining the amount of inorganic C present in the soil, as inorganic C is linked to higher pH (more alkaline). The importance of this will be discussed further on in the methodology when deciding on an approach to measure SOC. As it was not a key measurement in determining SOC levels, it was felt that measuring the pH of all the samples was not necessary. It was therefore decided that only the samples taken from core one from each field would be measured. The pH was measured using a pH meter and probe (Checker by Hanna Instruments). The probe was collaborated using buffers of pH 4 and pH 7 before every measuring took place. Approximately 1g of sample was placed into a 100 ml glass beaker. Distilled water was then used to 'wet' the sample. The contents of the beaker were then swirled around to fully combine the sample with the distilled water. The probe was then placed into the water sample solution and held there until the reading on the meter settled at a pH level. Once the pH level was recorded to an accuracy of two decimal places, the electrode of the probe was washed thoroughly with de-ionised water before being used to measure the next sample.

Soil Texture

The percentage of sand, silt and clay particles largely determines the amount of OM, and therefore C, that a soil is capable of holding. It also provided information on the value of comparing the paired farms to ensure that their soil type was similar. It is therefore critical that textural class of the soil was known so as to compare the total C results of soils with similar texture. The soil particles were measured using the Saturn Digisizer on all samples.

Approximately 10 g of the < 2 mm samples were weighed into 100 ml beakers to an accuracy of two decimal places. 10 ml of distilled water was then added to each sample, followed by 10 ml of hydrogen peroxide. The samples were then left for two to three hours with watch glasses, for the initial reaction to dissolve the OM. If after two to three hours the effervescence reaction had ceased, an additional 10 ml of hydrogen peroxide was added and then left overnight. When reactions were severe, a few drops of IMS were added to control the reaction.

The samples were then left overnight to ensure the reaction had ceased. They were then placed on electric hotplates, starting at a low temperature of 50°C which was gradually increased to approximately 100°C, and were left until the reaction of the hydrogen peroxide had ceased and a clear supernatant above the sample was present. This usually took around six hours.

Once cooled, usually the following day, the contents of the beakers were transferred into centrifuge tubes using a glass rod and distilled water to rinse the beakers. The tubes were then centrifuged at 25rpm for 1 hour.

The suspended soil from the centrifuge was then screened through a sieve (1000µm) using 0.4% sodium hexametaphospahte solution to rinse the tube with and to neutralise the hydrogen peroxide. A glass rod was also used to disaggregate the soil. The suspended solution was collected in 125ml plastic beakers. It was ensured that all soil residue from the centrifuge tube and from the sieve were washed through to a 125ml beaker, leaving behind no fine fractions.

The beakers were then placed on the carousel for the Saturn Digisizer for measurement. Before a sample of the solution was taken, each sample was treated with an ultrasonic wave to disperse the particles. A sample was then taken and the particle size was measured using the light scattering analysis technique. For each sample, a repeat set of three measurements was taken with the mean average being used as the final result. The results were exported to an excel worksheet.

Total Carbon

Total C was measured to characterise the soils, and proved to be of great value in determining a method for measuring SOC as it contains both inorganic and organic fractions of C, as discussed later on. As it was not a key indicator of SOC levels, it was felt that it was not necessary to measure the total C from all the samples and so it was decided that only the samples taken from core one of each field would be measured.

Samples were weighed on a micro balance to 4 decimal places, and weighed between 10 and 20 mg. The higher the perceived organic content was, the lower the weight. Samples were weighed into tin boats which were then folded over to secure the contents and then formed into a cube shape using tweezers and a micro spatula. The folded tin boats were then placed within a transparent box ready to be analysed. One blank tin boat, followed by a range of three calibration standards was used to begin the sequence for each transparent box. A check standard was then placed in every 8 to 10 samples. Ethylenediamine-tetra-acetic acid was used for the calibration standards, which has a known C and N value.

The samples were then fed into the elemental analyser (NA 2500 Elemental Analyser) where they were first burnt at 1000°C. The gases which were produced were then flushed with pure helium through various stages to a detector, which passes the information to a computer, giving the final determinations.

C:N Ratio

If a material has a low amount of Nitrogen (N) compared to the amount of C, it will have a large C:N ratio. Soil bacteria require a C:N ratio of 5:1 in order to grow (Forth, 1990). Soil and materials with C:N ratios with between 20 and 30 have just about enough N for the needs of decomposers (Forth, 1990). The C:N ratio is important, as if it is too high, a temporary N deficiency may occur which will prevent plants from growing effectively. Materials with smaller C:N ratios are good to add to soils, as it increases the available N for growing plants, and will lower the C:Nratio of the soil. The younger the C, the lower the C:N ratio. For example, humus[12] and animal muck have low C:N ratio, so will be decomposed quickly. The higher the C:N ratio, the slower the material will be decomposed. It was for these reasons that the C:N ratio of the soil was measured to assess the age and potential type and source of C present in the soil.

Total N was measured using the same method for Total C, using the Elemental Analyser. Total N was automatically measured when using the Elemental Analyser for all samples whilst being measured for SOC. Using this data the C:N ratio was calculated.

Soil Organic Carbon

SOC is integral to this research and so is the most important measurement to take to answer the original objectives. To measure the organic C content of the samples, the inorganic C had to be first removed. The necessity to do this became clear after measuring the total C for the first farm, where all but 3 out of the 18 cores for the fields, under the two types of management, had higher total C levels at depths of 40 to 50 cm than at the lower depths of 0 to 10 cm. A summary of the total C averages in table 4.3 demonstrates this. It was visibly clear that the samples had high amounts of inorganic C as there were pieces of Calcium Carbonate ($CaCO_3$)(chalk) within the samples.

Table 4.3: Average total carbon (%) for Farm 1.

Average Total Carbon for Farm 1 (%)			
Depth (cm)	**Baseline**	**12 Years Organic**	**4 Years Organic**
40 to 50	1.55	4.57	2.75
30 to 40	1.76	3.98	1.18
20 to 30	2.33	2.54	1.38
10 to 20	2.88	2.65	1.79
0 to 10	3.96	2.53	1.64

Firstly; Loss on Ignition (LOI) was conducted. Soil samples from farm one were placed into crucibles, weighing two or three grams per sample. The crucibles were then placed into a furnace at a temperature of 1000°C for two hours. The samples were placed in a desiccator to cool before being re-weighed to measure the amount of sample loss. However, LOI is not overly accurate and measures OM rather than organic C. Whilst organic C can be derived from OM results, it was felt that as the emphasis of this work is on organic C, an accurate measurement was needed rather than an estimate. As can be seen in table 4.4, the LOI results are fairly high in comparison to the total C results ascertained by the dry combustion method using the Elemental Analyser.

[12] Humus is the organic component of soil, formed by the decomposition of leaves and other plant material by soil microorganisms (Matthews *et al.*, 2003).

Table 4.4: Average Loss on Ignition (%) for Farm 1.

Average Loss on Ignition for Farm 1 (%)			
Depth (cm)	**Permanent Pasture**	**12 Years Organic**	**4 Years Organic**
40 to 50	4.19	4.15	4.29
30 to 40	5.05	4.34	4.95
20 to 30	6.59	5.82	5.54
10 to 20	7.73	6.08	5.94
0 to 10	10.83	6.19	5.91

Following a review of scientific literature, it was decided to try applying hydrochloric acid (HCl) to the samples in order to remove the inorganic C. Based on the method described by Van Moort and Vrieg (1970), 20 ml of 20% HCl was added to samples from farm one in 100 ml glass beakers. The samples were then left for an hour before being bought to the boil on the hotplate. HCl was added until no reaction was seen (approximately 60 ml of HCl). Following this, samples were air dried, weighed and analysed on the elemental analyser. Analysis indicated that the $CaCO_3$ was not fully removed from a large number of samples tested and so required additional applications of 20% HCl (up to 100ml in total).

Table 4.5 demonstrates some of the data obtained during these trials. With the first trial, approximately 60 ml of 20% HCl was added to the samples over a 48 hour period. The second trial which was performed on only a selection of the samples used previously, had up to 100 ml of HCl added over a 62 hour period. Whilst this seemed to have successfully removed the inorganic C from the samples, it was a very resource and time heavy method.

Table 4.5: Total organic carbon (%) using the direct HCL application method.

	Permanent Pasture		**12 Years Organic**		**4 Years Organic**	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Depth (cm)	Core 1		Averages for all cores	Averages for all core 1 (x3)	Core 1	
50 – 40	0.5	0.55	2.18	0.62	0.32	0.32
40 – 30	1.12	1.19	1.33	0.75	0.45	0.42
30 – 20	1.81	1.67	1.13	1.20	1.08	1.09
20 – 10	1.82	2.13	1.34	1.56	1.16	1.28
10 - 0	3.28	3.38	1.32	1.55	1.37	1.31

A decision was therefore made to use a fumigation method as referenced by Harris *et al*. (2001) which proved to be more time and resource efficient and also more effective at removing $CaCO_3$.

For the fumigation method, plastic trays with small wells in, usually used to hold samples in foil capsules in preparation for the elemental analyser, were used. A trial was first done using Ethylenediamine-tetra-acetic acid, which was used as the calibration standard for the elemental analyser, to ensure that there was no contamination of the plastics from the tray. A small portion of each sample was placed in a well (see figure 4.7). A record was made of the sample placed in each well.

Once the tray was full, it was placed in a glass desiccator which contained a glass 100ml beaker of approximately 50ml of concentrated HCl in the bottom. The tray was placed on top of the beaker and the desiccator was sealed using petroleum jelly. The desiccator was placed inside a fume hood for the duration of the fumigation (see figure 4.8).

Figure 4.7: Soil samples placed into the ‘wells’ of plastic boxes ready for HCl fumigation.

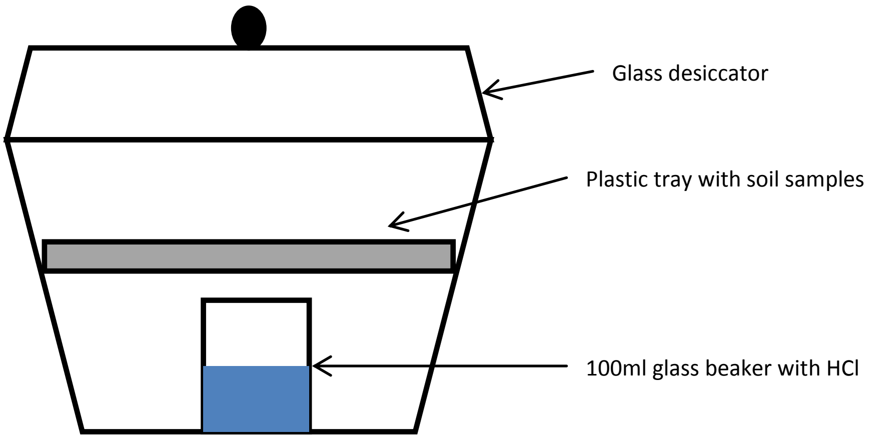


Figure 4.8: Apparatus set up for HCl soil fumigation.

The incubation period lasted for approximately four days (96 hours) which was found to be an adequate length of time as the results were similar to those from the previous trial of adding 100 ml of HCl over a 62 hour period. Once the incubation period was complete, the tray was removed from the desiccator and the fume hood and placed in a drying oven for 24 hours at 50°C to remove any HCl residue. Once cooled to room temperature, the samples were weighed for further analysis with the elemental analyser using the same method as used for total C analyses.

Data Analysis

The results from the laboratory analyses were analysed and compared between the farm pairs in order to assess the impact that different farm managements have upon SOC levels. Statistical analysis using analysis of variance (ANOVA) and analysis of co-variance (ANCOVA) were used to compare the difference in SOC levels between the farms. The statistical programme Statistica was used to perform this analysis.

4.3 Data Analysis

Following the data collection and initial analysis, the social and physical data were discussed and presented in separate chapters (Chapters 5 and 6). However, where possible, the two data sets have been used in conjunction with each other. For example, in Chapter 6 where the soil science data is presented and discussed, data from the interviews with the farmers is used to confirm some of the analysis. Chapter 7 focuses on the recommendations made by both the farmers and FAs from the interviews, but also draws upon the results presented in Chapter 6 with regards to SOC levels under different farming managements. It was important throughout the data analysis to ensure that the two data sets were presented as one project and not as two separate projects being run side-by-side. The difficulties and challenges faced in conducting and interdisciplinary project will be presented and discussed in more detail in the Chapter 8, the conclusion.

CHAPTER 5: FARMERS, FARM ADVISORS, SOIL ORGANIC CARBON AND THE POLICY ENVIRONMENT

The following chapter explores how soil organic carbon (SOC) has been framed and presented by farm advisors (FAs) and how farmers have responded to the challenges and opportunities of improved SOC management. This chapter draws directly from the in-depth empirical research undertaken amongst farmer and FAs, with the aim of addressing the following objectives;

Objective 2b: *Assess current policy and farm management advice regarding SOC and the practical impact it has on farm management decisions by conducting interviews with farm advisors.*

Objective 2c: *Analyse farmers receptiveness to SOC related policy and advice through conducting interviews.*

Objective 3b: *Through interviews; explore the responses of farmers and farm advisors, to the policies and management strategies identified, evaluating if current policy measures and advice pathways are effective.*

Through face-to-face semi-structured interviews (see Chapter 4) with farmers and FAs, their roles, practices, opinions and experience regarding SOC has been recorded and assessed.

The data used in this chapter is derived from the qualitative data analysis methods as outlined in Chapter 4, Methodology, and is based on the key themes outlined in section 4.2.3 which will address the objectives outlined above. These include SOC and its importance, policy and voluntary programmes, SOC enhancing practices, the sourcing and application of organic matter (OM) and carbon, climate change and carbon sequestration. A breakdown of the raw data is presented in Appendix III and V, whilst the interview schedules can be seen in Appendix IV and VI.

5.1 Introduction

This chapter presents the discussion of the main themes to have arisen during the interviews with the farmers and FAs, drawing on the results and using direct quotations where relevant and appropriate. Topics to be examined in this chapter were determined through a thorough review of the interview transcripts, identifying common themes and subjects of interest. The topics examined in this chapter fall within the scope of the original research questions and specifically address objectives 2b, 2c and 3b, as outlined above. A number of the topics raised during this review process did not relate to the original aims and objectives of this project, so the decision was made not to explore these. It is important to note the use of the term soil organic matter (SOM). This phrase was used during the interviews with the farmers and FAs as it was a term they were more familiar with than SOC in the context of everyday farming practices.

Within this chapter, the views of the farmers and FAs are examined with regards to soil, SOM and SOC. The application and success of agri-environmental schemes (AESs) and agricultural policies are examined, presenting a discussion of what the various actors felt the positives and negatives of various schemes were in relation to the management of SOM and SOC. An exploration of the opinions and experiences of the FAs and farmers regarding potential practices that enhance SOC, such as using minimum tillage and OM amendments is also portrayed. This discussion presents the optimum management approaches for improving and maintaining SOC according to those interviewed, as well as highlighting why such techniques were adopted by farmers, and factors which may discourage these techniques from being applied. The sourcing and application of OM was a subject that was repeated by almost all that were interviewed. This subject reflected the variation in farming practice between the SW and East, which differences regarding the sourcing of OM and the reasons behind why it was applied to the soil.

The final area of discussion conveys the opinions on climate change, C and carbon sequestration are also discussed and analysed. This subject allows for the exploration of potential blockages to the maintenance and improvement of SOC levels by assessing the FAs' and farmers' opinions held on these related subjects. It also assesses whether there is an understanding and appreciation of such issues whilst these topics have increasingly become a global political issue, as highlighted in Chapter 3.

5.2 Soil Organic Carbon and Soil Organic Matter: Are they important?

5.2.1 Introduction to the Importance of Soil Organic Carbon

Farmers' and FAs' opinions of SOC are an important consideration. If policy makers wish to put greater emphasis on C storage and sequestration, then it is down to the farmers and FAs to implement the information provided and employ it in a practical manner. If farmers and FAs do not think that SOC is important, either in terms of how productive it makes the soil or in a wider environmental context, then such attempts to increase soil C will not work effectively. Policy makers need to understand what farmers and FAs think about SOC to make any changes to policy and legislation practical and effective. By presenting what the farming community feels about SOC and whether it is a management issue, mechanisms to improve SOC levels can be developed.

5.2.2 The Farmers' Response

When asked if they felt SOM was important, all of the interviewed farmers said yes. This by itself can be considered a key result. It means that there is a strong foundation on which to build more knowledge and encourage improved management of SOM and SOC. When asked as to why they felt SOM was important, the farmers listed numerous reasons. In comparison to the interviewed FAs (presented further on), the farmers provided more information and detail on the subject. This reflects the fact that farmers are more closely linked to the soil, literally being 'hands on'. The responses from the farmers varied in complexity, ranging from soil structure, whereby F22 (East, organic arable) felt that SOM was critical to creating good soil structure;

> *'I think it's the most important thing. Because you know, the other most important thing is soil structure and if you have enough organic matter in there, I mean basically it's one huge great leap towards achieving a good soil structure with the amount of work that we put into our soil' (F22) (East, organic arable).*

To cation exchange, as demonstrated by F36 (SW, conventional dairy/arable) who stated that SOM is what ions are attached too, leading to an increased nutrient capacity;

> *'Yup, because it's what all the ions are attached to isn't? Well not attached to but the exchange, the holding nutrient capacity of your soil is determined by the organic matter to an extent isn't it?' (F36)(SW, conventional dairy/arable).*

To a more straight-forward answer, as F27 (East, conventional beef) demonstrated by simply saying that SOM is important, linking its benefits to money;

> *'Oh yes, definitely. They always say where's there's muck there's money, and that's the result from it normally' (F27) (East, conventional beef).*

A number of farmers commented that, whilst they thought SOM and SOC were important, they were not entirely sure how best to manage or improve their levels, or what levels of SOM and SOC were ideal. F24 (East, conventional arable) stated that he recognised that SOM was important but that he had not done a huge amount about it from a management perspective. He put this down to the fact that he has been incorporating crop residue for the past 25 years, following the burning ban, which he felt had improved soil structure, but was unsure as to whether or not the C levels had actually increased;

> *'It's one of those questions that we know it's important but we haven't done a lot about it. And some of that has been I guess assuaged by the fact that we've been incorporating crop residues ever since the burning ban, which is so long ago I can't remember when it was, about 25 years or more ago. And we can see some improvements, I don't mean that it necessarily means that carbon levels have improved but structurally ploughing in straw and oil-seed rape residues has improved the structure and the workability' (F24) (East, conventional arable).*

F31 (East, conventional arable), whilst saying that he thought SOM and SOC were important, did not know how they could be measured, or what levels were ideal. However, he does comment on an example where a lack of crop residue incorporation had caused deterioration in the soil structure;

> *'I do consider it to be important; I don't know how you'd measure it. I don't know how you know when you're right or when you're wrong, but all I do know is that I have a cousin who farms up in Suffolk, and for 10 years he removed the straw from his farm, and he is convinced that his soil structure has suffered, it's slumped, it doesn't drain it's just numb' (F31) (East, conventional arable).*

Again, F33 (East, conventional arable) commented that whilst he thought SOC and SOM were important, he questioned what the right levels should be;

> *'Well obviously yes, but there is the question of how much is the right amount and I'm not sure about that' (F33) (East, conventional arable).*

This demonstrates where there is room for improvement in the advice and guidelines regarding SOM and SOC. Whilst the above farmers recognised that SOM was beneficial, they all had questions regarding its management.

The Nutrient Benefit

The nutrient benefit from adding OM was noted by several farmers, with particular regards to a *'free-source'* of Nitrogen (N) (F25 (East, organic arable)). Farmer 22 (East, organic arable) went into more detail about soil nutrients, mentioning '*micro-nutrients'* being available in compost, increasing the amount of available nutrients in the soil;

> *'Well, what I believe it adds is some of the nutrients but mainly the micro-nutrients and maybe not all of those micro-nutrients, and the major nutrients are not available in the compost, but what I believe is that the compost conditions the soil and the soil is able to release nutrients that it's not able to release when it's without the amount of organic matter that I think that it should have in it' (F22) (East, organic arable).*

Farmer 22 (East, organic arable) was an organic farmer and therefore perhaps had more reliance upon soil nutrients gained from the addition of organic material.

Improved Moisture Retention

Improved moisture retention was mentioned as a positive benefit of SOM and SOC by farmers in both regions, particularly with regard to the recent droughts that had occurred, or were occurring at the time of interview. The improved moisture retention was demonstrated, as the three farmers below mentioned, by improved growth in crops during periods of drought. Both farmers 32 (East, conventional arable) and 34 (SW, conventional poultry) commented on the improved moisture levels in soil during a drought which they attributed to SOM, helping the crop to grow better than it otherwise would;

> *'Yes, I think it helps, especially in a dry year where we're short of moisture, I think it helps the crop. Holds the moisture' (F32) (East, conventional arable).*

> *'Yes, we have done, especially within the last two years when it's been a dry summer. The crop is able to...I think moisture is retained more. So it's able to grow though the dry season' (F34) (SW, conventional poultry).*

Farmer 22 (East, organic arable) commented on the recent droughts that he had experienced, stating that applying compost has created better crop yields due to improved moisture retention;

> *'And we've had two terrible droughts, as you probably know, for the last two years, wherever we put compost on it's always yielded better because it's held more moisture so although it's difficult to see year on year where the benefits are, that's where I believe it is, your soil being in better condition so therefore being alive, being able to provide the nutrients that an organic crop needs and also improving work rates because the soil is easier to work and also the retention of moisture' (F22) (East, organic arable).*

Improved Soil Structure

Farmer 22 (East, organic arable) mentioned that the soil is easier to work following the application of compost. Workability, occasionally referred to as the *'soil body'* (F35), or mentioned when talking about improved structure, was noted as being improved following OM additions or by having higher SOM contents. F25 commented that ploughing soil that had OM applied was easier compared to soil that had not had any OM additions, stating that it does not break up as easily;

> *'Yeah, it does make a big difference. When you plough, you know, you're sitting there watching it and you can see it break open. And when you got a bit that hasn't had any on, you go over like it's leather and it doesn't break up and when it dries, it's hard to pull to bits but when...in fact sometimes where you have a lump of muck come out, you know, and that split opens and it's all decayed muck. So you wouldn't get that if you didn't put it on, it would just be one lump' (F25) (East, organic arable).*

F25 also commented on the improved workability of soil following OM application via compost;

> *'But also for…to try and sort of over the years I think it will make it work easier and that's why I've started to use the compost as well to make the soil easier to work. I don't know whether that's because of the organic content or what. I suppose it is' (F25) (East, organic arable).*

The improved workability of the soil following OM additions is described here by both of the above farmers, in very physical terms. The improved workability of the soil is something that can be easily seen by farmers whilst they work the land. Workability does not require testing in a laboratory and so is a very visible impact of SOM.

Additional Benefits

Other, wider positive benefits were also mentioned, benefits that are not perhaps so well known or obvious, with Farmer 26 (East, conventional arable) mentioning the term *'Soil Health'*;

> *'Yes I do, I consider it very important, I consider it's all down to workability and soil health, worm activity. It all adds to the workability doesn't it?' (F26) (East, conventional arable).*

Soil health refers to the ability of a soil to meet a range of ecosystem functions as appropriate to its environment. It is a term largely used in academic circles that is not in wide circulation in farming advice. Farmer 37 (SW, conventional dairy) spoke about trying to create a *'soil environment'* optimising soil '*bacteria and the bugs'* to help recycle and breakdown nutrients, placing emphasis on the *'soil life'*;

> *'Yes, I mean we're trying to create a soil environment or ecosystem where we've got a lot of organic matter, not from just what we apply but through the bacteria and the bugs increasing in volume as well, so we get a good recycling of nutrients breaking down stuff. So we've got nutrients in an organic form that the plants can take up rather than being locked up so yeah. Organic matter in its fullest sense' (F37) (SW, conventional dairy).*

Soil life was also mentioned by farmer 42 (SW, conventional dairy) who referred to worms;

> *'Yes because that holds the nutrients. It's what the worms like and worms are good aren't they?' (F42) (SW, conventional dairy).*

This approach to the soil demonstrates that these farmers see it as a living system which involves numerous processes and interchanges. By encouraging this system, the farmers hope to create a productive soil environment. Ultimately, by encouraging the soil's natural system, less artificial inputs will be needed, creating a more sustainable system. It is also an approach that is most commonly linked to organic farmers.

Variation in Soil Organic Matter and Soil Organic Carbon Importance

It was commented by a number of farmers that the importance of SOM and its benefits vary depending upon the farming type and the location. A couple of the farmers raised the importance of how the type of agriculture will determine how important SOM and SOC both are. For example, farmer 25 (East, organic arable) recognised that SOC was important for organic farming, but questioned its use for conventional farmers.

> *'Yes, for certainly in an organic situation. I'm not quite sure it's so important for conventional farmers' (F25) (East, organic arable).*

Farmer 30 (SW, organic beef/poultry) highlights that the importance of SOC can vary depending upon soil type also as well as land use, whether arable or livestock farming. He explains that on his current farm, a livestock farm which was mainly grassland, the SOM content was easier to maintain, whereas at a previous farm where the soil was lighter and he grew vegetables, the SOM content was harder to maintain.

> *'I mean here it's not difficult...I assume with the soil type, it shouldn't be difficult to maintain high organic matter bearing in mind it's pretty much just grass and it's a heavier soil. Having grown veg on light sandy soil down near Exeter for 10 years and the amount of...we were designated green waste site and we were putting on up to...I don't know, ridiculous amounts of green waste on an annual basis and you just watched it disappear. So on this farm I don't think it's so much of an issue but on that sense, on that soil, you just watched the colour change. You know, we'd put it on, the green waste stuff was black, you'd put that on, turn it over and the soil, and through the seasons you would just see it go back to how it was before. But to be fair over the years the soil did start to change because it was, it went through conversion to organic so it had a proper rotation using green manures and incorporating those and tonnes and tonnes of green waste' (F30)(SW, organic beef/poultry).*

Another example of this is farmer 39 (SW, conventional dairy/sheep). Although he recognised the importance of SOM and SOC, he felt that as a dairy farmer, he never really had any problems due to the amount of OM that was available for use.

> *'I think it is important but incorporating as much slurry as we do, I don't think it's something we need to worry about. But I mean, yes, it's important for soil structure and for worms and so and so forth, but I don't think it's something, that on a dairy farm you need to be concerned about with all that organic material going back' (F39) (SW, conventional dairy/sheep).*

Thus, the farmers' responses to the importance of SOM and SOC varied in complexity. Physical benefits, such as improved water holding capacity and workability, are easy to see and assess at the field level. As are the improved nutrient availability, with the farmers requiring less fertiliser. However, improved soil life, or ecosystem, are perhaps less obvious and the benefits of which may take longer to become apparent. A number of farmers also recognised that the various benefits of SOM will be more or less important depending upon the soil type and farming practice. Whilst there was some difference in the degree of scientific understanding of SOM and SOC, all of the farmers recognised the importance of SOM in their farming systems, seeing it as a key component.

5.2.3 The Farm Advisors' Response

Almost all of the interviewed advisors regularly gave advice to farmers on, or related to, SOC and SOM with around half of them saying they felt that farmers were generally receptive to the advice. This data contrasts to the farmers' responses, all of whom said that they considered the OM content of their soil to be important. The higher proportion of farmers considering SOM to be important, when compared to the FAs, can more than likely be explained by some comments made by the advisors, who said that it was largely the forward thinking or the young to middle aged farmers who were receptive to advice on, or related to, SOC. It is likely that the interviewed farmers would largely fall into these categories as those in other groups would not be receptive to conducting the interviews, as highlighted in section 4.2.2, Chapter 4.

Half of the FAs interviewed said that they considered SOC to be very important, with only one saying it was not important at all. The following two quotes demonstrate what the FAs felt about SOM. FA8 (SW, charity) stated that SOC is an integral part of the system, holding everything together, and FA18 (East, consultancy) refers to it as being fundamental;

> *'It's (SOM) an integral part of the system. It holds it all together really' (FA8) (SW, charity).*
>
> *SOM is 'Absolutely fundamental to everything we do to the soil' (FA18) (East, consultancy).*

The one advisor who said that SOC was not important placed more importance upon soil physics. He felt that the physical state of the soil can be altered relatively quickly and can change a lot of the workings of the soil system, whereas the chemistry and C take longer to respond to alterations (FA17) (SW, government body). Of the remaining FAs, whilst they responded positively to the importance of SOC, a number said that other issues were more important. As one advisor put it '*It's [SOM] important but not overarching*' and it is *'A minor issue compared to other things'* (FA7) (East, self-employed). Several reasons were given for this point of view. Predominantly, location and soil type appeared to play a role in forming this opinion. A FA from the SW simply suggested it was because low SOM was not an issue present in the region due to the soil types and abundance of livestock. A FA from the East, when asked the question on how important he felt he OM content of the soil, stated:

> *'Well, not very (important). I mean that sounds irresponsible' (FA11) (East, self-employed).*

His reasoning for this opinion was that on the light soils he helps to manage the SOM levels have been shown to be less than 1%, despite adding OM, but yet the soils are still producing the necessary output in yields. However it is important to note that he stated this sounded irresponsible, indicating that to some degree, he acknowledges the importance of SOM even if it is not always visible.

Formal Responsibility to Soil Organic Carbon

Despite the advisors' views that SOM and SOC were important in terms of the soil system, the majority of the FAs did not feel that they had a formal responsibility to provide advice on SOC. Those that did feel they had a formal responsibility, noted that this fell under their remit with respect to other areas of government advice and scheme delivery. For example, soil advice forms part of cross-compliance, the Soil Protection Review (SPR), in relation to RB209 (fertiliser advice), and that it formed part of their job to provide advice on SOM and soil management. FA16 (East, consultancy) said that if he did not provide advice on SOM it would be a dereliction of duty. A common theme throughout the interviews was that the subjects of SOM and SOC were not addressed directly in advice. This could be why the majority of FAs said they did not have a formal responsibility as their advice did not specifically cover SOC and SOM as an independent subject.

Do Farmers Understand the Benefits of Soil Organic Carbon and Soil Organic Matter?

In response to the question as to whether the advisors felt that farmers understood the benefits of SOM and SOC, a mixed picture was presented. From many of the FAs perspectives, farmers understood the benefit of adding OM to their soil and were aware of the many positive outputs, for example:

> *'…well they [farmers] mainly look at soil organic matter as a cheap way of getting fertiliser and nutrients…' (FA19) (East, self-employed).*

However, overall it appeared that there were varying degrees and levels of understanding and interest from the farmers. Perhaps unsurprisingly, several FAs credited organic farmers with having a better understanding of SOC and soil systems compared to conventional farmers. This is most likely due to the fact that organic farmers rely on natural processes as they *'can't use artificial fertilisers'* (FA18) (East, consultancy). There is also the possibility that the advice organic farmers receive contains more information regarding SOC, as highlighted by FA18, who felt that information in the organic sector was broad in comparison to main stream advice, which he referred to as being conservative. His reasoning for this difference was due to the greater reliance on soil biology that organic farmers have;

> *'Most of the main stream advice out there is fairly, well it's very conservative and it's fairly, I guess, it's not very imaginative. I guess in the organic sector we've broadened our perspective somewhat, quite simply because we rely on that soil biology so much more that we have to look wider' (FA18) (East, consultancy).*

In addition to the broader advice, organic farmers approach farming in a different manner and are more receptive to different ideas that are 'outside of the box'. FA8 stated that organic farmers were more receptive to new and different ideas compared to conventional farmers;

> *'…organic farmers have got the right, not the right frame of mind…they're more aware, they're more receptive to different ideas and things…' (FA8) (SW, charity).*

At the other end of the scale, a couple of FAs stated that farmers are not always aware of the importance that SOM and SOC has and how it can affect them and their farming in the short or long term. For example FA4 (SW, self-employed) stated that farmers have a lack of awareness and knowledge of SOM and SOC and fail to see the relevance of it on a day to day basis. However he does say that if there was a financial reason, they would be more aware of SOC and SOM;

> *'Well lack of awareness, lack of knowledge, lack of the importance of it…the lack of relevance of it, or how they would see the relevance of it on a day to day basis, so you know what's it going to do for me? How much fertiliser you could save tomorrow? Therefore there's a financial reason as to why they would do it, not how it would improve the soil over a ten year period' (FA4) (SW, self-employed).*

Additionally a number of advisors said farmers were only 'somewhat' receptive. The causes for a 'somewhat' receptive audience are illustrated in the quote from FA4, above. Financial incentive was a key factor as to how interested a farmer was in the advice concerning SOM and SOC. Other factors included the drivers behind the farmer in seeking the information, the reliability of the evidence and information, and the cost of OM, including if transportation costs were reasonable. It was also noted that the information and advice needed to be tailored to a way in which the farmer understood, for instance; showing the improved practicalities of increasing OM, both in the long and short term. The FAs also raised the issue that some farmers are not within the advice circle. Many farmers do not attend events and meetings which may be of use to them, meaning that they do not receive the advice through those communication methods. On a positive note however, FA14 (East, consultancy) felt that farmers were definitely taking more notice of their SOM compared to previous years;

> *'There is no doubt that farmers are definitely taking more account of soil organic matter (FA14) (East, consultancy).*

Variation in Soil Organic Matter and Soil Organic Carbon Importance

Critically, how important SOC and SOM were perceived to be, partly depended upon the area, soil type and agricultural practice. For different soil types, the addition of OM can serve very different purposes. FA14 (East, consultancy) stated that farmers on light or heavy land are the ones who are interested in SOM and its various benefits, highlighting this issue;

> *'So it's the extremes I would say, the lightest land and the heaviest land farmers rather than the medium land farmers who are particularly interested in it' (FA14)(East, consultancy).*

For farmers on light land, the addition of OM '*helps attain nutrients in the soil and also helps the plants survive drought, as it increases the soils ability to retain moisture*' (FA16)(East, consultancy). This notion is seconded by FA14 (East, consultancy):

> *'Because I work in East Anglia, it is important. We have low rainfall. If you look at the information we have the lowest levels of organic matter within the soil' (FA14)(East, consultancy).*

Both FAs 14 and 16 refer back to the notion that OM in the soil helps maintain soil water holding capacity which can be vital in low rainfall areas. On the other hand, farmers on heavier soil or those that do not face such extreme periods of dry weather may also find the advice suitable, but for different reasons. The quotes below demonstrate this argument, both again from FAs 14 and 16. Both FAs state that OM additions to heavier soils will improve drainage as well as the workability, potentially reducing the amount of diesel used in cultivating the soil;

> *'...heavy land farmers at the same time realise that it's important for improving the drainage and the workability of heavy land and it might then mean that it reduces the amount of horse power that you need or at least the amount of diesel that you need to cultivate the land' (FA14)(East, consultancy).*

> *'...And on heavy land, organic matter helps break up the clay particles therefore allowing natural cracking of the soils and improving natural drainage and rotting of the crop. So both soil types tend to benefit greatly from the addition of organic matter wherever possible' (F16)(East, consultancy).*

Instead of helping to maintain moisture, additions of OM provide farmers on heavier soil with a better soil structure, improving natural drainage and also reducing the amount of power needed to pass and cultivate the fields.

All except one FA felt that SOM and SOC were important aspects of the farming system, mainly commenting on the nutritional benefit that OM can provide. The response as to whether FAs felt that farmers understood the benefits of SOM and SOC were slightly at odds with the results from the farmer's interview data. The FAs commented that it tended to only be the forward thinking or the younger farmers who were interested in SOM and SOC. This difference is likely to be a reflection of the background of the interviewees, rather than a marked difference of opinions between the farmers and FAs of the wider farming community. The FAs commented that the importance of SOM varied depending upon location, soil and farming type.

5.2.4 A Review of the Farmers and Farm Advisors Response

The farmers and FAs largely agreed in their responses regarding the importance of SOM and SOC. The farmers highlighted the benefits of SOM which included its use as a fertiliser, improved water holding capacity and workability of the soil. The FAs agreed with these benefits, largely highlighting the value OM had as a source of nutrients. Whilst all of the interviewed farmers said that they felt SOM and SOC were important, the FAs commented that not all farmers were concerned with this aspect of their farming system. This discrepancy in results is caused by the fact that, as commented by the FAs, that it is mostly the forward thinking farmers who are concerned with the SOM and SOC. It is very probable, that only forward-thinking farmers were interviewed. It would have been more difficult to contact and interview a farmer who was not interested or overly concerned with their soil, compared to those farmers who have a strong interest in the topic.

It was clear from the interviews that the degree to which farmers and advisors considered SOC to be important varied significantly according to location, soil type and farming practice. The organic farmers appeared to be the most concerned with SOC, largely owing to the fact that they cannot use artificial fertilisers and so rely on alternative sources for nutrients instead. Farmers on very light or very heavy land were also said to be more concerned with SOC, due to the physical benefits it provides.

Although the interviewed farmers recognised the benefits of SOM and SOC, several commented that they did not always know the best way in which to manage it, or to improve their levels. This highlights an area of knowledge that could be further developed in order to maximise the benefits that these farmers can receive from SOM and SOC. In addition to this, the majority of the FAs said that they had no formal responsibility to advise on SOC. Again, this too could be a potential area for development in which policy makers could improve the management of SOC.

5.3 National Policy, Voluntary Programmes and Soil Organic Carbon

5.3.1 Introduction

The following section will look at the perceptions, attitudes and understanding of the interviewed farmers and FAs in relation to national agricultural policy and AESs with particular reference to SOM and SOC. By presenting and discussing the opinions and experiences of the FAs and farmers with regards to the mechanisms under cross-compliance and AESs it is possible to gauge the practical impact they have upon farm management and as to whether or not they are a positive tool to improve SOC and SOM levels. The opinions of the farmers and FAs as to how these mechanisms could be improved will be touched upon briefly here, with a full discussion being presented in Chapter 7. To achieve the best outcome for maintaining and improving SOC levels, it must be viewed as a policy issue in agriculture. It is also critical to understand the effect the current policy environment has on SOC levels and the opinions of farmers and advisors, if the maximum benefits of SOC are to be achieved and utilised.

5.3.2 The Soil Protection Review

The Soil Protection Review (SPR) was Good Agricultural Environmental Condition (GAEC) 1 under cross-compliance. During the interviews with the farmers, the SPR caused the most extreme reactions. All of the farmers who were asked about the SPR had an overwhelmingly negative opinion of it. The legislation in England is devised to cover a range of environments and farming systems and therefore not always applicable to all environments, meaning that for some farmers the legislation appears to be redundant. For example, a FA based in Suffolk, said that soil erosion is not an issue he sees often and neither do his farmers. They therefore do not understand the purpose of an SPR and see it as '*complete nonsense'* (FA19) (East, self-employed).

All of the interviewed farmers overwhelmingly supported this view of the SPR. The most common response was that it was too basic and therefore insulting to farmers. Many simply said it was rubbish. Farmer 25 (East, organic arable) commented that he did not see the point in ticking a box to say that he had done basic soil management, stating that they all know what is good for their soil;

> *'I think the Soil Protection Review is absolute meaningless rubbish. I mean we all know what's good for our soil and what is the point in ticking a box to say you've done it?' (F25) (East, organic arable).*

Farmer 38 (SW, conventional sheep/arable) felt that because it was so simple, it was an insult to farmers';

> *'Absolute load of rubbish…I think it's an insult to farmers to be honest' (F38) (SW, conventional sheep/arable).*

It was repeated that the SPR was far too simple and contained information that farmers already knew. As a result, several of the farmers did not see the aim of the document, as it did not achieve anything. For example, F29 (East, conventional arable) felt that the SPR was pointless and it did not serve a useful purpose;

> *'What is the point of it? Seriously what is the point of it? Why do we have to write down what we're going to do if we've got a problem? We know what we've got to do, what's the point of writing it down and recording it. It doesn't serve a useful purpose other than give the jobs-worth boys who come round to do inspections something to read' (F29) (East, conventional arable).*

In comparison to this, farmer 39 (SW, conventional dairy/sheep), although he stated that he thought it was a waste of time, appreciated why such a document existed. He stated that most farmers would not act in a way that would cause damage to their soil as it would ultimately cost them money, however, he admitted that some farmers may not actually know what is best for their soil, and that it is them the SPR is designed for;

> *'I think it's a waste of time. I think it's again...I can see why it's there, so there is a document which can be waived in front of people's faces saying you should've known, but if you're sensible, professional farmer stroke business man, whatever, you know, I mean I wouldn't dream of taking a tractor and driving it across one of my fields in February. Why? Because I'm going to make a mess, if I make a mess, it's there for the rest of the season or I've got to repair it or you know, I mean, we just don't do it and there are a few really obvious reasons so therefore I don't need a Soil Protection Review to tell me why I shouldn't because I already know. But I'm sure there are some people out there that don't know....and things like not growing maize on a steep field adjacent to a river or road and being surprised when half the field ends up on the road with the weather we've had in the last week, well it should be obvious really shouldn't it? You shouldn't have to sit down with the map and point out high, low, medium risk, and so I think it's a very, very blunt stick to bash people with' (F39) (SW, conventional dairy/sheep).*

Farmer 37 (SW, conventional dairy) also recognised that a document like the SPR had some merits, but that it fell short of its aims;

> *'It has the right intention but it's...it doesn't go far enough' (F37) (SW, conventional dairy).*

Although he felt the SPR had good intentions, it did not go far enough as it was seen as being far too simplistic. Both farmers 41 (SW, conventional, dairy) and 42 (SW, conventional, dairy) stated that the SPR was common sense, and included things that did not require to be written down;

> *'It's just common sense isn't it?' (F41) (SW, conventional dairy).*

> *'It's common sense really' (F42) (SW, conventional dairy).*

It is unfortunate that the only direct piece of legislation which focuses on soil and that could influence SOC levels via appropriate management, was seen in such a negative light and appeared to fall short of creating any positive changes in soil practices. Such a document could have a huge potential in raising the profile of SOC amongst farmers. It is hoped that with better consultations with farmers, that something similar to the SPR could be re-introduced into the cross-compliance framework following the 2013 CAP reform.

5.3.3 Nitrate Vulnerable Zones

Nitrate Vulnerable Zones (NVZs) were Statutory Mandatory Requirement (SMR) 4 under cross-compliance. A small number of FAs argued that the rules accompanying NVZ designation conflicted with good SOM management as they restricted the amount of OM that could be applied as well as the timing of applications. FA1 (SW, self-employed) commented on the limitation of OM input caused by the regulations;

> *'...if we're talking about stabilising the soil, trying to get the organic matter up, we've got limits on nitrogen, total nitrogen and crop available nitrogen so that does, in terms of the codes of practice recommendation and NVZ recommendations, that does limit the amount of nitrogen, organic matter that somebody might be able to put on a given field, so there's a bit of a conflict there' (FA1) (SW, self-employed).*

FA18 (East, consultancy) felt that the limitation on the use of farmyard manures (FYM) created a conflicting issue;

> *'There are some conflicting issues with things like Nitrate Vulnerable Zone legislation, because that specifically limits the amount of farm yard manures which can go into the system...Yeah, that would be the biggest one [restriction] I guess' (FA18)(East, consultancy).*

FA20 (SW, consultancy) also commented on the restriction of FYM application as a negative;

> *'...so you're down to an application [of FYM or sewage sludge] perhaps once every three or four years to stick within good agriculture practice, so yes there are limits [from the NVZ legislation]' (FA20) (SW, consultancy).*

In addition, NVZs were also noted as a reason as to why farmers have sought advice regarding OM because of the restrictions, and to prevent them falling foul of the law, as FA1 highlighted;

> *'With organic manures, it's legislation driven now with the NVZ's requiring five months storage so that's an end road to that. So those are the motivations for the farmer. That's what drives them to seek advice' (FA1) (SW, self-employed).*

Overall the FAs did not have much to say with regards to NVZs and SOC, except with regards to application timings and rates of OM which could cause a conflict with good soil management. The farmers, however, had more to say on NVZs regulations, with a number having quite strong opinions about the regulations

A number of the farmers in the East said that the NVZ regulations impacted their farm management practices although, in general, the rules were not a nuisance and generally fitted in well with good agriculture practice. Farmers 22 (East, organic arable) and 32 (East, conventional arable) both concur that the regulations were sensible and within the realms of their everyday management plans. Farmer 22 (East, organic arable) said that the measures the NVZ rules required him to do were sensible and would be practices that he would adopt without the regulations with relation to compost and OM;

> *'The only thing that we have to apply NVZ rules to is our application of compost and organic manures and so that does have an effect but as far as I'm concerned all the measures they require me to do are completely sensible so I'm quite happy and actually they're management practices that I would adopt anyway' (F22) (East, organic arable).*

Farmer 26 (East, conventional arable) said that the NVZ rules had very little impact on his soil management even with recent changes, indicating that levels of N and OM input under the regulations were the same that he would be adhering to anyway;

> *'In all honesty very little, obviously we comply with the NVZ rules, they have changed them, tweaked them over the last couple of years which hasn't been a problem. Certainly doesn't affect our soil management in anyway shape or form. Within NVZs you do have a little wriggle room to argue your case, although the latest change, a couple of years ago, brought in a ceiling. You can't go beyond that ceiling no matter how much you argue. But no, it hasn't had an effect on our soil management' (F26) (East, conventional arable).*

Farmer 25 (East, organic arable) also stated that NVZs have had little effect on him and explains that he recently started filling in the yearly form at the time of the interview. He spoke indifferently about the regulations and that apart from the form filling that is required, the rules did not impact him in terms of his OM management;

> *'Not really, no. Apart from the form filling and keeping the record, it doesn't really affect me…Well I started to do it yesterday and where I had put on the poultry muck and the compost, I was getting fairly close to the limit, on that field. But then, you know, most of the other fields haven't had anything so it doesn't really affect me that much' (F25) (East, organic arable).*

These farmers have painted a generally positive image of NVZ regulations. The rules and regulations fitted in well with their current farm management practices, which indicates they all had good agricultural practices already in place. If farmers are not disgruntled about the legislation then it will more than likely be implemented correctly and successfully, so this is a positive reflection upon the success of the NVZ regulations. However, not all farmers in the East were happy with NVZ regulations or found them non-intrusive. When asked about the NVZ regulations and if they had an impact on farm management at all, farmer 27 (East, conventional beef) responded negatively referring to it as '*crap'*;

> *'Yeah, you've got all that crap' (F27) (East, conventional beef).*

This strongly suggests that he did not find the NVZ rules as trouble-free as the previously mentioned farmers did. The reason for this could be, unlike the rest of the farmers interviewed in the East, F27 was a cattle farmer rather than a solely arable farmer. Therefore, he will have had more rules and regulations to follow with regards to animal muck, its storage and application than the arable farmers.

Similarly to the Eastern farmers, the SW farmers largely commented that being in an NVZ area did not have a huge impact on the soil management of the farm, and biggest effect was the paper work that came with it, as F34 states;

> *'More paperwork rather than practicality on the farm...it's just been making sure that application rates are correct' (F34) (SW, conventional poultry).*

Overall, NVZ regulations were met with indifference. The regulations regarding timings and application rates were largely seen as common sense, although it was commented that flexibility is required to allow for extreme weather events. In terms of SOM and SOC levels, NVZs appear to have little effect on the interviewed farmers. It was repeated a number of times that the limits on the amount of OM input was 'common sense' and similar to what the farmers would be doing without the legislation. The paperwork was complained about briefly so it appears that the interviewed farmers have an issue with the form filling rather than the actual regulations themselves.

5.3.4 Catchment Sensitive Farming

Catchment Sensitive Farming (CSF) is a project which enables farmers to take voluntary measures to reduce diffuse water pollution from agriculture in priority catchments with the use of Capital Grants. When asked about the impact of CSF, only one advisor responded negatively;

'...but with Catchment Sensitive Farming and all this, that's going to get more and more restrictive, and probably the people who wrote that legislation didn't have any idea of soil fertility or how to get rid of the wastes, and they hadn't even thought of it probably' (FA19) (East, self-employed).

In his view, CSF imposed restrictions on how to handle livestock waste. He also criticises the people who wrote the legislation, saying that they probably did not know that much about soil fertility. This may reflect his experience of where the scheme and other pieces of legislation have not 'fitted in' well with certain practicalities of farming.

Although voluntary approaches and legislation may sometimes appear restrictive, it can also create positive changes and alterations. FA12 (East, government body) said that many farmers comply with CSF because it looks good that they are doing the right thing and that they have 'ticked all the boxes' as it is voluntary. But at the same time;

'They see a benefit for themselves in terms on improving practice and protecting the environment. Most of the farmers I come across are actually keen to do their part to protect the environment. Some are not but they are a minority' (FA16)(East, consultancy).

The farmers provided a mixed response when asked about CSF. The most common answer was of mild confusion, either not knowing if they were in a priority area or not, and confusing the initiative with NVZ and other AESs. For example;

'I think so, is that the NVZ thing?' (F25) (East, organic arable).

Farmer 24 (East, conventional arable) was confused as to whether he was in a priority area commenting that it gone 'very quiet' since the scheme was launched.

'Yes, I think we are, in fact I'm meeting a lady tomorrow about it. But we're slightly puzzled because we thought we were in and they launched the scheme and it all went very quiet and now they seem to be re-launching it' (F24) (East, conventional arable).

This potentially reflects either a lack of extension from the scheme or the farmer not being proactive about his involvement. As farmer 32 (East, conventional arable) comments with regards to whether or not he receives any CSF information;

'We probably have but I didn't take too much notice of it' (F32) (East, conventional arable).

This highlights that it is possible for farmers to receive information but not necessarily acknowledge or activate it. There was also some annoyance from farmer 22 (East, organic arable) who had thought he was in an area, tried to apply for a grant, only to be told they were not eligible. For example;

'....Catchment Sensitive Farming, I don't think....we're not in a priority area, I know that because we buy in a lot of compost, I was looking for some aid in

putting up storage boxes and that wouldn't be available to me because apparently I wasn't in a target area so that's all I can say' (F22) (East, organic arable).

However, in general, although there was some confusion about the initiative, it was generally regarded in a positive light. Farmer 23 (East, conventional arable) had recently been put in a target area and seemed optimistic about the benefits it would bring, in particular the available grants and information on preventing run off from soils;

'We are in an area now they've located a new one which is the Camb...I mean there are the possibilities of grants to put in...cleaning your sprayer out thing, can't remember what it's called, so yeah those and they give you advice on run off on soils etc. So yeah I think it will be beneficial, I think it will be a good thing' (F23) (East, conventional arable).

Farmers 35 (SW, conventional beef) and 42 (SW, conventional dairy) commented that they too had benefited from the grant scheme;

'Well not too bad within our system. We benefited from it because...We've got some funding from it to do various things so that has been quite useful' (F35) (SW, conventional beef).

'We have had a grant from them this time for some concrete and some tracks' (F42) (SW, conventional dairy).

In general, CSF appeared to have little impact upon how the interviewed farmers managed their soil. It was only those farmers who had been eligible for grants that had benefited from the scheme and made improvements to their soil management as a result. The issue that some farmers were not aware if they were in CSF area or not needs to be addressed also, as they may not be getting all the help they could be entitled too. It perhaps also demonstrates that the role-out of the scheme was confusing and was lacking in extension. Overall though, the CSF scheme was seen in a positive light by almost all of those interviewed. In terms of SOC, the CSF has very little direct impact, although certain measures promoted by the project, have the potential to enhance SOM/SO, for example the promotion of reduced tillage systems, (see table 3.6, Chapter 3) and are similar to those practices in table 2.1 which have the potential to maintain and enhance SOM and sequester C (Bhogal *et al*., 2009). However, as the initiative already promotes good soil management and helps farmers to avoid soil erosion and run-off, it is perhaps well placed to increase the awareness of SOC as a management issue. The fact that CSF is largely seen in a positive light would help this plight, and is better placed than the SPR to achieve this. The positive views associated with CSF are likely a result of the grants that are attached to the scheme, providing farmers with incentives to take part. Such incentives could be used to promote management practices that increase SOM and SOC levels.

5.3.5 Agri-Environmental Schemes

AESs, whilst not necessarily promoting farm-wide practice changes such as reduced tillage systems, reach a wide farming audience. It is for this reason they are examined here. They have the potential to promote mechanisms which will increase SOC on a large scale, due to their popularity, if they focused on methods that would enhance C levels (e.g. higher OM input and reduced tillage systems, see column 3, table 2.1).

Farmers' Response to Agri-Environmental Schemes

All but one of the farmers interviewed were in some form or another of AES; either ELS, HLS, OELS or Countryside Stewardship. The one farmer who was not in an AES said the reason for this was because the farm was too small and so it did not make sense to go into one. He also commented on the amount of paperwork that is involved. In general, most farmers responded that being in an AES had had very little impact on their farm management. This seems largely down to the fact that farmers were able to choose the options they went for and choose the ones that suited their farm the most. For example, farmer 40 (SW, conventional dairy), when asked if being in an ELS agreement had impacted his farm management, responded with;

> *'No, we make sure it doesn't' (F40) (SW, conventional dairy).*

Both farmers 22 (East, organic arable) and 29 (East, conventional arable) agree with this statement that AES agreements have not impacted their farms, stating that they only put areas of land into stewardship agreements which were less productive. Farmer 22 (East, organic arable) opted for field edge options which are permanent and so do not need rotating unlike other options, as well as only including less productive areas into the scheme. Field edge options include buffer strips and hedges and shelter beds, which have the potential to enhance SOM levels (Bhogal *et al*., 2009).

Similarly, farmer 29 (East, conventional arable) stated that he only included land that was more conducive to wildlife rather than crop production;

> *'Not really, because we've put in areas that are conducive to wildlife and not conducive for producing crops, so we now we've tried to hit the balance with it really' (F29) (East, conventional arable).*

By putting marginal areas of land into field edge options, means the farmers do not lose out on production and may actually see a rise in income if the land in question receives more money through the AES than it would if left in production. Contrary to this, farmer 32 (East, conventional arable) noted that by taking land out of production and into the schemes, that he is actually losing profits but feels the environmental benefits are worthwhile. He states that by having the buffer strips, which are mentioned by Bhogal *et al*. (2009) as a way to enhance SOM, that he hopes no fertilisers or slug pellets make their way into the water, stating this as the main reason for having the strips;

> *'No, not really. I mean the biggest benefit is that we have the buffer zones beside the water courses so hopefully no sprays or fertilisers or slug pellets get into the water, and that's the main reason of doing them. I think financially we would be better off farming the land than what we would be having with the grass margins' (F32) (East, conventional arable).*

He goes on to justify as to why he is continuing with the schemes despite the opinion that he feels he is losing money on taking the land out of production. He felt that it was unacceptable to be putting fertilisers and the like, into water courses. Another motive for him was to try and prevent more chemicals from becoming banned by preventing them from appearing in water courses;

> *'...because I don't think it's acceptable to put sprays and fertilisers near the water so that's basically for environmental reasons...but you've got compromise a little bit, that's the problem, and you see if they keep finding these chemicals in the water, they will eventually ban the chemicals. Say we're losing £500 profit a year at the moment through these grass margins, in 10 years' time we could be gaining a lot because we could be using the same chemicals rather than losing them. So basically you've got to think about the filter a little bit' (F32) (East, conventional arable).*

Part of his reasoning is down to environmental concerns. This is rather unique as not many farmers mentioned the environment as a reason for conducting environmentally-friendly practices with financial reasons usually given as the primary driver. It was also unique to see a farmer think about the long term effects with regards to chemicals being banned. Most of the farmers and especially the advisors, placed a lot of emphasis on the short term benefits. Whether or not his reasoning is based on evidence does not matter in this example, it is his motives that are the most poignant.

Other farmers noted the changes they have had to make for AESs but appeared to be satisfied with the requirements. Farmers 23 (East, conventional arable), 28 (East, conventional arable) and 31 (East, conventional arable) all mention wild bird mixes, grass margins/strips (enhances SOM) and no-spray headlands as managements they have had to impose. None of these farmers spoke of the changes with negativity. Farmer 31 (East, conventional arable), whilst commenting that the grass strips reduce the production area available, admits that '*they do have their advantages'*.

Farm Advisors Response to Agri-Environmental Schemes

Whilst the farmers provided a rather indifferent position on AESs, in general, the FAs commented there was a lack of consistency, lack of extension and the schemes were too prescriptive. The prescriptive nature of the AESs was mentioned several times by advisors, commenting that they do not allow for much movement or thinking ‘outside of the box’. FA18 gives an example of this using over winter stubble (the use of cover crops and crop (stubble) residue has been highlighted as a possible method to enhance SOC (Bhogal *et al*., 2009) as an illustration. He states that the restrictions in place concerning what can and cannot be grown as part of the winter cover crops, limits the ability to add SOC;

> *‘Some of the agri-environment schemes, ELS, OELS, HLS, which put specific prescriptions on what sort of covers…you can use an over winter stubble because it’s targeting farming birds, but you couldn’t enhance that over winter stubble by, let’s say, a low level clover in there which would put more organic matter in and maybe attract quite a lot of beneficial insects which the birds could feed on. So it’s very prescriptive in what it can do and rather limits the ability to add soil organic carbon’ (FA18) (East, consultancy).*

In order to receive the money from the schemes, the farmers have to follow the prescribed rules of the different options available to them. If the rules are not followed, then they do not receive their payments. This can potentially limit individual thinking, but also in the example given by FA18 (East, consultancy), can cause opportunities to improve other aspects of the ecosystem to be missed.

Although AESs promote voluntary actions for environmental protection, they oblige farmers to follow the standards and procedures laid down in the contractual agreement. The schemes were generally seen as very prescriptive, not allowing room for farmers to think outside the box, act entrepreneurially or to introduce innovative ideas. They did not facilitate the level of engagement with conservation work that is required to produce a change in the culture of conventional farming. This is supported by farmers who have said that joining an AES has had very little or even no impact on how they farm. As Westbury *et al*. (2011) highlighted, the participation of a scheme *per se* does not guarantee the delivery of environmental protection or the improvement the scheme is intended to cause. A motivation or factor influencing a farmer’s participation, is whether or not the scheme can be incorporated into the farm development plans. Or in other terms how well the AES fits in with existing practices and the future plans of the farmer. For example, Ingram *et al*. (2012) conclude from their study that AES participation is not a distinct development pathway but rather an additional strand that is to be incorporated into an existing collection of development pathways.

In terms of SOC, AESs do not have a direct influence and neither is SOC mentioned. Instead, practices and managements promoted by the AESs have the potential to influence SOC levels via good soil management. AESs have the potential to improve the profile of SOC through directed management approaches and promotional information. However, if AESs are to create changes in farming practices or the opinions of farmers towards the environment, including SOC, then they need to be designed in order to make them more engaging so as to promote an actual change in farm management.

5.3.6 Review of Policy and Voluntary Programmes

Overall, the interviewed farmers felt indifference towards the NVZ regulations. Whilst there were restrictions regarding OM input, many of the farmers commented that the limits were reasonable and complied with common sense. The FAs recognised that the limits on OM input reduced restricted the possibility of increasing SOC levels. Overwhelmingly, the SPR was seen in a negative light. The farmers interviewed all felt that it was far too simplistic, was common sense and did not go far enough to achieve anything.

CSF was overall seen as a positive scheme. The grants helped to aid farmers improve soil management on their farms and encouraged certain practices that have been shown to enhance SOM and SOC. The only negative thing to be said about CSF was that some farmers were not sure as to whether they were in a catchment area or not, perhaps indicating that the roll out of the scheme was not as clear as it could have been. As it was not available to all farmers, only those within priority areas actually benefited from it.

AESs generally had a mixed response. From the farmers' perspective, they largely had very little impact as they could choose options to suit the management already on their farms, meaning that any potential AESs had of improving SOM and SOC were extremely limited as a management change was less likely. Whilst they encouraged good environmental behaviours, they didn't necessarily promote new managements. Others, including the advisors felt that they were too prescriptive. The AESs did not allow much room for flexibility or innovative farming. In conclusion therefore, the current legislation system is fulfilling its role as it is encouraging current good environmental practices, but there is more scope for legislation to introduce greater changes in managements and encourage more innovative ideas.

Whilst OM additions were mentioned within the context NVZ regulations, SOC barely got a mention. The only piece of policy which was directly linked to soil, the SPR, was dismissed by the farmers as being pointless. The SPR, or similar document, could be made much better use of. At the time of the interviews, the SPR was not reaching the full potential of what such a piece of legislation could achieve.

5.4 Potential Soil Organic Carbon Enhancing Practices

During the interviews, both the FAs and farmers discussed and described measures and techniques that could be taken to conserve the soil. This section will examine two measures, as highlighted by Bhogal *et al*. (2009) as potentially enhancing soil C levels (table 2.1) and which were mentioned by the farmers and FAs. These are reduced tillage practices, and OM amendments including crop residue incorporation, and reflect those practices which were measured in the farms selected in the sampling plan.

5.4.1 Reduced Tillage Practices

Reduced tillage practices, including min-till and zero-till, are often mentioned in scientific literature and in some advice as a practice which preserves soil C. The reduced use of the plough minimises soil disturbance, reducing the amount of C released to the atmosphere, but it can also lead to a reduction in fossil fuel use due to reduction in the number of passes. Min-till was mentioned by a number of the interviewees as a practice to aid in good soil conservation. For example an organic FA described a farmer who after switching to min-till and after seeing the positive benefits would not go back to the plough:

> *'We've got one farmer I know who has completely ditched the plough and gone to reduced tillage over the last seven years I think. I mean that was because he wanted to reduce reliance on fossil fuels as well but he wouldn't go back now' (FA8) (SW, charity).*

Another FA, also specialising in organic farming, comments that ploughing is the main culprit for loss of organic C and matter from soil.

> *'...I've put this farm through three different carbon audits so I'm well aware of where the issues are, mainly to do with ploughing' (FA17) (SW, government body).*

On the other hand, FA17 (SW, government body) was not convinced that min-till helped in the build-up of organic C in the soil saying that it depended upon the type of OM and C in the soil;

> *'...they were on to this active fraction [of carbon] versus passive fraction [of carbon] and saying that people for example say that minimum tillage is better than ploughing and it's more complicated than that because it depends on the type of organic matter you're looking at. Because if you've got plenty of air in the soil and it's incorporated with ploughing, and it's all mixed in, it could be better*

> *than just having a detritus layer on the top that's not doing much...to be honest I don't think people understand organic matter, that's the conclusion I've come to' (FA17) (SW, government body).*

In the SW, five of the farmers interviewed were trying to utilise min-tilling practices, the success of which was largely dependent on good weather. In the East, six of the farmers were developing min-tillage practices, again weather dependent and five of the farmers were practising direct drilling. Farmer 32 (East, conventional arable) explains why he does not plough conventionally, stating that he felt ploughing negatively affected the soil structure too much. By not ploughing he felt that he was keeping the seed bed in a better condition and improved OM at the soil surface;

> *'And actually a lot of things we do benefit our soils without even thinking about it because it's what we do naturally. So, we don't plough, I say we don't plough, I think out of 1600ha we plough 30 ha this year max. Why don't we plough...we don't plough because we think it effects the soil structure too significantly to do annually and we find that if we use a method of non-inversion tillage, we're still going 8-10 inches deep, we just not inverting it so we're keeping all that fresh tilth on top that's naturally been produced, we're keeping as many seeds on top as we can, we're getting a better mix of organic matter. So the straw from the previous crops, so the residue from the previous crops, is stirred with that 8-10 inch band rather than if you plough, what you're doing is putting the top 3 inches of the soil with all the residues 10 inches below the soil and it just forms a mat and you can find it the following year because it hasn't broken, whereas if you really mix it up I think you've got more oxygen in there, you've certainly got better drainage and we know, talking to T***, who you know, he did a couple of test pits, he did tell me that you've got a lot more worms where you haven't ploughed which obviously helps break down the organic matter in the soil' (F31) (East, conventional arable).*

Farmer 36 (SW, conventional dairy/arable) also mentions reducing cultivation and converting to min-till as a way on conserving his soil;

> *'I've been here about 14 years now, we have spent a lot of time and money on getting better tyres, better practices...we're all min-till now. We've got fatter tyres than we used to have. We used to grow sugar beet but I stopped that before we had to stop...we voluntarily gave it up because it was; we were doing a lot [of] soil structure damage with that. Yeah, the main thing really, is just reducing cultivations really' (F36) (SW, conventional dairy/arable).*

5.4.2 Crop Residue Incorporation and Organic Matter Amendments

Incorporating straw and crop residue was previously discussed as a way many farmers add OM to their soil. Finances and profit are the underlying catalyst for any decision made. For this reason, there has recently been some controversy over the management of straw and whether to bale or chop. A weekly poll, by the Farmers Weekly online, demonstrated that 79% of those who answered said they would be baling their straw, with only 21% saying they would chop their straw (FWI, 1st July 2011). While not a scientific or robust poll, it echoed the general feeling amongst the FAs interviewed. FA19 (East, self-employed) explains some of the benefits that incorporating straw has had on the farms he is associated with, mainly improved soil structure and workability:

> *'I suppose one thing that has changed is that when straw burning was banned and we had to chop and cultivate straw in, I think the general feeling on heavy soils was that it was going to be difficult and there would be lots of problems with slugs and it wouldn't incorporate well and it wouldn't do any good, but actually people noticed almost straight away that it did improve soil structure and the soil workability which is what they noticed and I think farmers are certainly very receptive to that' (FA19) (East, self-employed).*

However, he does add at the end that farmers are happy to incorporate their crop residue, unless the money for selling their straw was high enough;

> *'They're quite happy to crop in the straw and they would only bail it if there was a lot of money involved...' (FA19) (East, self-employed).*

FA20 explains this issue in slightly more detail;

> *'...over here in the West, straw is bailed for livestock bedding. I mean we often think about...the first thing farmers would think about would be how much nutrient their using but a quick calculation I did the other day, there was still a huge margin to be made selling straw over [incorporating]...you know, you might as well sell the straw and buy a bag of phosphate and potash, you'd be quid's in basically...If they sold the straw for a hundred pound an acre, they're only using 40 pound an acre of nutrients so it's more financially viable at the moment to sell the straw' (FA20) (SW, consultancy).*

FA14 (East, consultancy) hinted that the lack of straw being incorporated was maybe caused by the fact that farmers do not understand the benefits it can bring, and that these benefits can outweigh the financial expenditure;

> *'Well I've mentioned to you, you know a that a lot of farmers I'm afraid still do remove their straw and sell it off because it is worth money to them there, whereas they can't say conversely putting it into the ground incorporates organic matter and the organic matter is worth more money to me than I would be selling off my straw for bedding or for burning it as a power plant' (FA14)(East, consultancy).*

As has been previously mentioned, adding manures to the soil is the most common way to add OM to the soil. Here, the discussion made by the FAs regarding manure application is presented. FA20 described the use of manures within arable farming and benefits it could bring financially;

> *'Firstly the immediate saving will be in the amount other farmer has to spend on fertilisers, and secondly, the long term benefit, it could be ease of cultivation maybe on some soils, increase availability of water capacity, which will ultimately*

> *give them more yield. So you know, there's a short-term immediate financial benefit and the rest would be, you know, longer term' (FA20) (SW, consultancy).*

However, FA20 continued to explain that such benefits of manures are not applicable to all farmers. Livestock farmers may see manures as a hindrance rather than as something that can benefit them and improve their finances.

> *'...intensive, livestock producers, I mean their organic manures could always be a cost to them. If they can't sell them, you know, there are limits as to how much they put on their own land, so unless they've got a ready market locally, they can be more of a hindrance than a help' (FA20) (SW, consultancy).*

This review of organic manures perhaps marks the main differences between the agricultural sector of the East and the SW, which will be presented in more detail further on. The use of manures and OM can sometimes cause problems and challenges. A common issue was the storage of manures;

> *'...you've got pollution...obviously if you're going to store manures and spread manures you've got problems there and you've got the annoyance that if you start spreading sewage sludge near a village you can get problems' (FA19) (East, self-employed).*

Manures and sewage sludge are known sources of water pollution. Run-off from fields can enter water supplies which can be problematic, especially if the farm is in a NVZ. Another issue is the smell of sludge and manure. Neighbours nearby to the application site may not appreciate the smell and it may be off-putting to potential new buyers of properties. Another issue FA19 (East, self-employed) raised, is the combination of adding manures with a min-till regime.

> *'...if you're talking about min-tilling and this sort of thing, you'll have problems getting bulky manures into the soil' (FA19) (East, self-employed).*

OM applications can conflict with other practices too. For example, FA16 (East, consultancy) described a situation where manures blocked the work of agri-chemicals.

> *'...the label always says on the can on a residual herbicide, don't spray on a field with more than 10% organic matter which is probably fairly unlikely round here but if you're putting huge levels of organic matter on as we used to do a few years ago that can lock up some of these chemicals and provide less than satisfactory weed control' (FA16)(East, consultancy).*

FA15 (East, consultancy) lists a number of problems which can arise from adding OM to the soil in arable production:

> *'I suppose the only [OM] advice it conflicts with is the need to turn around crops quickly after the harvest and you know, putting on manures can delay that process, although a lot of farmers have rotations where the delay is probably not significant' (FA15) (East, consultancy).*

The need to turn crops around quickly comes from the pressure to intensify farming to keep up with demands from the supermarkets, as well as the global need for more food due to a growing population. A further issue is the damaged caused by extra wheelings on the soil from applying the manures:

> *'And the only other advice it conflicts with is obviously is the extra wheeling's on the field and the potential soil damage done, but again a lot of tractors, a lot of farmers now have specialist tyres on their spreaders to make sure they don't damage the soil too much' (FA15) (East, consultancy).*

There is also a restriction regarding sewage sludges. They can only be applied to combinable crops and cannot be applied to any organic crops or malt and barley which are used in beer making;

> *'But other than that I think there's no conflict, except this business of cultivating...sewage sludge and malt and barley and the restrictions there' (FA15) (East, consultancy).*

A few of the FAs suggested that it is possible to get around the potential issues associated with adding OM by thinking in an innovative way.

> *'...and I guess being very conservative about cropping [is a blockage]. Yeah, for example, I advocate a lot of...a mixture of soil organic management and weed management, over winter green manures, then spring cropping. And most would say 'Ooh we couldn't..., for example in your neck of the woods, in Essex, it's too heavy, I couldn't possible spring crop. Well you can, you've just got to do it in the right way. So it's looking at things like that really. So some are quite conservative in their approach' (FA18) (East, consultancy).*

FA21 described a case where a farmer had thought outside of the box and made the most of resources available to him;

> *'In Holland, he took from the local councils all the road side cuttings and hedge cuttings, and because there's a lot of ditches and canals in Holland, he took on all the organic matter that came out of the canals, you know, when they cleaned out the ditches and canals. He put it in his farm, composted it and applied it to his fields' (FA21) (SW, consultancy).*

5.4.4 Soil Organic Carbon Enhancing Practices Review

Clearly, both FAs and farmers were generally well informed about practices which improved soil quality. Reduced tilling was a method that several of the farmers were attempting to employ. However, the practical success of this depended largely upon the weather. Ploughing was recognised as a method which releases C from the soil as well as using a large amount of fossil fuels. It was mostly for the latter reason and associated financial costs that farmers were attempting to reduce their tilling. OM additions, in the form of crop residue incorporation, FYM and sewage sludge were also recognised as methods which improved SOM and SOC content, although they were primarily done to improve soil structure. As briefly mentioned, OM application and their use, reflected the difference in farming systems between the SW and the East. The following section will now address some these differences in more detail.

5.5 Organic Matter: Type, Source and Application

5.5.1 Introduction

The discussion of OM, its type, source and how and why it is applied is where the greatest difference between the East and the SW was demonstrated from the interviews. The driver behind this difference was caused by variation in farming type. As highlighted in section 4.1, Chapter 4, the two areas were chosen to study as they contrast with each other in terms of the type of agriculture practiced in each area. In the SW, agriculture is dominated by livestock farming. This means that farmers have readily available OM, usually in the form of FYM, to apply to their land, with little or no costs involved in sourcing the material. In the East however, arable farming is dominant. As a result FYM is scarce, and the distances involved in transporting the material from its source to another farm is often a limiting factor. The following section presents the view of the FAs with respect to this topic, followed by the farmers' opinions, highlighting the differences between the two regions, and the restrictions which may inhibit an improvement in SOC levels.

5.5.2 The Farm Advisors' Experiences

Farm Advisors in the East

FAs in the East repeatedly commented on the scarcity of OM resulting from the specialising of agriculture within the UK, with large arable farms in the East and livestock farms in the SW. For example, FA15 (East, consultancy) who is based in the East said that there was not enough OM available across the country to increase SOC levels everywhere;

> *'We know that we can't increase organic matter over the whole country because there's not enough organic matter to spread around, so how do we best use it from a national perspective or from a wider perspective?...How to manage a scarce resource to the best advantage for the whole farm?' (FA15) (East, consultancy).*

FAs 3 and 14 both commented that the lack of livestock and OM in the East was a challenge. FA3 (East, charity) referred to finding OM to put back into the soil as a big problem;

> *'But the big problem in the East is where do I get my organic matter from to put back into the soil' (FA3) (East, charity).*

FA14 (East, consultancy) stated that farmers in the East were concerned by the lack of livestock in the region resulting in less manure being available to them;

> *'We are in the Eastern region seeing more farmers getting concerned that there is less livestock and so less livestock manure available for them to take' (FA14)(East, consultancy).*

FA11 (East, self-employed) highlighted the questions that arable farmers in the East had to ask themselves if they were to bring in organic matter from an outside source, including where to buy it, how to transport it and who is going to spread it;

> *'If you're a straight arable farmer and you've got to import FYM, are you going to buy it? Who's going to transport it? Where are going to put it? Who's going to spread it?' (FA11) (East, self-employed).*

As a result of the lack of livestock OM available, farmers in the East have had to look elsewhere to find usable sources of OM to incorporate into their soil. These included duck, pig and poultry manure, paper crumble, green waste, and sewage sludge. However, these alternatives do not solve the problem. FA11 (East, self-employed) commented on a local supply of duck manure that was available but said that it was not very fertile;

> *'There is a supply locally of duck manure from indoor ducks, but duck manure is not very fertile' (FA11) (East, self-employed).*

Compost and green waste were also used and was noted as being beneficial from a nutrient input perspective as well as increasing OM. However, as FA11 (East, self-employed) highlighted, these sources pose risks of contamination;

> *'And a lot of it is contaminated, it's glass and wire and bits of plastic, you know, do you want to put that on your field for the next 20 years? Some people are happy to do it but I've never been a great fan of it' (FA11) (East, self-employed).*

By using green waste, FA11 (East, self-employed) was concerned that it would introduce rubbish into the farming system, which could pollute the soil. He was also concerned that any 'rubbish' could be there for a long length of time. Some other FAs interviewed were more than happy to use green waste, saying that the quality of the material had improved over the years. Another material, which seemed to cause problems was sewage sludge. Sewage sludge cannot be applied to all crops (malt, barley and vegetables and other combinable crops) and nor can it be used within an organic system. As FA15 (East, consultancy) highlighted, he was unable to use sewage sludge on one of his farms as they grow malt and barley;

> *'What we're not looking at is sewage sludge because our farm produces malt and barley and once you've used malt and barley you can't use sewage sludge' (FA15) (East, consultancy).*

FA19 (East, self-employed) stated that the Environment Agency classifies some sewage sludges and other types of organic waste materials as toxic waste. This means that these materials are difficult to apply and require testing to be done every time they are to be used which may put some farmers off of using them. In addition to this, the Environment Agency also classifies compost as industrial waste. Therefore compost can be applied to soil, but requires a large amount of paperwork, as FA16 (East, consultancy) comments;

> *'How the EA class compost as an industrial waste, that doesn't help...it's a lot of bureaucracy and getting the exemptions certificates from paragraph seven which is what you can now have, is just a pain in the neck' (FA16)(East, consultancy).*

It was clear that both FA19 (East, self-employed) and FA16 (East, consultancy) felt frustration at the bureaucracy related to the application of OM in the form of sewage sludge and composts. Another issue was the initial cost of buying in the material. FA14 (East, consultancy) commented on the price that water companies charge for sewage sludge, stating that the price was higher in the East of England;

> *'Anglian water typically charge £4.50 per tonne for sewage sludge cake, they are the most expensive. The rest of the country, for example Seven Trent water, they charge about £2.50 per tonne' (FA14)(East, consultancy).*

FA14 (East, consultancy) then went on to say that Anglian Water had increased their costs in the last few years, as they know there is a large market demand for the material;

> *'Anglian water can get away with more because they have got more farmers calling them up saying 'I can't get hold of livestock manures, I haven't got a composting site near me, and therefore Anglian Water, please can I have some of your sewage sludge cake, I should call it biosolids, because I want organic matter in my soil'...But they can charge the most in Anglia, Anglian Water because the farmers realise they need organic matter' (FA14)(East, consultancy).*

Whether this impression from FA14 (East, consultancy) is true, or not, is perhaps debatable, but if the advisor feels this is the case, then there is clearly an issue. However, some water companies, along with councils, give sewage sludge and green waste to farmers for free, as it is a waste product for them, and it is probably cheaper than disposing of the material through other methods.

Once famers have secured a source of OM for their soil, the next challenge is the cost involved in transportation, when compared to the value gained in productivity by adding it to the soil. The majority of FAs who raised the issue of sourcing OM mentioned that the transport costs are usually the limiting factor in the application of OM, as the cost benefit cannot be realised. Many farmers have to import the OM resource a number of miles, dramatically increasing cost as FA14 (East, consultancy) describes;

> *'...because there's not a lot of livestock manures or compost around, transport is a problem. Unless you have got a neighbour, a pig farmer, and intensive pig farmer or a poultry farm near by then you can swap straw for muck you know just over the fence, transport are so expensive you can't afford to put on organic manures you know, 30, 40 tonnes per ha, depending upon the nitrogen content that's typical for organic manures, it's a very expensive job is transport. That's a barrier' (FA14)(East, consultancy).*

FA14 (East, consultancy) refers to the transport costs involved as a barrier to adding more OM to the soil. That the OM is generally bulky means that more fuel would be needed in transporting it in the amounts needed by the farmer, adding more costs. The farmers who have neighbours with livestock are in the most advantageous position. FA15 (East, consultancy) commented that if the material has to travel for more than 15 miles to be applied, the nutrient value to be obtained is not worth the cost of the transporting it;

> *'I think some farmers have worked out that if you live more than 15 miles away from its source it's not worth it in terms of P and K and things like that. And a lot of these manures are very bulky obviously and therefore the transport costs are a major consideration in their use. So you can't move it across the country and things like that and that's another issue of course' (FA15) (East, consultancy).*

Farm Advisors in the South West

Interestingly, but perhaps not surprisingly, the subject of sourcing OM was almost entirely raised by FAs in the East. In fact, it was only mentioned by one FA from the SW, and that was whilst commenting on the differences between the two areas on this issue. FA20 (SW, consultancy) commented that in SW livestock farmers have got too much manure than they really need, but that in the East the situation is very different;

> *'...but it's a rather different situation in the East really...you know we've [in the SW] got lots of livestock farms, they [the livestock farmers] have probably got too much organic manure' (FA20) (SW, consultancy).*

5.5.3 The Farmers' Experiences

As with the FAs, the specialisation in agriculture between the two were regions were reflected in the farmers' responses too. In the SW all farmers applied FYM to their soil, but in the East only half did. There was a greater variance in the type of material added in East compared to the SW, along with different reasons behind adding the material.

Farmers from the South West

In the SW, all of the farmers applied some sort of FYM to their land, with the majority being cow slurry. As can be seen from the responses of farmers 30 (SW, organic beef/poultry), 39 and 41 (SW, conventional dairy) below, when asked about whether or not they apply organic matter to their soil;

'Well only in the form of the manure' (F30)(SW, organic beef/poultry).

'Cow slurry' (F39) (SW, conventional dairy/sheep).

'Yes, loads of it. It's called dung' (F41) (SW, conventional dairy).

Farmer 35 (SW, conventional beef) also applied FYM, but also had an arrangement with a local farmer over the use of his straw, produced from the cereal crops. Instead of incorporating the crop residue, which only two farmers in the SW did, he would give the straw to a neighbour, who used it as bedding for his livestock. The straw would then be returned to famer 35 at the end of the winter to put back onto the land;

'Yeah, farmyard manure...Well we do actually import farmyard manure as well. That would be from a neighbouring farm. And the sort of deal that we've got is that they will take straw from us at harvest, the straw we produce from our cereal crops, they bed their animals through the winter, and then they give the straw back to put on our land. So it's only a small proportion, only about 100 tonnes' (F35) (SW, conventional beef).

Other materials added, included poultry litter (Farmer 34) as well green waste from councils;

'We do add some [cow slurry]. We haven't got enough to make a difference but do have a small amount of FYM from the cattle but we also bring in Green Waste Compost from the Devon Waste management. We bring in about 5000 tonnes a year...Certainly [good] as a soil conditioner. What we find is, it's got no nutritional value but as a soil conditioner it helps, but it does need applying for about four or five years before you start seeing any results. A one-off application doesn't show any results' (F38) (SW, conventional sheep/arable).

Farmer 38 (SW, conventional sheep/arable) has used green waste from the local council to make up the shortfall in FYM from his own cattle stock. Even though the green waste is a source of organic matter, he says that is most useful as a soil conditioner[13], rather than to increase the soil nutrient value. He also adds that the visible value of adding green waste is a long term process, but he seemed to be fairly happy with the results it produced. This is contrary to the view held by F11 who did not think it was a good material to add to soil. Two farmers, 41 and 42, both used digestate from a local biogas plant. Organic waste, including cow slurry is anaerobically digested, the end products of which are biogas and digestate. Farmer 41 (SW, conventional dairy) describes how at one point, the biogas plant used to take

[13]A soil conditioner is a material applied to a soil to improve the physical qualities, predominantly the soil structure but also including the availability of soil nutrients to plants, the cation exchange and water holding capacity (Hickman and Whitney, 2006).

away some of the slurry, put it through a digester and then return it to the farmer, after which process the material was higher in nitrogen;

> *'They used to take cow slurry and bring it back because they put it through a digester and make electric out of it and bring us back the product which is higher in nitrogen and used to be quite high potash but it's not so much now' (F41) (SW, conventional dairy).*

Farmer (SW, conventional dairy) 42 stated that he added the digestate as well as the cow slurry and dung from his own farm;

> *'Well we add slurry and dung and we have digestate from the factory in Holsworthy' (F42) (SW, conventional dairy).*

This was beneficial as the only costs involved in adding the digestate to the field, were those associated with the contractor company spreading the material.

The SW farmers gave several reasons as to why they applied OM to their land. The initial response was generally that they applied manures as there was no better way to dispose of it and it was a way to get rid of the material. For example, farmers 42 (SW, conventional dairy) and 30 (SW, organic beef/poultry) both initially said that there was nothing else you can do with it and that it had to go somewhere;

> *'Well it's got to go somewhere. But we try and use it as a fertiliser' (F42) (SW, conventional dairy).*
>
> *'Well there's nothing else you can do with it for one...You're taking nutrients out by cutting it and basically it's just going through the cows and you're putting it back where it came from essentially' (F30)(SW, organic beef/poultry).*

Farmer 30 (SW, organic beef/poultry) mentions the life cycle of the grass. The grass is cut, goes through the cows and then is put back on to the land and so the nutrients which were taken away when the grass was cut are returned in the form of manure or slurry. It was common for the farmers to give a secondary reason for applying OM. This was usually related to soil nutrients or soil body as farmers 37 (SW, conventional dairy) and 39 (SW, conventional dairy/sheep) in the quotes below demonstrate. Farmer 37 that adding manure fitted in to the nutrient plans and the crop requirements;

> *'To get rid of it...No, no, we add it to try and get the crop rotation, all nutrient plans, so we're trying to match the crop requirements with what's in the soil and also the value, the fertiliser value we can get from the manures and then just top up as and when we need with inorganic fertilisers' (F37) (SW, conventional dairy).*

Farmer 39 (SW, conventional dairy/sheep) goes into more detail with his answer, describing how the muck used to be a waste material but that it is now a valuable product. He states that the improved management of the slurry is driven by financial reasons, due to the increased cost of N fertiliser. The waste management plan and fertility are also mentioned, whereby the nutrient value of the slurry is calculated and combined with the nutrient needs of the crops in order to spread the most efficient amount of slurry;

> *'Well we've always done it; it's a way to get rid of it. Again, 20 years ago it was a waste material that you just had to get rid of, now I do a waste management plan, or fertility plan, and I'll sit down and work out from RB209, the nutrient values of the slurry, the crop requirements and then we'll spread the slurry, and generally speaking we don't spread any nitrogen, for example on our cutting ground. We do spread nitrogen on the grazing ground because obviously if we put slurry back on the cows won't eat it, so I mean, I'm not saying that there aren't times when we just spread slurry to get rid of it because the tank or the pit is full, but we are, and again that's financially driven, because when nitrogen was £100 a tonne, it didn't matter, well now it's £300 a tonne, it does matter. Finance is a big incentive' (F39) (SW, conventional dairy/sheep).*

Farmer 41 (SW, conventional dairy) also applies slurry to his soil for nutritional value and has it analysed so applications are more effective and efficient. Again, there was also a financial incentive;

> *'One, it's got nutritional content we obviously have to use because fertiliser is really expensive so we make full use of that. We actually have it analysed to work out what we're putting on' (F41) (SW, conventional dairy).*

As well as nutrient value, slurry was also applied to the soil to improve the soil structure, or body as some of the farmers referred to it as. Both farmers 34 (SW, conventional poultry) and 40 (SW, conventional dairy) said that they added slurry to improve the soil body and the soil condition;

> *'Two reasons; nutritional and then also to give body. The land is, being sandy; it's lost its body in arable rotation, so it's just trying to give body back to the land' (F34) (SW, conventional poultry).*
>
> *'Fertiliser and soil conditioner' (F40) (SW, conventional dairy).*

Most of the farmers in the SW had been spreading FYM for as long as they can remember, as it had always been something which they did to get rid of the material. Therefore, they did not necessarily see a benefit from adding it, except when they began to record the nutrient values when developing the nutrient plan for their farms. Improved crop-growth was also noted as a positive benefit from adding OM to the soil. Farmer 41 (SW, conventional dairy) felt that the roots of his grass grew better with the slurry added to the soil;

> *'...obviously it's got nitrogen and potash in it and grass uptakes that and it's green and it grows and then obviously the roots grow better and then it does good for the soil. So I think it all goes round' (F41) (SW, conventional dairy).*

Farmer 42 (SW, conventional dairy) commented that the colour of the grass was improved as well as the growth;

> *'Yes, you can see where it's added...We're looking at colour of grass. T** goes out, well not so often now, but in the summer he'll go out every week with his plate monitoring grass growth because he knows what it's supposed to look like' (F42) (SW, conventional dairy).*

Farmers from the East

The Eastern farmers applied a greater variety of OM compared to the farmers in the SW. FYM was applied but was not as prevalent as it was in the SW. Farmer 27 (East, conventional beef) applied '*cattle muck*' to his soil; however he was the only cattle farmer in the East to be interviewed so this is not surprising. Farmer 25 (East, organic arable) also used cattle muck as well as poultry manure and green waste;

> *'I have to be quite careful as to how I source my muck but I do use local cattle muck. In fact one of the people is the chap who bought my cattle. So we get farmyard manure locally and if I can get free range poultry muck I get that as well. And then this year I mixed that with compost, so 50/50' (F25)(East, organic arable) (NB: compost is Green Waste).*

Farmer 32 (East, conventional arable) also used poultry manure as well as incorporating crop residues;

> *'I do, I add about 30 acres a year with chicken manure...We don't bale any straw anyways. It's all put down to the ground' (F32) (East, conventional arable).*

Another set of materials mentioned was sewage sludge and bio solids. For farmer 23 (East, conventional arable) it was the only OM input applied to his soil;

> *'No, sewage sludge is the only thing, we don't put any farmyard manure on' (F23) (East, conventional arable).*

For farmer 26 (East, conventional arable), also, bio solids were the only OM to be applied to the soil, in addition to the crop residue which was incorporated;

> *'We do, we use bio solids from time to time...But apart from bio solids, other than we have a policy, we don't bail any of our straw. All the chopped straw is returned to the soil. I take the view that we want to minimise the depletion of organic matter. I don't want bailers running around on the soil' (F26) (East, conventional arable).*

All the farmers in the East incorporated their crop residues, unlike those in the SW. For farmer 29 (East, conventional arable), this was the only type of OM to be added to the soil;

> *'...we don't put muck or silage, sewage sludge or anything like that. It's just purely the residue of the previous crop' (F29) (East, conventional arable).*

Green waste, which has been mentioned previously, was another popular material in the East. Farmer 30 (SW, organic beef/poultry) used green waste in conjunction with incorporating crop residue, and felt that is was a good material;

> *'Generally we only return to the soil what was left from the previous crop residue. Organic matter wise we have two fields were the Autumn before the one just gone, we did put in some compost from a waste recycling centre, which I think is a great thing and I'm sure will make a difference' (F30)(SW, organic beef/poultry).*

Farmer 32 (East, conventional arable) used a mix of poultry manure, green waste and a material called Limex;

> *'Yes we do. We import poultry manure which usually goes on at about 8 to 12 tonnes a hectare depending upon its nutrient make up, we have that tested every year, but that's imported from a poultry producer. We also import a lot of green waste. So we put on 30 tonnes a hectare of green waste rotationally on all our fields and we also import Limex from the British sugar factory in Bury St. Edmunds, as a soil conditioner, and we put that on the rotation as well. So in most rotations the soil will either have limex and green waste, or it will have poultry manure because the poultry manure has the organic matter plus it has the nutrients whereas the balance of the compost and the Limex give us what we need to grow a reasonable crop' (F32)(East, conventional arable).*

Whereas the manure and green waste provided OM and some nutritional value, Limex improved the soil condition and structure. Limex is a waste product produced from making sugar out of sugar beet.

Both farmers 28 (East, conventional arable) and 33 (East, conventional arable) made their own compost to add to the soil. Farmer 28 used manure from local livestock farmers, and turned into compost with a compost turner;

> *'I buy farmyard manure from local livestock farmers and then I'm making it into compost myself with a compost turner' (F28) (East, conventional arable).*

Farmer 33 (East, conventional arable) however used horse manure rather than livestock manure. He said there was a plentiful of supply in the local area and he could take it for free. He too, turned it into compost and applied that to his soil, in addition to incorporating crop residues;

> *'I make a bit of compost out of horse manure that I pick up from local stables and things. I make that into compost and spread that. That's all I do really. And I keep all the straw, I don't sell any straw' (F33) (East, conventional arable).*

An issue that was mentioned by several of the farmers in the East was once they had found a source of OM, the cost of haulage was very high. Farmer 22 (East, organic arable) used a combination of green waste and poultry manure on his land. He justified the cost of the haulage of the poultry manure in response to a question regarding the distance that some FYM has to travel in order to get it to the farm;

> *'It's definitely a limiting factor as you have to pay for the haulage but organically we don't have any choice. I mean I feel that you can't just keep on growing crop after crop without you know, balancing, without doing a proper nutrient balance*

> *sheet and if it's not stacking up then you shouldn't be doing it...' (F22) (East, organic arable).*

Farmer 22 (East, organic arable) felt that he had no choice but to pay the cost of haulage because as an organic farmer, he relied on the input OM to balance the soil and its nutrients. Farmers 25 (East, organic arable) and 26 (East, conventional arable) commented on the cost of hauling material if the source is not local to the farm. Farmer 25 referred to the cost as being 'a bit of a killer';

> *'As soon as you get lorries involved it becomes a bit of a killer' (F25) (East, organic arable).*

Farmer 26 (East, conventional arable) stated that he would like to apply FYM, but as he was long way from the nearest livestock farmer, it was not possible due to the cost of transporting the material. He said this issue was down to the specialisation of farming that had occurred in recent years, stating that large pig and dairy units had gone from his local area;

> *'...I would love to put farmyard manure on, if we had a livestock unit I would, if we had a neighbouring livestock producer if he would let me have it at a reasonable price. But because of the way farming has specialised, we are long way from the nearest livestock farmer. There are one or two smallish chicken units, but large pig units and dairy units are just all gone, sadly' (F26) (East, conventional arable).*

The majority of the farmers in the East stated that the main reason for adding OM was for nutrient value, although farmers 23 (East, conventional arable) and 32 (East, conventional arable) both mentioned the increased levels of SOM as a positive outcome. Farmer 23 (East, conventional arable) stated that applying sewage sludge helped to put the OM back onto the soil, in addition to the source of phosphate;

> *'To put the organic matter back in the soil and phosphate. Mainly for the phosphates in fairness but it is a very good source of organic matter' (F23) (East, conventional arable).*

Farmer 32 (East, conventional arable) also noted the benefit of increasing SOM levels through the addition of OM to his soil;

> *'You're putting on Nitrogen, phosphorus and potash and I think that lasts into the second crop as well so you get two years benefits and I think you also get more organic matter' (F32) (East, conventional arable).*

Farmer 26 (East, conventional arable) stated that incorporating crops residue improved his soil structure whilst the bio-solids supplied nutrients;

> *'My reasoning for it is, because the received wisdom is that it improves soil structure...But we are told it improves soil structure so I'm prepared to believe the experts and obviously for bio solids I'm not sure there is a lot to be done for soil structure but it's the nutrients we are after really' (F26) (East, conventional arable).*

Other benefits mentioned by farmers included improved yield, improved drainage and increased water holding capacity. Farmer 23 (East, conventional arable) mentioned an improved yield with the use of sewage sludge as well as improved workability;

> *'The soils become more friable and workable. And we do defiantly get a yield response from land that has had sewage sludge compared to land that hasn't' (F23) (East, conventional arable).*

Farmer 33 (East, conventional arable) stated that he had improved root growth and better drainage with the additional of OM to his soil;

> *'Well amazing, it just seems to open the soil up and makes its better draining and the roots go down better and it just big improvement, yeah. Because I was, I was starting off from no really top soil or no real organic matter at all, you know, and it made a big difference straight away' (F33) (East, conventional arable).*

Both farmers 31 (East, conventional arable) and 32 (East, conventional arable) said they had improved drainage, and most importantly, reduced fuel use (F31) as a result of applying OM;

> *'We get a much better seed beds. I haven't mole [drained]...Now I haven't had to do that, or rather I haven't done that for eight years, and I think I haven't had to do it because my soil is draining better...but what I do know is we're getting less compaction so I suppose we must be getting a better yield but we are also using less fuel' (F31) (East, conventional arable).*

> *'Makes the soil work better and holds more moisture in the dry time...I think the land breaks up easier with the straw inside it yeah' (F32) (East, conventional arable).*

5.5.4 Organic Matter Review

The addition of OM to the soil demonstrated the biggest difference between the SW and the East. The FAs in the East repeatedly mentioned the scarcity of OM, especially FYM, in the region due to the lack of livestock farmers, whilst the SW FAs did not mention OM in terms of sourcing it. All of the farmers in the SW applied FYM, with a number also using poultry manure and green waste. In the East however, the number of farmers using FYM was much lower. Other materials had to be used instead such as green waste and poultry manure. Farmers from the East appeared to be more willing to incorporate their straw than the SW. This was for two reasons; firstly because it provided a source of OM, and secondly because the price for selling it was not high. In the SW however, farmers were more likely to sell their straw because of the high price they could receive but also because there was not such a requirement for the OM it could supply. The limiting factor behind the lack of FYM use, in areas such as the East, was the cost of transporting it due the distances between the farm and the nearest livestock farm. Farmers in both regions stated that they added OM in order to improve the nutrient value of the soil, as well as the soil structure, or soil body.

Whilst asking farmers and FAs about OM additions to the soil, SOC was rarely mentioned. Instead the terms SOM and OM were used. All of the farmers recognised the importance of having good OM levels in their soil, ranging from improved structure to increased nutrient availability. It is encouraging that the interviewed farmers in the East were looking for alternative sources of OM to apply to their land in order to improve the quality of the soil rather than settling with the lack of OM available to them. The good management of OM is positive in terms of increasing SOC levels in soil.

5.6 Carbon, Climate Change and Sequestration

During the interviews with both FAs and farmers, the term SOM was often used in replacement for SOC. This was done as it was felt that SOM would be a more familiar term than SOC. SOM and SOC are closely linked as roughly half of SOM is SOC. When conducting the interviews, the use of this terminology was explained. However, this section will look at how many farmers and advisors made the link between SOM and C. Not just in terms of the soil but also with regards to reduced carbon dioxide (CO_2), carbon sequestration and climate change mitigation.

The interview transcripts reveal how farmers and advisors employed the various key terms of this research and in what context; terms such as 'soil carbon', 'carbon sequestration' and 'climate change' were used. Only a few of the farmers directly said 'carbon' in relation to their management and OM additions. The following quotes are taken from interviews where the farmers mentioned 'carbon' without being prompted;

> *'And we can see some improvements, I don't mean that it necessarily means that carbon levels have improved but structurally ploughing in straw and oil seed rape residues has improved the structure and the workability'(F24) (East, conventional arable).*

> *'We grow wheat and barley because of where the ground is. If it was all together we would keep more cows and it would all be grass so we'd do that, not necessarily for a soil carbon reason but for practicalities…But we're buying in a lot of sawdust every year that goes back out in the ground and a lot of straw back out on the ground and a lot of dung back out on the ground, so really there's very little we can do to add more carbon and I'm sure if you were to measure our carbon there wouldn't be deficit really' (F42) (SW, conventional dairy).*

Farmer 24 (East, conventional arable) spoke about the historic legacy of previously used farming practices and their impact upon current soil C levels;

> *'Yes which is actually quite an interesting issue because in the sort of mixed farming that would have been going on around here 50 plus years ago, clearly*

> *there would have been more carbon sequestered because there would have been a lot more grassland and I'm not quite sure whether on your arable fields it would have been vastly different but the amount the locked up must have dropped with the change to mostly arable cropping' (F24) (East, conventional arable).*

One farmer admitted that he did not know that much about at all about C;

> *'With regards to carbon, that's probably something I wouldn't know a lot about because I actually...the trouble is I don't want to comment on something that I don't know much about...I suppose it's because it hasn't point directly affected us, there's my ignorance a little bit, but I don't know that much about it because I haven't had too. Does that make sense?'(F35) (SW, conventional beef).*

The Prominence of Organic Farmers

The transcripts of the FA interviews showed that, from the FA perspective at least, organic farmers were more aware of soil C. This could be because an organic farmer is far more likely to know the SOM and SOC content of their soils as they rely more heavily on the nutrients contained in the organic amendments to substitute for artificial fertilisers. FA21 (SW, consultancy) says that it is his organic farmers who are interested in SOC improvements via the subject of soil fertility;

> *'…the main interest for the soil organic carbon content improvements are really from my organic farmer clients because we're looking at improving soil fertility which is nitrogen based and the only way to actually increase nitrogen content is actually by providing more carbon and increasing soil carbon levels at the same time...' (FA21) (SW, consultancy).*

FA18 (East, consultancy), an organic advisor also commented that in the organic industry, there is focus on soil health, including increasing SOC levels which is seen as a component of a healthy soil;

> *'In the organic industry we focus a lot on soil health, improving soil organic matter, soil organic carbon, as a sort of functional component of a healthy soil' (FA18) (East, consultancy).*

Another FA, also specialising in organic farming, comments that ploughing is the main culprit to losing organic carbon and matter from soil.

> *'...I've put this farm through three different carbon audits so I'm well aware of where the issues are, mainly to do with ploughing' (FA17) (SW, government body).*

However, contrary to the image presented by the FAs above, farmer 33 (East, conventional arable) commented that he felt organic farmers were not always as environmentally friendly as they appear. This was in relation to their ploughing and cultivation techniques whereby they lose a lot of C from the soil system;

> *'I have a problem with organic farmers because they keep ploughing and cultivating, and they keep losing their carbon all the time, the more air they're putting in it, they're losing it. Not only that but they're releasing nutrients out of the organic matter which are suddenly available which is sort of what they want but if it's not used up straight away by the plants then it goes down into the water. And organic farming is not the answer to environmentally friendly farming' (F33) (East, conventional arable).*

Therefore it can be seen that although organic farmers may understand and/or be interested in C and environmental friendly practices, they are not always looked upon as such. Ploughing is, undoubtedly, the most C-releasing practice in farming and so it must be with great care that extra OM is added to the soil, if conventional ploughing is still occurring, as that C will otherwise be released to the atmosphere.

Carbon, Sequestration and Climate Change Related Workshops

The subjects of C, climate change and carbon sequestration were also mentioned in context to workshops. A FA from the East described a case study where a farm workshop which was:

> *'focused entirely on soil organic matter and basically why it's so important in terms of erosion, run-off and water quality and also in terms of building up the carbon reserves within the soil and the impact on climate change and those sorts of things' (FA12) (East, government body).*

Initially two workshops were run by the advisor, but due to oversubscription a third one was organised, which meant that over 50 farmers attended the workshops in total. Whether the popularity was due to the format of the workshop or the topic to be discussed is unclear, but it does send out a positive image of both the workshop as a viable means of communication and that the topic was popular. As the FA said *'So it was interesting because the farmers were more interested in that [SOM] as a topic than they were in some of other stuff we offered at the same time. So we were quite pleased and surprised'* (FA12) (East, government body).

Farmer 22 (East, organic arable) expands on this comment by discussing the workshops he has attended, which have focused on climate change and how to adapt to it. Although not directly linked with C, the workshops nevertheless demonstrate how climate change may affect farming and what can be done to address it. As increased CO_2 concentrations have been associated with climate change, C was mentioned in passing at this event;

> *'The organic ones? Yes. They centre around soils, farm biodiversity, but also diversity of crops on the farm. So looking at things like wheat population so looking at drought resistance, looking at...it's mainly looking at actually...a huge amount of organic, looking at the effects of climate change and what we should*

be doing to try and mitigate the perceived problems, or actually what is happening, as far as climate change is concerned. ' (F22) (East, organic arable).

Additionally, FA14 (East, consultancy) commented that soil C was increasing in popularity in the information being provided by government resources as well as amongst the farmers and was coming more to the forefront of soil management advice;

'...If I was doing a soil management workshop 30 years ago, I wouldn't have mentioned soil organic carbon or organic carbon because farmers wouldn't have known what it was' (FA14) (East, consultancy).

Despite this, famer 37 commented that he felt more advice and information was needed on the subject;

'Yeah, I think there is. I think soil biology, soil carbon, carbon release. Yes, I think there could be a lot more' (F37) (SW, conventional dairy).

He follows on from this by adding that soil C could have a bigger part to play in farming in the future;

'Yeah, I think it could be, have a big part to play in farming, further down the line when we're looking at carbon footprint, that sort of thing. I think there might be more of a move towards more grass and less tillage' (F37) (SW, conventional dairy).

Farmers' Awareness of Their Role in Mitigating Climate Change and Their Motivations

Despite the examples demonstrated here of farmers being aware of C, some FAs nevertheless concluded that farmers did not really understand C and climate change. When asked, the FAs gave a mixed response as to whether or not they felt farmers were aware that they had a potential role in mitigating the effects of climate change. Some said that farmers are simply not aware of their potential role in mitigating against climate change with very few maintaining that farmers saw themselves as having a direct role in doing something about it. Although advisors acknowledged that the more forward-thinking farmers knew about climate change and the part agriculture could play in mitigating it, others believed that farmers were generally sceptical of climate change and that many refused to accept it as a reality. Certainly, it would seem that information about climate change and how individuals can respond to it has rarely been specifically directed at farmers and the agricultural community

FA18 (East, consultancy) commented that when it came to managing soil C, farmers had to think about the long-term benefits against the short-term cost involved, and that sometimes this limits farmers from doing more to manage C;

> *'Everything to do with soil organic matter and soil organic carbon is a long term process whereas they've got to balance that against the short-term cost. It's a tricky one' (FA18) (East, consultancy).*

When speaking about alternative energies and climate change, FA19 (East, self-employed) was negative in regards to farmers' awareness of what the situation is perceived to be. He felt that farmers thought climate change was rubbish, and that what they did would have very little impact on the global scale;

> *'I think they think it's (climate change) a load of rubbish. You know they've seen where the patterns...you know people have local weather records going back to the 1880's and there isn't really a lot of signs in that that really you can see the patterns change, so I don't think they're very convinced that there's much in it, or much they're going to do anyway. Compared to what they might do and what China might do, it's utterly irrelevant, so I think they think it's a load of rubbish (FA19) (East, self-employed).*

Digging a little deeper, FAs were then asked if farmers had taken on any environmental-friendly, or C reducing practices. The most common response was that farmers are doing their bit for climate change by actively reducing their fossil fuel use (10 FAs) but that most of them were doing it for financial reasons rather than environmental. Four FAs said that farmers are using alternative energy sources on their farms, such as solar panels and small wind turbines, but again the majority were doing this for primarily for financial reasons rather than environmental. FA19 (East, self-employed) said that he knew of farmers who had wind turbines bit that it was purely for financial reasons. He also continued to state that he thought farmers were cynical of climate change;

> *Yeah, some people have windmills and things but it's purely for money. Purely for money, I don't...I haven't come across a believer yet. You know I think some people may have a marginally open mind and they might think there's something in it but you know, probably the natural effects of climate change are getting much more than the man-made, so what are they going to do? That would be the attitude I think. Cynicism or scepticism' (FA19) (East, self-employed).*

Two FAs said that they knew of farmers who were aware of carbon sequestration and were actively seeking ways to sequester carbon on their land. The farmers in question were organic farmers. As farmer 37 (SW, conventional dairy) mentioned, soil C could potentially have a bigger role to play in farming in the form of the carbon footprint.

The Use of Carbon Footprints

C footprint is the calculated amount of CO_2 or other C compounds emitted into the atmosphere by the activities of an individual, company or country.

Farmer 29 (East, conventional arable) mentioned C footprint without being prompted demonstrating that he understood the concept of a C footprint, considering the inputs and outputs as well as the wider distribution once the product has left the farm gate;

> *‘Oats are cheaper to grow, don’t need too much on, so that helps from Carbon footprint point of view…Yeah, Whitworths are a big flour miller, the biggest in the country and CambGrains, between here and Cambridge, so it’s all about food miles and the carbon footprint and all that’ (F29) (East, conventional arable).*

Conducting a C footprint evaluation on farms is something that a couple of farmers had already experienced due to the requirements of the company that they had supplied their milk to. The company conducted the audit themselves with the farmers providing the auditors details of their electricity use, inputs and outputs. Farmer 39 (SW, conventional dairy/sheep) described the process of his C footprint audit, saying he supplied the company with energy bills and other information that is required, and they calculated his C footprint for him;

> *‘No, we have to do things like carbon footprints, electricity use, carbon reduction from our dairy cattle and the electricity used...<u>Is that all quite easy to do?</u>[interviewer question]...Someone just comes in and asks loads of questions…<u>Oh ok, so you don’t have to do it, someone else does it for you</u>[interviewer question]…No, I mean we have to obviously show how much electricity we’ve actually used and things like that…We do an annual thing and they come in and they assess...it’s basically things like how much forage we produce, how much fuel we use and they count the contractors fuel and then it comes down to how much carbon dioxide the cow produces and the methane the cow produces, our electricity use. We get bonus points if we’ve got solar panels or a wind turbine and then they rank you out of the other members of that group and there’s a bar chart with traffic lights situation’ (F39) (SW, conventional dairy/sheep).*

Whilst this is good to see that companies are taking an interest in such things, farmer 39 (SW, conventional dairy/sheep) does admit that he does not value the outcome of the C footprint all that much stating that it does not influence him too much;

> *‘I value it so much that I look at it and chuck it away to be quite frank…I mean it doesn’t influence me at all. If it showed me that my electricity was in the top 25%, in the top 10% then I might sit back and go, hold on why am I up there compared to everyone else, there must be some reason. But if I’m in the green or the amber, I don’t’ worry too much about it’ (F39) (SW, conventional dairy/sheep).*

Farmer 42 (SW, conventional dairy), who also did the same carbon footprint describes it as ‘…*a hoop we have to jump through*’ (F42) (SW, conventional dairy).

This is shame as such a scheme has the potential to make a difference to how farmers think and manage their farm. Farmer 39 (SW, conventional dairy/sheep) does however explain why he is not over-concerned about it, by explaining what he feels are the faults with the auditing; highlighting the issue with the financial year causing imbalances between years;

> *'And it's taken straight off our accounts if you like, our electricity use, straight off our accounts, and for example our year ends the 1st April or 31st March so if there's a bill due on the 31st March and it's paid on the 5th April, you've got five quarters in one year and three quarters in the other, so you've got to take it with a bit of a pinch of salt I think' (F39) (SW, conventional dairy/sheep).*

Farmer 42 (SW, conventional dairy) notes that the audit does not take into account carbon that is sequestered from the grassland, which he feels is something important which has been overlooked;

> *'They're computer model doesn't take into the sequestration of carbon of grass…Doesn't it?!...So they say that a high input farm would be...Would be better carbon wise than us because we give a tonne and half of feed and everything else is grown on the farm' (F42) (SW, conventional dairy).*

Farmer 39 (SW, conventional dairy/sheep) comments that there is no real incentive for reducing his carbon footprint as there is no cut off point that the company would stop dealing with you at;

> *'There is no cut off to say that if we use over this then you're out the group and any real incentives to do anything different' (F39) (SW, conventional dairy/sheep).*

Farmer 25 (East, organic arable), whilst not having to develop a C footprint for his farm, mentions C foot printing and C trading without being prompted, in relation to the value to of soil C, saying he is not sure whether there will any benefit in the future;

> *'I'm not sure whether there's going to be any benefit either in the future for carbon trading' (F25) (East, organic arable).*

C trading is a market-based approach used to control CO_2 emissions by providing economic incentives for achieving reductions. Companies are able to sell, or trade their C quotas to others, if they themselves are below their quota and the other party need to expand theirs. Farmer 25 (East, organic arable) does not agree with this ethos as he feels it gives someone the chance to increase their C output by taking advantage of someone else;

> *'I'm sort of against that in principle really because it's giving someone the chance to increase their carbon output thinking that they can get someone like me to take it which I think is the wrong ethos. I mean I'm happy to do it for the good of the planet, but I'm not really happy to do it so that Joe Bloggs down the road can belch out a bit more carbon'. (F25) (East, organic arable).*

5.6.1 Carbon, Climate Change and Sequestration Review

Overall the terms C, carbon sequestration and climate change were not mentioned frequently by either the FAs or farmers, without first being prompted. According to the FAs, it was the organic farmers who were more aware of soil C and the impact or influence they have. However, on a positive note, it was mentioned that soil C is becoming increasingly popular and is being mentioned more often at workshops.

There was a mixed response over whether farmers realise the potential role they have to play in climate change mitigation. Whilst climate friendly practices were being adopted, this was mainly being done for financial reasons rather than environmental.

C foot printing was something conducted by the companies that some of the farmers supplied their produce to. This is a huge step forward in addressing C use and emissions in farming; however it appeared that the assessments had very little impact on the farm or farmer.

5.7 Conclusion

The interviews conducted with farmers and FAs raised many points which have been evaluated above. These themes can be broken down into those associated with; SOC and SOM, OM sourcing and application, policy and AESs, SOC enhancing practices and carbon sequestration and climate change.

5.7.1 Soil Organic Carbon and Soil Organic Matter

The interviews have shown that SOM and SOC are important to both farmers and FAs. The benefits of SOM were highlighted, including; its use as a fertiliser, improved water holding capacity and the workability of the soil. The FAs supported the benefits of SOC and SOM, especially the value of OM as a source of nutrients; however the FAs believed that not all farmers appreciated SOC and SOM when farming. This discrepancy between the FAs and farmers' feedback highlights the difficulties in gaining a fully representative sample of farmers, as only the forward thinking farmers are concerned with SOM and SOC, with the same being those who wish to be interviewed in regards to academic research into soil.

Farmers and FAs agree that the importance of SOC to a farm varies depending upon location, soil type and farming practice. Organic farmers are the most concerned with SOC, as they cannot use artificial fertilisers and so rely on alternative nutrient sources.

Farmers on either very light or very heavy land are also more concerned with SOC, due to the soil structure benefits it brings.

Despite this recognition of the benefits of SOM and SOC, several of the farmers interviewed stated that there was a lack of knowledge on the management and improvement of SOC and SOM levels. Development of this knowledge base could maximise the benefits of SOM and SOC. Additionally, many FAs interviewed had no responsibility to give advice on SOC; development of policy in this area would improve the management of SOC and SOM.

5.7.2 Policy and Voluntary Programmes

FAs and farmers gave a mixed response in regards legislation and AESs. Some farmers and FAs saw NVZs regulations as common sense, having minimal impact on their farm management with OM input limitations being reasonable. SPR feedback was overwhelmingly negative, with all interviewed farmers stating that it is simplistic, was common sense and did not achieve its aims due to limited scope. CSF, on the other hand, was positively viewed. The grants aided farmers in improving soil management on their farms, with uncertainty of roll-out of the scheme to various catchment areas and clarity over those areas being the only negatives. Unfortunately, as it is a targeted scheme, only those within priority areas benefited from it.

As outlined, AESs received a mixed response in the interviews. For farmers', many had little impact, as they can be tailored to suit existing farm management procedures. Therefore, whilst encouraging good environmental behaviours, it does not promote new management techniques. The FAs felt that AESs were too prescriptive, not allowing flexibility or innovation in farming.

The current AESs are encouraging current good environmental practices, but there is greater scope to improved management and encourage more innovative ideas. The only piece of policy which was directly linked to soil, the SPR, was dismissed by the farmers as being pointless. The SPR, or something similar, could be made much better use of. At the time of the interviews, the SPR was reaching the full potential of what such a piece of legislation could achieve.

5.7.3 Potential Soil Organic Carbon Enhancing Practices

Soil conservation is something that FAs and farmers were well informed about. Practices such as reduced tillage are being employed, the success of which unfortunately depends heavily upon the weather. This increased uptake is due to the recognition that ploughing releases C, as well as using fossil fuels. The addition of OM in the form of crop/straw incorporation, sewage sludge and FYM was recognised by the FAs and farmers as a means of improving SOM and SOC. However, the primary reason for adding OM material was to improve soil structure and as a nutrient source.

5.7.4 Organic Matter

The methods of OM addition to the soil demonstrates, as highlighted in the interviews, the differences in the availability of OM, especially FYM application, between the SW and the East. The Eastern FAs outlined the scarcity of OM in the region, mostly due to the lack of livestock farmers, with green waste and poultry manure being utilised instead. This concern was not raised in the SW, with all interviewed farmers in the SW applying FYM, possibly supplementing with the use of poultry manure and green waste. The limiting factor behind the lack of FYM use in the East is the cost of transportation due the distances between the farmers and a FYM source. However, farmers in the East were attempting to use a wider range of materials to substitute for the lack of livestock, including making their own compost and an increase use of green compost.

5.7.5 Carbon, Climate Change and Sequestration

C, carbon sequestration and climate change were not primary discussion points in the interviews. The FAs believed that it was the organic farmers who were more aware of soil C and the impact or influence it has. However, it was mentioned that soil C's profile is rising and is being examined at workshops more frequently. The farmers' response on their role in climate change mitigation was mixed. Some climate friendly practices are being adopted, although this was mainly driven by financial pressures.

C footprint evaluations have been conducted on the farms of some of the farmers' interviewed; this was conducted by the companies that were buying produce. Unfortunately, these assessments did seem to have minimal impact on the farm, despite this it is seen as a step forward in addressing C use and emissions in farming.

5.7.6 Summary

The purpose of this chapter was to address the objectives 2b, 2c, and 3b, and assess what impact policy and advice has on SOC, farmer's receptiveness to SOC, and to evaluate whether current policy and voluntary initiatives are effective. Farmers and FAs consider SOC to be important although they are more aware of the term SOM and OM rather than C. The benefits of SOM are known by farmers and FAs, however there is a lack of knowledge amongst farmers on the methods and management practices needed to improve and manage SOC levels. This lack of knowledge shows that there is room for improvement in many aspects of the advisory system, in this area. SOC is not mentioned in any formal policy or advice; hence FAs do not feel that they have an obligation to advice on SOC. This lack of initial briefing is the cause of the lack of knowledge, as farmers do want more information or at least the directions to obtain it.

There is a mixed view of many AESs between the farmers and FAs. Since AESs reach such a wide farming audience, they are well place to help improve SOC levels at large scale. To do this however, more information on SOC is required, as well as the greater need for more changes in farm management which would increase SOC levels to occur. If English agriculture is to reach its full potential in maximising SOC levels, policy and legislation will have to be altered in ordered to include SOC in its advice.

The following chapter, Chapter 6, presents SOC levels measured at six farms in the East of England, all of whom were practicing various regimes. These included various reduced tilling regimes and OM amendments, which has highlighted in this chapter and Chapter 2, have the potential to increase soil C, as well as organic farming. The six farms that had their soil tested were managed by farmers previously interviewed.

CHAPTER 6: AN INVESTIGATION INTO SOIL ORGANIC CARBON LEVELS AND FARMING PRACTICE

This chapter presents and discusses the soil sampling results with reference to the paired farms and their management practices as outlined in Chapter 4, Methodology. Data analysis of soil texture (with particular emphasis on clay percentages), pH, total Carbon (C), Carbon:Nitrogen (C:N) ratios and soil organic carbon (SOC) are presented including statistical analysis. This chapter addresses objectives 1c and 4a;

Objective 1c: *Measure SOC levels in soil samples for paired sites, representing different farming practices, comparing and contrasting variations between management approaches.*

Objective 4a: *Analyse SOC levels in soil samples for paired sites representing different farming practices (ranging from conventional, high carbon input/organic and no-till regimes) in England.*

The farms selected were paired so as to compare SOC levels between opposite management approaches on geographically close sites with similar soil types. The results from this chapter provide additional data to the existing knowledge regarding SOC levels and farming practice in England, as well as providing local, specific results for the interviewed farmers on whose farms samples were taken from. This combines both the social and soil science components of this research.

6.1 Farm Pair A

6.1.1 An introduction to Farm Pair A

Farm pair A consists of farm one and farm two. Both farms were in South Suffolk and situated approximately 2.5 miles apart (see figure 4.5 for location). Farm one was an organic arable farm whilst farm two was a large scale, conventional arable farm. The farmer from farm one (F22) was particularly keen to be part of the study as he wished to see if his SOC levels were higher than his neighbour's (F26). He was very confident that his levels would be higher as he had been practising an organic farming system for some years, whereas F26 was a conventional arable farmer. Table 6.1 below displays the classifications of management at each farm used within this study. The comparison between the farms is largely that of organic arable versus non-organic arable, with an additional comparison between the use of conventional ploughing and 15 years of minimum tillage.

Table 6.1: A summary of management practices employed at farms one and two (Farm Pair A) which were analysed as part of this study.

Farm Number	Baseline (1 field)	Management 1 (3 fields)	Management 2 (3 fields)
Farm 1	Permanent pasture used for grazing sheep (3 sheep only).	Organic farming for 12 years, conventional plough.	Organic farming for 4 years, conventional plough.
Farm 2	Permanent pasture, occasionally used for grazing a horse.	Conventional arable, 15 years of minimum tillage.	Conventional arable, 9 years minimum tillage followed by 6 years conventional plough.

Particle Size

Particle size analysis provided information of the textural makeup of the soils that were sampled. Table 6.2 presents the average sand, silt and clay percentages measured for Farm Pair A from 0 cm to 50 cm with 10 cm intervals. By using the pyramid soil textural class diagram (figure 6.1) (Rowell, 1994) it was possible to classify the soil samples. Figure 6.1 depicts both the United States Department of Agriculture (USDA) and the UK textural classes which differ slightly. The USDA classification system requires a higher clay percentage than the UK for ‘Clay Loam’ and ‘Silty Clay Loam’. It also has two additional classifications; ‘Loam’ and ‘Silt’; which the UK classification does not.

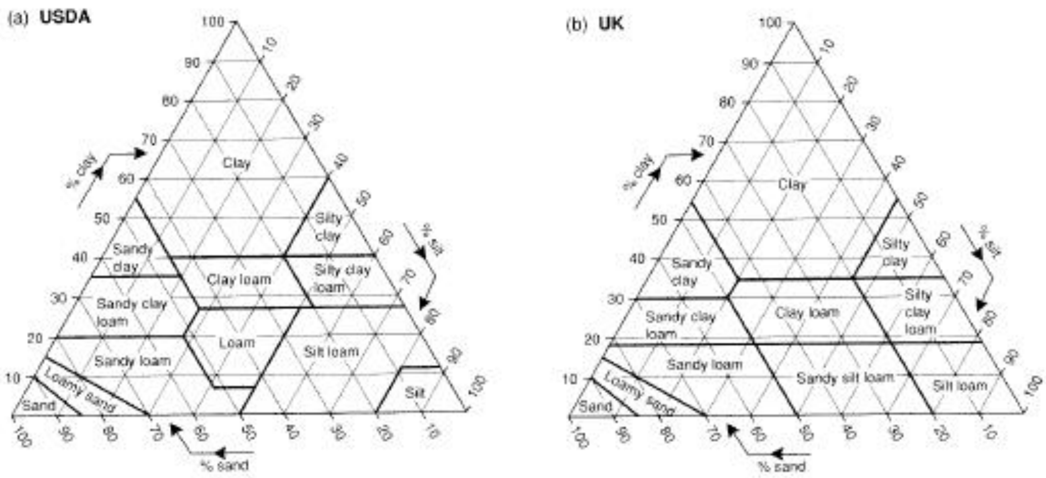


Figure 6.1: The USDA and UK pyramid soil textural classification diagrams (Rowell, 1994).

Table 6.2 below presents the soil classifications as demonstrated by the UK system, but also highlights where the USDA system differs (in italics).

Table 6.2: Average sand, sit and clay percentages for farms one and two and textural classification (Rowell, 1994), across all three management types measured at each farm from depths of 0 cm to 50 cm with 10 cm intervals. *Italics* indicate where the USDA classification system differs from the with the class type (Figure 6.1).

Farm No.	**Depth (cm)**	**Baseline**				**Management 1**				**Management 2**			
		Av. Sand (%)	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*	*Av. Sand (%)*	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*	*Av. Sand (%)*	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*
Farm 1		**Permanent pasture**				**Organic farming for 12 years, conventional plough.**				**Organic farming for 4 years, conventional plough.**			
	0-10	15.87	70.58	13.56	Silt Loam (SL)	11.54	67.94	18.79	Silt Clay Loam (SCL) / *Silt Loam (SL)*	11.14	71.66	17.20	SL
	10-20	13.79	72.21	14.00	SL	11.43	67.82	18.99	SCL/*SL*	11.82	71.43	16.75	SL
	20-30	12.94	72.01	15.04	SL	9.68	68.68	19.80	SCL/*SL*	11.81	70.36	17.83	SL
	30-40	10.69	73.70	15.61	SL	4.60	68.74	24.38	SCL/*SL*	7.97	69.72	22.32	SCL/*SL*
	40-50	9.51	75.13	15.36	SL	4.69	67.36	25.62	SCL/*SL*	6.24	68.24	25.52	SCL/*SL*
		Av. Sand (%)	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*	*Av. Sand (%)*	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*	*Av. Sand (%)*	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*
Farm 2		**Permanent pasture**				**Conventional arable, 15 years of minimum tillage.**				**Conventional arable, 9 years minimum tillage followed by 6 years conventional plough.**			
	0-10	10.97	52.28	11.74	SL	15.67	65.73	18.60	SCL/*SL*	10.80	67.37	21.83	SCL/*SL*
	10-20	11.46	70.64	17.90	SL	15.05	65.97	18.98	SCL/*SL*	11.34	67.39	21.27	SCL/*SL*
	20-30	11.74	70.10	18.15	SCL/*SL*	10.93	66.50	22.73	SCL/*SL*	9.58	68.26	22.16	SCL/*SL*
	30-40	10.22	70.53	19.24	SCL/*SL*	10.32	66.60	23.09	SCL/*SL*	8.50	68.29	23.20	SCL/*SL*
	40-50	8.15	71.67	20.19	SCL/*SL*	8.78	66.16	25.06	SCL/*SL*	8.23	68.17	23.61	SCL/*SL*

Both farms were classed as ‘Silt Loams’ across all managements and at all depths from 0 to 50 cm under the USDA classification system. Using the UK system, the baseline field at farm one was classified as a silt loam from 0 to 50 cm. Fields with 12 years of organic farming were classed as ‘Silt Clay Loam’ from 0 to 50 cm. Fields with 4 years organic farming also had ‘Silt Clay Loam’ from 30 to 50 cm. From 0 to 30 cm, the soil was classed as ‘Silt Loam’. According to the farmer of farm one (Farmer 22 (F22)), the majority of the soil was Hanslope clay series, with small patches of the Melford clay series. Hanslope clay is described by Landis as a ‘Slowly permeable calcareous clayey soil’ (NSRI, 2013). The Melford series is described as a ‘Deep well drained fine loamy over clayey, coarse loamy over clayey and fine loamy soils, some with calcareous clayey subsoils’ (NSRI, 2013). F22 noted that the Melford series was ‘*loamier with less stones in it and lighter*’ than the Hanslope series. Figures 6.2 and 6.3 present the brief profile descriptions of the Hanslope and Melford series. The soil classifications concur with the descriptions of the soil series given by the farmer with the top 25 cm of the Melford series being a clay loam.

Under the UK system, at farm two, the threshold field had a ’Silt Loam’ classification from 0 to 20 cm and ‘Silt Clay Loam’ classification from 20 to 50 cm. Both managements, 15 years minimum tillage and 6 years ploughed, were classed as ‘Silt clay Loam’ from 0 to 50 cm. The farmer for farm two (F26) also said that his farm was largely Hanslope clay, which as previously stated matches the soil classification. Figure 6.4 presents three cores taken from farm two, each from one of the three managements analysed in this study. As demonstrated the profiles are similar to that of the Hanslope profile found in figure 6.2.

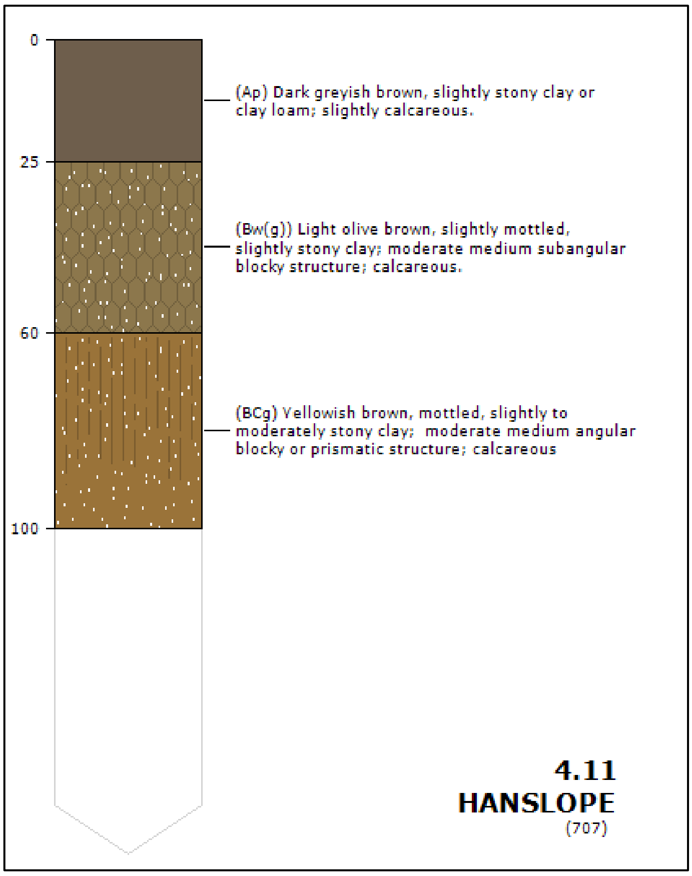


Figure 6.2: Brief profile description of Hanslope series (NSRI, 2013).

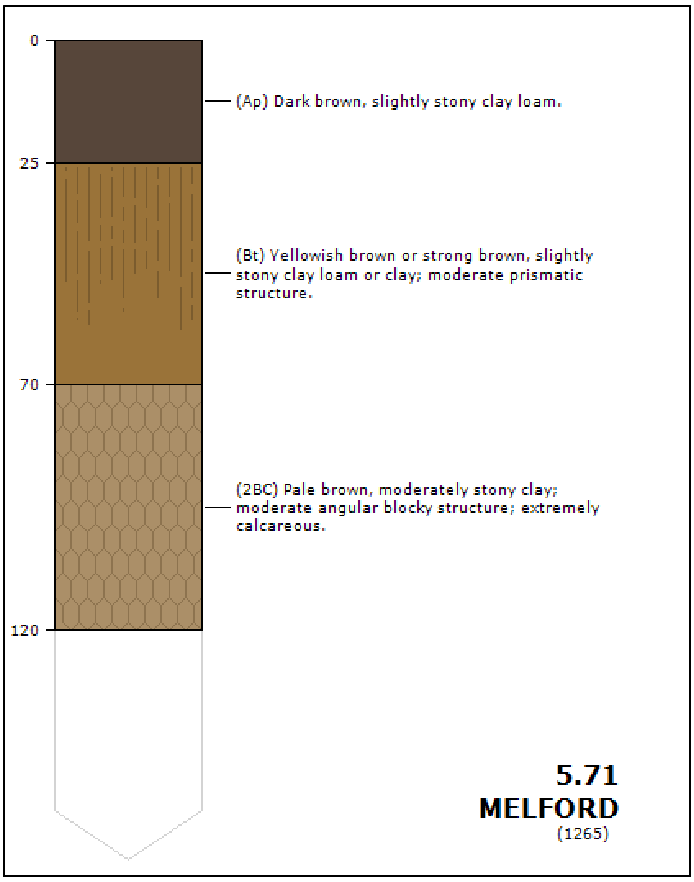


Figure 6.3: Brief description of Melford soil series (NSRI, 2013).

Farm two had a very similar soil texture to that of farm one, making them fairly comparable. Based on the particle size analysis, it can be assumed that soils at farms one and farm two were similar enough in composition to warrant being compared with regards to their organic carbon content. The importance of clay in the context of SOC levels is in relation to organo-mineral complexes and the cation exchange capacity (CEC). The cation exchange is the interchange between a cation in a solution and another cation on the surface of a negatively charged material (clay colloid). The negative charge or CEC of most soils is dominated by secondary clay mineral and organic matter (OM); therefore cation exchange reactions occur mainly near the surface of clay and humus particles. In summary, the greater percentage of clay particles, results in a higher CEC, which ultimately means that clay particles can bond with more OM particles, increasing the SOC concentration.

A. Baseline

B. Minimum Tillage, 15 years

C. Conventional ploughing, 6 years

Figure 6.4: 50 cm cores taken from Farm two from fields under three different types of management.

pH

For farm pair A, with the exception of the baseline field for farm one, the soils become more alkaline with depth (table 6.3). This is likely caused by the increase in Calcium Carbonate ($CaCO_3$) from the parent material as seen in figure 6.4. The baseline field at farm one is more alkaline at 0 to10 cm depth (pH 8.34) than it is at 40 to 50 cm (pH 8.11). Excluding this field, both farms in pair A have similar pH readings ranging from pH 7.82 (0 to 10 cm, baseline, farm two) to pH 8.76 (40 to 50 cm, 4 years organic, farm one).

Table 6.3:pH levels for farms one and two (Farm Pair A) from 0 cm – 50 cm depth, across all three managements at both farms.

Farm 1 pH	**Baseline**	**Management 1**	**Management 2**
Depth (cm)	**Permanent Pasture**	**12 years organic (Av.)**	**4 years organic (Av.)**
0-10	8.34	7.91	7.88
10-20	8.06	8.09	7.81
20-30	8.24	8.28	8.03
30-40	8.32	8.52	8.51
40-50	8.11	8.67	8.76
Farm 2 pH			
Depth (cm)	**Permanent Pasture**	**15 years min-till (Av.)**	**6 years ploughed (Av.)**
0-10	7.82	8.03	7.96
10-20	8.02	8.25	8.14
20-30	7.90	8.28	8.42
30-40	8.50	8.39	8.18
40-50	8.15	8.37	8.26

6.1.2 Farm Pair A; Carbon Analysis

Total Carbon

Total C was measured on the first cores taken from each of the seven fields sampled at each farm. Total C includes both the inorganic and organic fractions of C.

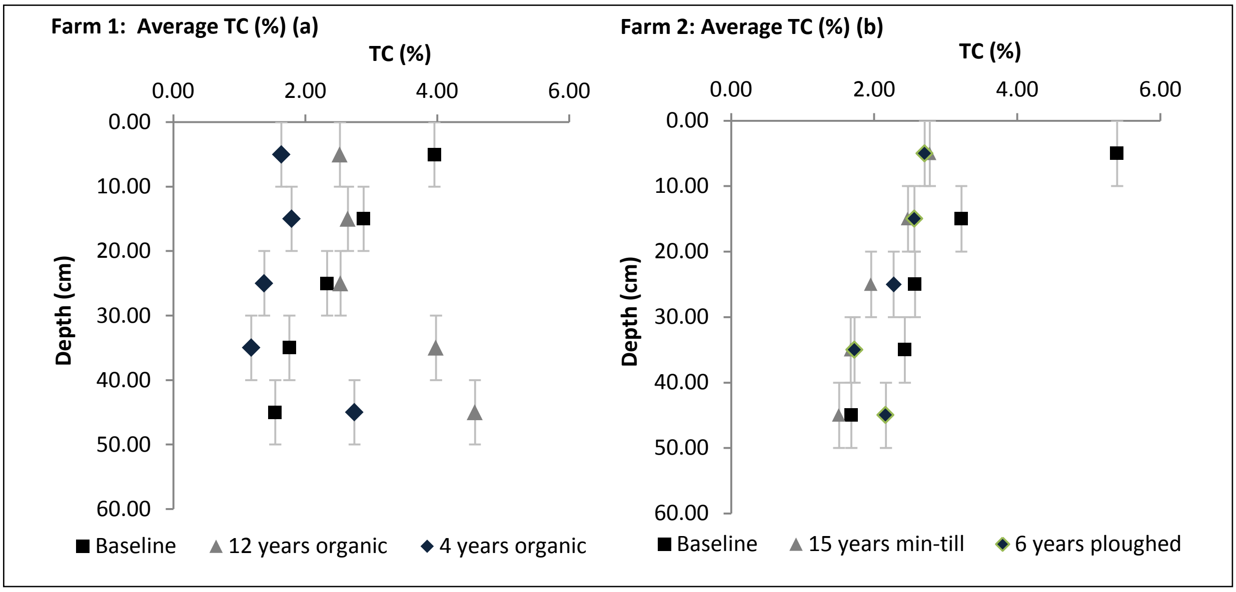


Figure 6.5: Total C (TC) (%) for farms one and two (Farm Pair A), from 0 to 50 cm depth across all three managements at each farm.

The two managements at farm one presented a higher total C (%) at 40 to 50 cm than in the top 10 cm of the soil profile. Fields under 12 years organic farming had the highest total C % with 4.6% at 40 to 50 cm. The baseline field had the biggest difference between 0 to 10 cm and 40 to 50 cm with 4.0% and 1.6%, respectively. All fields at farm two had higher total C (%) at 0 to 20 cm compared to 40 to 50cm. The baseline field had the biggest difference between the top and bottom of the profile with 5.4 % and 1.7 %, respectively. Both the baseline field and fields with 15 years minimum tillage had a smooth, gradual transition throughout the profiles. Fields with 6 years conventional plough had a gradual decrease in total C until 40 to 50 cm where levels increased to 2.2% from 1.7% at 40 to 50 cm.

Soil Organic Carbon

Following the removal of the inorganic C by Hydrogen Chloride (HCl) fumigation, the concentrations of SOC were analysed. Figure 6.6 shows SOC levels as percentages and figure 6.7 as kg/m$_3$ for Farm Pair A. Both percentage and kg/m^3 are shown as percentage gives the concentration of SOC and kg/m^3 provides information on the stocks.

In farm one, (figure 6.6, graph a,), all three management types had their average highest SOC % at 0 to 10 cm, and their lowest at 40 to 50 cm. The baseline had the highest average SOC % at 4.5%, over double the SOC % found in both management types at 0 to 10 cm. The baseline also had higher SOC % for the top 30 cm of the soil profile compared to the other two managements. Fields with 12 years organic farming had an average of 2.0% of SOC at 0 to 10 cm, and was higher at all depths compared to the average SOC % of fields with 4 years organic farming. Fields with 4 years organic farming had an average SOC % of 1.6% at 0 to 10 cm. The difference in SOC % between the 12 and 4 years organic farming fields, could present a potential for C sequestration.

For farm two, (figure 6.6), graph b, in all management types the highest SOC % was found in the 0 to 10 cm. The baseline field had the highest SOC % at the surface with 4.2%, again, over double the SOC % found in the two management types at 0 to 10 cm. The baseline profile also had higher SOC % at all depths. The fields with 15 years minimum tillage had a higher average SOC % at 0 to 10 cm, compared to the fields with 6 years conventional ploughing, with 1.9% and 1.9%, respectively. However, from 10 to 50 cm, fields with 6 years conventional ploughing had higher average SOC % than fields with 15 years minimum tillage. This suggests that there is little change in the overall SOC % between the two managements, but there is a distribution change in the soil profiles.

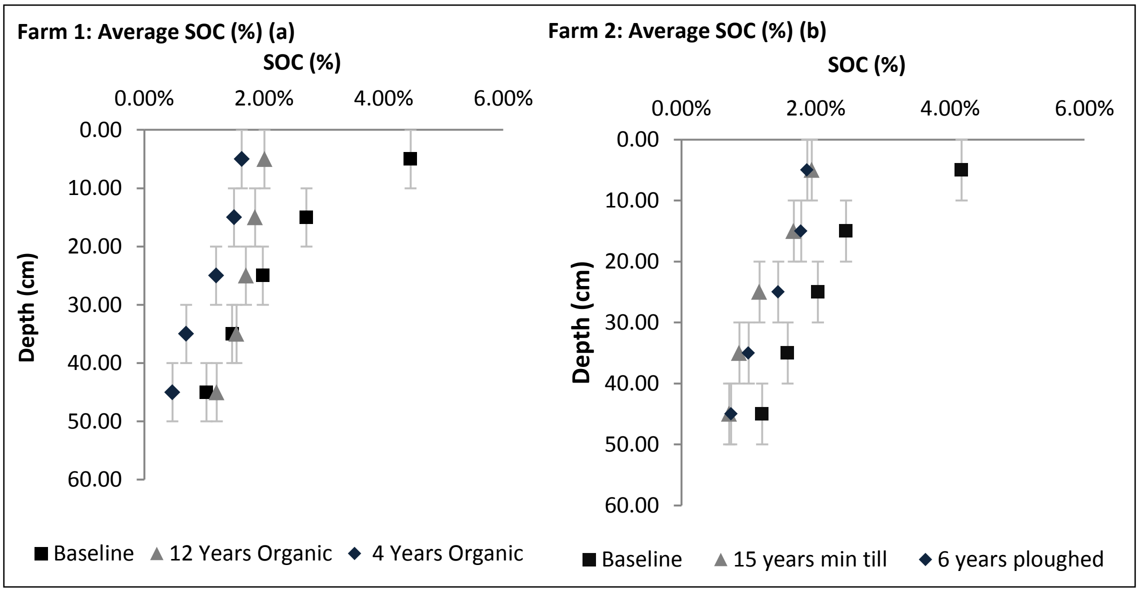


Figure 6.6: Average SOC (%) for farms one and two (Farm Pair A), across all three managements for each farm, from 0 to 50 cm depth.

For farm one, (figure 6.7, graph a,) the highest SOC was found in the baseline field at the 0 to 10 cm depth with 45.13 kg/m^3. The baseline profile also had the biggest drop in SOC from the surface to 50 cm depth, with a difference of 29.83 kg/m^3 between

45.12 kg/m^3 at the surface and 15.3 kg/m^3 between 40 and 50 cm. Fields with 12 years organic farming, had a higher surface SOC concentration compared to the fields with 4 years organic farming, with 18.10 kg/m^3 and 13.08 kg/m^3 respectively. Neither the fields with 12 years organic farming, nor the fields with 4 years organic, had their highest SOC concentration at the surface. The fields with 12 years organic farming had the highest SOC at 30 to 40 cm depth with 19.34 kg/m^3, and the fields with 4 years organic farming at 20 to 30 cm with 15.7 kg/m^3. This differs from the percentage results where there was straight reduction in SOC % from 0 to 10 cm down to 40 to 50 cm. The differences in bulk density which has caused the irregularity in the kg/m^3 could be caused by the conventional ploughing, causing a hard pan below the plough layer. However, if this was the case, it would perhaps be expected that the peak of kg/m^3 of SOC would occur at the same depth. Another explanation is it that it is the result of soil variability. The clay percentage increases for both managements with depth, as seen in table 6.2, which could cause an increase in bulk density due to a reduction in pore space.

For farm two, (figure 6.7, graph b,) the highest SOC was again found in the baseline field at the 0 to 10 cm depth with 39.12 kg/m^3. The baseline profile also has the biggest drop in SOC from the surface to 50 cm, with a difference of 23.82 kg/m^3, between 38.12 kg/m^3 at the surface to 14.3 kg/m^3 at 40 to 50 cm depth. The fields with 6 years conventional ploughing, had a higher SOC concentration at the surface compared to the fields with 15 years minimum tillage, with 25.95 kg/m^3 and 25.78 kg/m^3 respectively. Both managements had the highest SOC concentration between 0 and 10 cm..

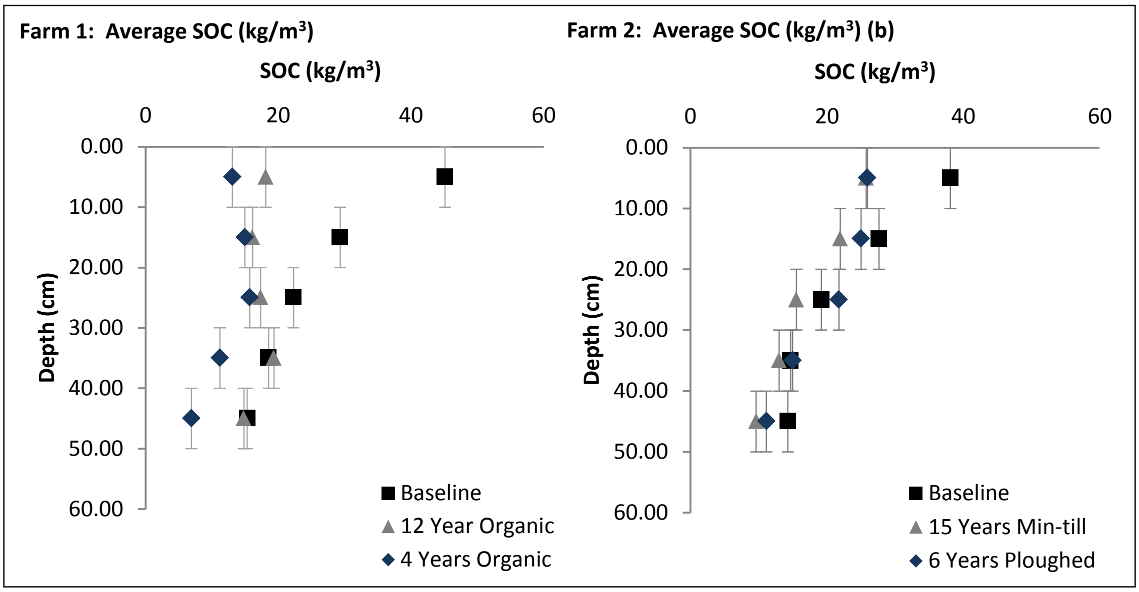


Figure 6.7: Average soil organic carbon (kg/m3) for farms one and two (Farm Pair A) for each management type from 0 to 50 cm depth with 10 cm intervals.

C:N Ratio

Table 6.4 shows the C:N ratios for farms one and two across all three managements at each farm and from the surface to 50 cm at 10 cm intervals. The relatively low C:N ratios of farm one indicate that there was sufficient N for plant growth at the time of sampling. The exception is for fields with 12 years organic farming from between 30 to 50 cm depth where the ratios are both 20:1. This indicates that the C measured here, is perhaps older than the C measured nearer the surface with higher C:N ratios. Such a pattern is not recognised within the fields with 4 years of organic farming.

For farm two, the C:N ratios are generally lower. Once again though, the baseline field has a higher C:N ratio at 0 to 10 cm compared to the rest of the profile. For fields with 6 years conventional ploughing, there is a bigger difference between the C:N ratio from 10 to 20 cm to 20 to 30 cm compared to the other management fields and the baseline. This is the approximate depth (20 cm) at which the ploughing has a physical disturbance upon the soil. The higher C:N ratio at the 20 to 30 cm depth may indicate that this C is older and more stable than the C found above it. The C:N ratio is relatively high also at 40 to 50 cm for fields with 15 years minimum tillage. Similar to farm one, this may indicate that the C here is older, more stable and that there is a potential C sequestration.

Table 6.4: Average C:N ratios based on the SOC results for farms one and two, across all three managements at each farm and from 0 to 50 cm depth with 10 cm intervals.

Farm 1	**Baseline**	**Management 1**	**Management 2**
Depth (cm)	**Permanent Pasture**	**12 years Org**	**4 years Org**
0-10	12:1	12:1	10:1
10-20	10:1	11:1	9:1
20-30	9:1	11:1	10:1
30-40	10:1	20:1	10:1
40-50	11:1	20:1	10:1
Farm 2			
Depth (cm)	**Permanent Pasture**	**Min-till 15 years**	**Ploughed 6 years (min till previous 9 years)**
0-10	9:1	10:1	9:1
10-20	8:1	10:1	9:1
20-30	8:1	10:1	10:1
30-40	7:1	10:1	11:1
40-50	8:1	12:1	11:1

Statistical Analysis

Statistical analysis was performed to evaluate the tested farming approaches in terms of their effectiveness in improving or maintaining SOC levels. Analysis of variance (ANOVA) was conducted to analyse the statistical differences in SOC levels between the farming approaches. For farm one, the ANOVA test demonstrated that management is significant at the 0.95 confidence level across all depths, meaning that there is a significant difference between C levels in the soil under 12 years and 4 years organic farming (table 6.6 and figure 6.8). When clay was considered in the Analysis of Co-Variance (ANCOVA) analysis; neither clay nor management were significant between 0 and 20 cm (table 6.6). However, from 20 to 50 cm, management only was significant at the 0.95 confidence level.

The ANOVA test for farm two showed that management was not significant at any level (table 6.6 and figure 6.9). However, the ANCOVA test showed that clay was significant from 0 to 30 cm. Neither clay nor management were significant from 30 to 50 cm. The fact that clay had a significant effect on SOC levels from 0 to 30 cm, could indicate why two different tillage systems were in operation at that farm. For example, the fact that one field was minimum tillage for 9 years but has been ploughed for the last 6 years, could be because the soil in that part of the farm heavier and not conducive for min-tillage.

Table 6.5: Key for Statistical Analysis

Key for Statistical Analysis	
ANOVA	
Management is sig.	(+)
Management is not sig.	(-)
ANCOVA	
Management only is sig.	***
Clay & Management are sig	**
Clay only is sig.	*
Neither Clay nor Management are sig.	-

Table 6.6: ANOVA and ANCOVA analysis for SOC % for farms one and two, Significant to 0.95 confidence level. See table 6.5 for key.

Depth (cm)	Farm No.	
	1	**2**
0-10	- (+)	* (-)
10-20	- (+)	* (-)
20-30	*** (+)	* (-)
30-40	*** (+)	(-)
40-50	*** (+)	(-)

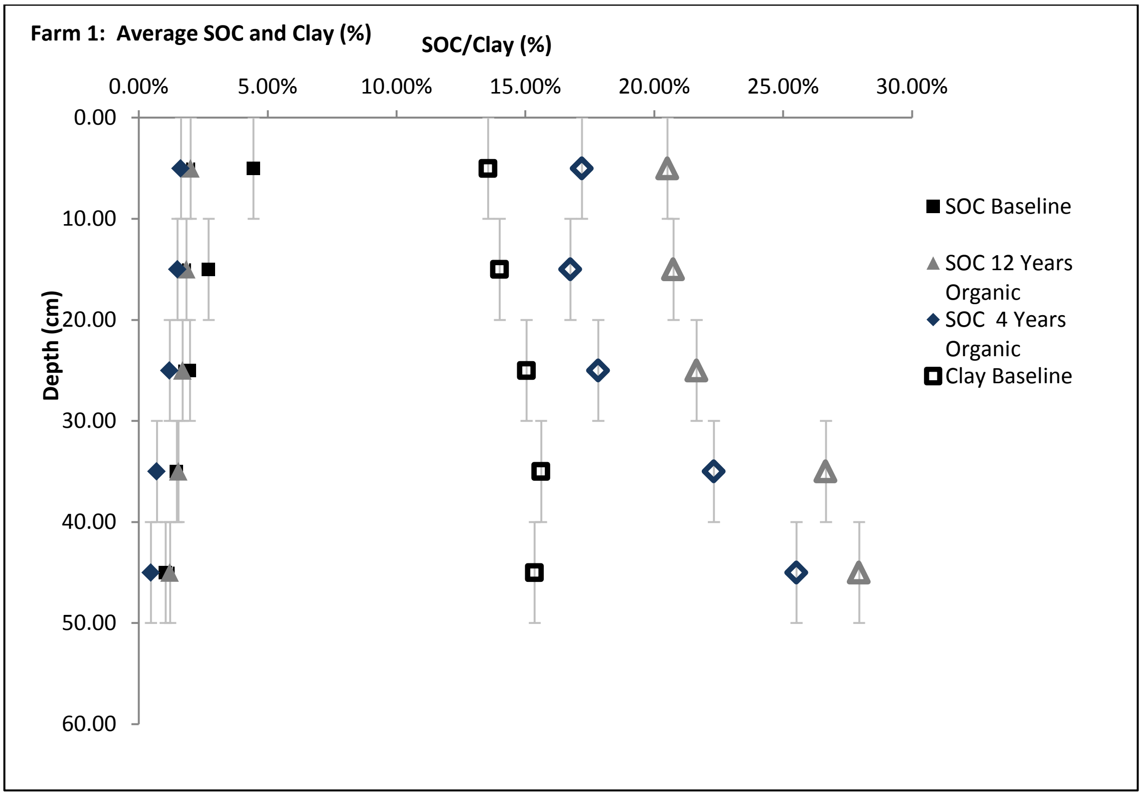


Figure 6.8: Average SOC and Clay (%) for farm one across all three managements from 0 to 50 cm depth with 10 cm intervals.

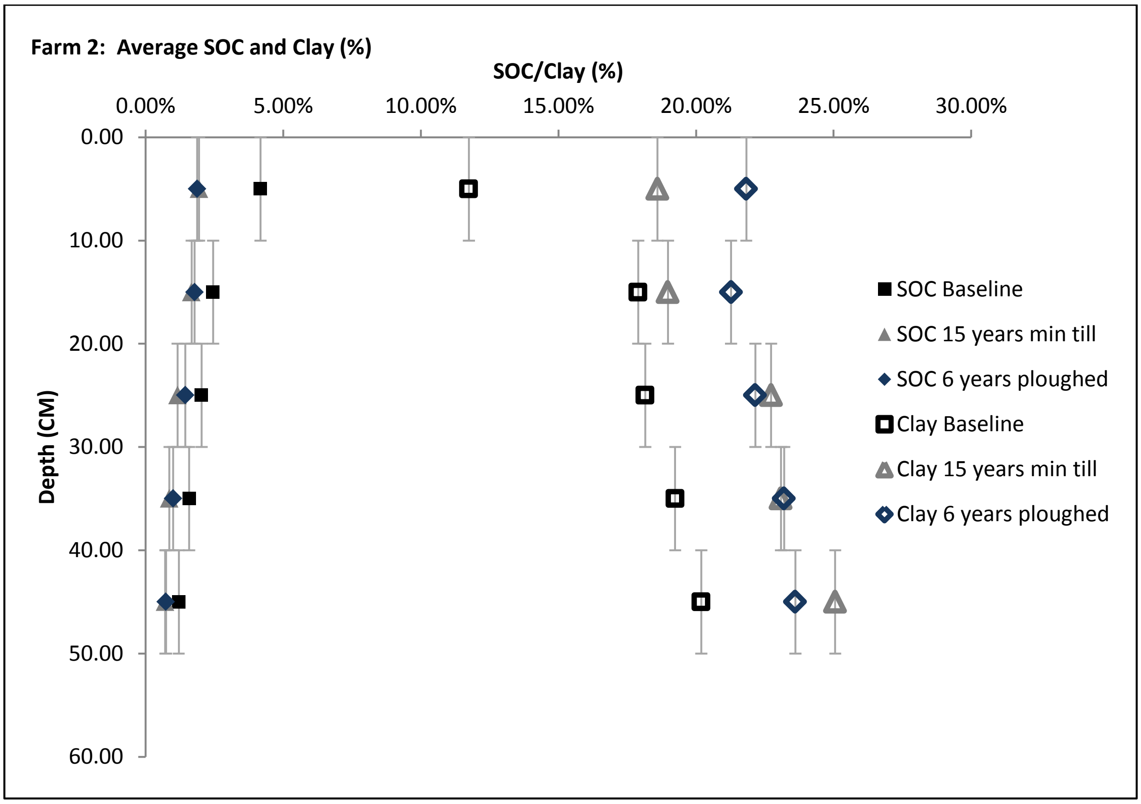


Figure 6.9: Average SOC and Clay (%) for farm two across all three managements from 0 to 50 cm depth with 10 cm intervals

Table 6.7: ANCOVA and ANOVA statistical analysis for Farm Pair A, comparing organic and non-organic SOC levels, and 15 years min-till and conventional till SOC levels. See table 6.5 for key.

Depth (cm)	Farm Pair A (Farm 1 & 2)	
	Organic vs. Non-Organic	15 Years Min–Till vs. Conventional Till
0-10	- (+)	* (-)
10-20	- (+)	* (-)
20-30	*** (+)	** (-)
30-40	*** (+)	- (-)
40-50	*** (+)	- (-)

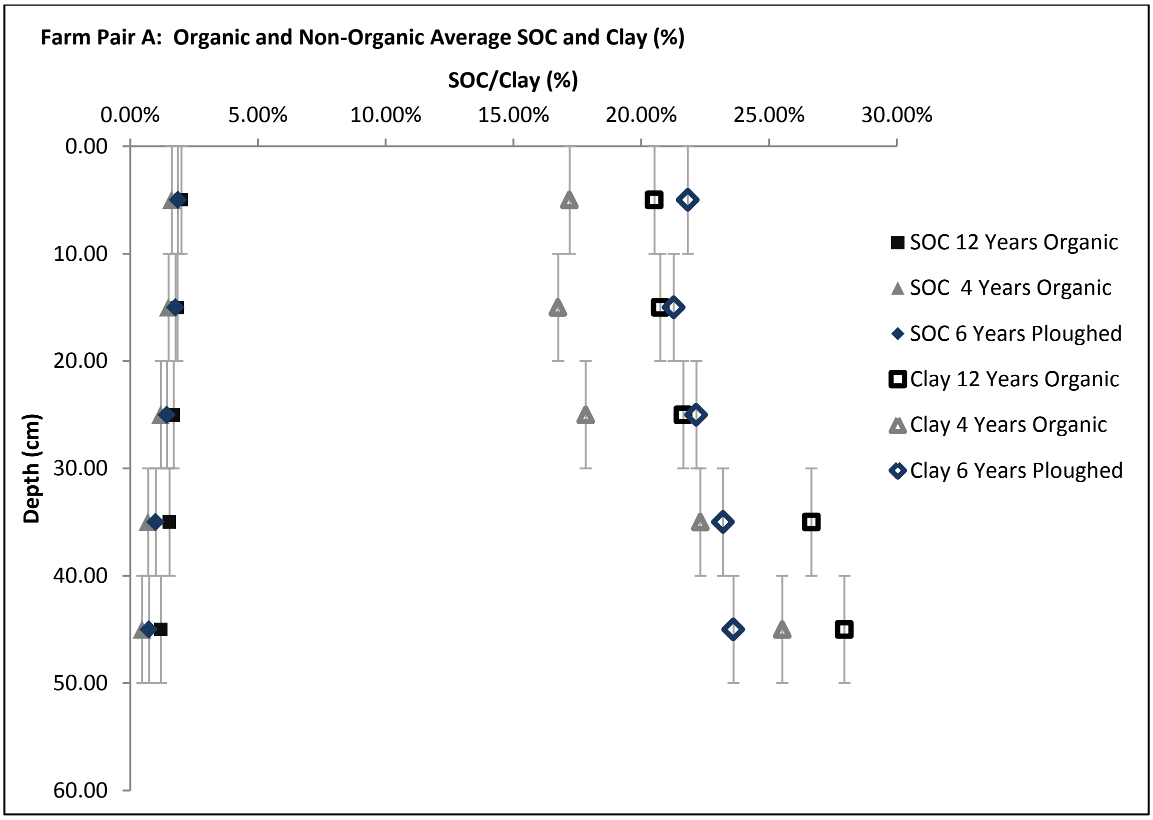


Figure 6.10: Farm Pair A: Average SOC and clay (%) for organic and non-organic managed soils from 0 to 50 cm with 10 cm intervals.

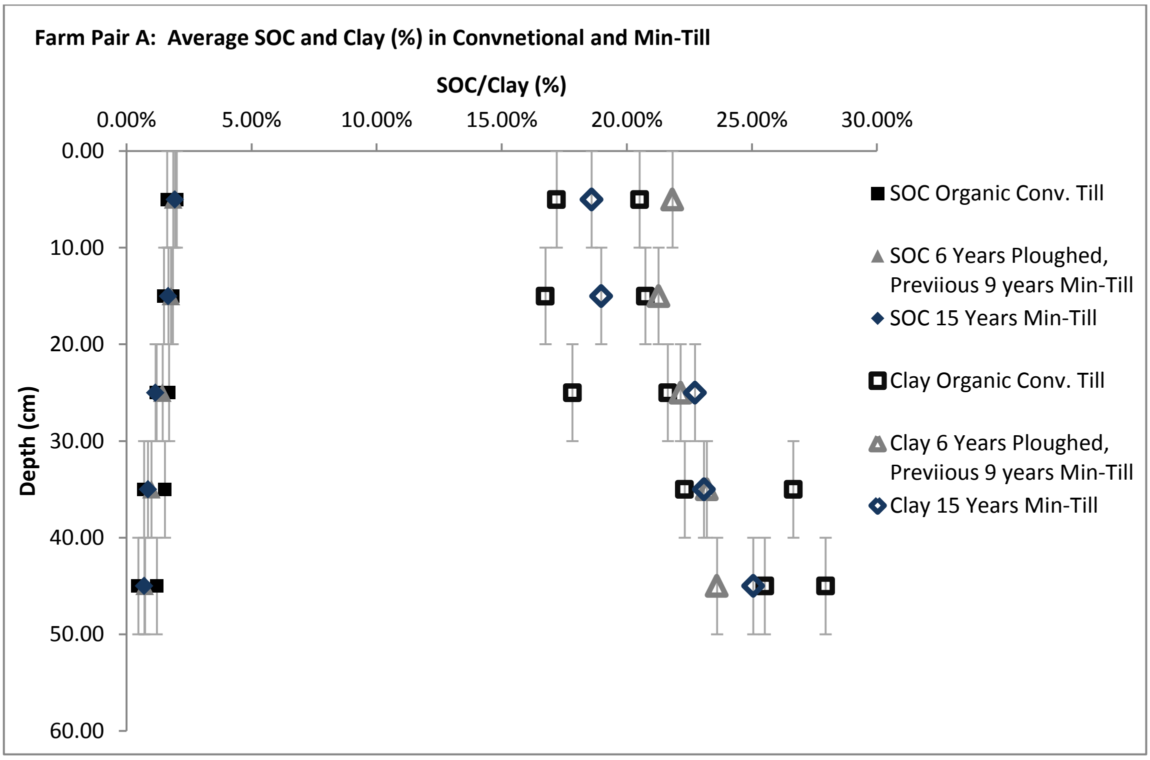


Figure 6.11: Farm Pair A: Average SOC and Clay (%) in conventional and minimum-tilled soils from 0 to 50 cm with 10 cm intervals.

ANCOVA and ANOVA tests were applied to various fields from farms one and two (table 6.7, figures 6.10 and 6.11). Firstly, organic versus non-organic management was tested. The two organic fields from farm one were pooled together, and compared against SOC levels from non-organic soils that had been ploughed conventionally for 6 years. All three of these managements used conventional tillage, allowing for the statistical analysis to compare the organic or non-organic aspects of the farm management. The ANOVA test which considered the management type only, found the management to be significant at all depths. This potentially means that the differences in SOC levels (as demonstrated in figure 6.10) was caused by the different management practices, either organic or non-organic. The ANCOVA test which considered the clay percentage of the soil as well as the management type, found that neither were significant in the cause between the different SOC levels measured from 0 to20 cm depth (the plough layer). However, from 20 to 50 cm, management was found to be significant.

When comparing SOC levels for soil that had 15 years min-till with conventional-till (figure 6.11), the ANOVA test found that management was not significant at any depths from 0 to 50 cm. The ANCOVA found that from 0 to 20 cm, clay only was significant, at 20 to 30 cm, clay and management were significant, and 30 to 50 cm , neither clay nor management were significant.

6.1.4 Discussion

Both farms had similar soil types, described by the farmers as being Hanslope clay and Melford. The particle size analysis demonstrated, that overall, the two farms had very similar soil types, with a combination of silt clay loam and silt loam. The similarity in soil type, as well as location meaning that climate is similar, meant that the two farms were comparable to each other in soil type and environment. Total C results for both farms indicated $CaCO_3$ presence, due to relatively high total C levels at deeper depths as demonstrated in figure 6.4.

Statistical analysis demonstrated that organic farming had a positive impact on SOC levels found at farm one. The ANOVA test found that the difference in SOC levels between 12 years organic and 4 years organic was due to the difference in management. When clay percentage was considered in the ANCOVA test, management remained significant but only from 20 to 50 cm depth. Why there should be seen to be a greater effect upon SOC at a greater depth is perhaps unanswerable within the realms of this project but it is possible to speculate. Firstly, there could be greater microbial life at lower depths, or beneath the plough layer, in soil that has been organically farmed for longer, resulting in higher SOC levels. The fields with 12 years organic farming may have an improved soil life compared to the fields with 4 years organic farming. Secondly, the organic C found at the lower depth could potentially be a more stable form C as demonstrated by the C:N ratios (table 6.4), which could then also lead to sequestration.

If the assumption is made that both soils started off with similar SOC levels, and as they share very similar characteristics and historical uses, the difference in SOC % between the two managements could indicate that C sequestration is occurring and there is greater potential to be had. In theory, the soils with 12 years and 4 years organic farming could at least double their SOC % in time to reach that of the baseline field. This theory is further confirmed by the statistical analysis comparing organically managed soil with that of conventionally managed soil from farm two. The ANOVA test which considered the management type only, found the management to be significant at all depths. This means that the differences in SOC levels (as demonstrated in figure 6.10) was caused by the different management practices, either organic or non-organic. The ANCOVA test which considered the clay percentage of the soil as well as the management type, found that neither were significant in the cause between the different SOC levels measured from 0 to 20 cm depth. However, from 20 to 50 cm, management was found to be significant. This suggests that by farming organically the

SOC levels have been increased. The results indicate that organic farming promotes greater SOC concentrations at depth.

Overall, the results indicate that organic farming has the potential to increase SOC levels, particularly at depth where C may be more stable and less likely to leach out of the soil system. This could indicate the potential for carbon sequestration. The levels of SOC for 12 years organic farming are indicative of the levels that the fields under 4 years of organic farming could reach in the same time span. The baseline field represents the potential SOC levels that both managements could reach under the correct circumstances. When the organic results were compared to those of conventional arable, organic farming was shown to be higher in the SOC levels observed. These results are in line with what has been noted in published literature. The Soil Association (2009) and Gattinger *et al*. (2012) both found that organically managed soils generally had higher SOC levels when compared to non-organic soils. At the time of writing, organic farming is currently promoted via the Organic Entry Level Environmental Stewardship (OELS), whereby farmers practising an organic farming system receive money for undertaking certain environmental beneficial managements. Organic farming being present in an AES demonstrates that it is recognised as productive farming system. When F22 was presented with the results of this study, he was relatively pleased with the conclusions.

The SOC analysis at farm two indicates that cultivation has had an impact on SOC distribution throughout the soil profile. Higher SOC levels were found at the surface on the fields which had been managed under minimum tillage for 15 years, compared to those under conventional ploughing. However, the statistical analysis shows that the management was not statistically relevant in explaining these differences, but that the amount of clay particles was. It is likely that the clay content of the soil determined the type of ploughing regime implemented. Clay was found to have a significant effect on SOC levels from 0 to 30 cm, which could indicate why two tillage systems were in operation at the farm. Table 6.2 shows that from 0 to 20 cm depth, management two (6 years conventional ploughing) had slighter higher clay concentrations than management one (15 years min-till). F26 may have found the soil too heavy for minimum tillage in the fields under management two and so transferred back to a conventional plough routine.

Higher levels of SOC were found at the surface under fields with 15 years minimum tillage. The higher SOC % found at the surface for fields with 15 years min-till can be explained by the management being applied. Under min-tillage, the litter; mainly made up of remnants from previous crops and the OM applied by the farmer, will stay on the surface of the soil longer as the soil is not turned over. Therefore, it may take longer the OM to be decomposed and make its way down the soil profile. The fields with 6 years conventional ploughing, will have the surface of the soil turned over far more often, perhaps allowing the movement of the OM to move down the soil profile but also losing C though mineralisation at the surface.

From this study it is not possible to conclude that minimum-tillage encouraged improved SOC levels, but that the different ploughing regimes do have an impact on SOC distribution throughout the soil profile. This is similar to what has been presented in published literature; Bhogal *et al*. (2009) found that there was limited scope for increased SOC levels from reduced tillage practices. In addition to this, Barker *et al.* (2007) and Palm *et al*. (2014) found that although SOC levels may increase near the surface under reduced-tillage regimes that the overall SOC levels in the soil profile will not, instead resulting in a distribution change throughout the soil profile. The uncertainty surrounding reduced tillage systems is perhaps why it is not being widely promoted within current AESs.

6.2 Farm Pair B

6.2.1 An introduction to Farm Pair B

Farm Pair B consists of farm three and farm four, both from the North West Essex, South Cambridgeshire border area and approximately 10 miles away from each other (see figure 4.5 for location). Farm three was a conventional arable farm which had been practising non-inversion tillage for 7 years on parts of the farm. Farm four was also a conventional arable farm which had been practising non-inversion tillage for 5 years on parts of the farm. Table 6.8 displays the classifications of managements at each farm used within this study. Whilst both farmers were keen to take part in the study, neither were overly engaged in the sampling of their farms (F23 and F24).

Table 6.8: A summary of management practices employed at farms three and four (Farm Pair B) which were analysed as part of this study.

Farm Number	Baseline (1 field)	Management 1 (3 fields)	Management 2 (3 fields)
Farm 3	Permanent pasture.	Conventional arable, Non-inversion tillage for 7 years.	Conventional arable, Non-inversion tillage for 5 years followed by 2 years of conventional ploughing.
Farm 4	Permanent pasture.	Conventional arable, conventional ploughing 1 in every 3 years.	Conventional arable, non-inversion tillage for 5 years.

Particle Size

Table 6.9 presents the average sand, silt and clay percentages measured for each management from 0 to 50 cm at 10 cm intervals. By using the UK pyramid soil textural class diagram (figure 6.1), it was possible to classify the soil samples. As table 6.9 demonstrates, all samples from farm three had an average soil textural class of silt loam. Farm four also had a majority of silt loam, except for 30 to 40 cm for the fields with conventional ploughing, where the soil was classified as a silt clay loam. This was also the case at 40 to 50 cm for fields with 5 years non-inversion tillage. Classification in italics demonstrates where the USDA textural system differs to that of the UK’s.

Table 6.9: Average sand, silt and clay percentages for farms three and four (Farm Pair B) and textural classification (Rowell, 1994)), across all three management types measured at each farm from depth of 50 cm to 0 cm at 10 cm intervals. *Italics* indicate where the USDA classification system differs from the UK with the class type (Fig. 6.1)

Farm No.	**Depth (cm)**	**Baseline**				**Management 1**				**Management 2**			
		Av. Sand (%)	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*	*Av. Sand (%)*	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*	*Av. Sand (%)*	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*
Farm 3		**Permanent Pasture**				**Non-inversion tillage, 7 years**				**Non-inversion tillage 5 years, followed by 2 years conventional ploughing.**			
	10-0	11.94	72.09	15.97	Silt Loam (SL)	12.55	69.43	18.02	Silt Loam (SL) /*Silt Clay Loam (SCL)*	12.67	67.98	19.35	SL/*SCL*
	20-10	10.72	72.54	16.73	SL	11.04	70.18	18.78	SL/*SCL*	12.24	68.49	19.27	SL/*SCL*
	30-20	11.38	72.92	15.70	SL	9.93	70.40	19.66	SL/*SCL*	12.14	69.25	18.61	SL/*SCL*
	40-30	11.04	73.23	15.73	SL	6.79	68.15	25.06	SL/*SCL*	10.71	70.11	19.18	SL/*SCL*
	50-40	10.16	74.03	15.81	SL	7.40	66.24	26.36	SL/*SCL*	10.33	70.91	18.76	SL/*SCL*
		Av. Sand (%)	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*	*Av. Sand (%)*	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*	*Av. Sand (%)*	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*
Farm 4		**Permanent Pasture**				**Conventional ploughing, 1 in 3 years**				**Non-inversion tillage, 5 years**			
	10-0	28.54	56.42	15.04	SL/*Sandy Silt Loam (SSL)*	15.75	52.02	21.12	SL/*SCL*	26.78	53.77	19.44	SL/*Clay Loam (CL)*
	20-10	27.11	57.99	14.91	SL/*SSL*	17.08	58.90	24.03	SL/*SCL*	23.03	55.98	20.99	SL/*CL*
	30-20	26.63	58.35	15.01	SL/*SSL*	15.03	59.77	25.21	SL/*SCL*	20.23	57.19	22.59	SL/*CL*
	40-30	24.71	59.25	16.04	SL/*SSL*	13.02	59.50	27.48	SCL	15.86	57.91	26.23	SL/*CL*
	50-40	24.50	59.04	16.46	SL/*SSL*	15.14	59.06	25.80	SL/*SCL*	14.52	57.11	28.37	SCL

According to the farmer of farm three (F23), the soil was mainly '*typical Essex clay*' with '*Lots of Hanslope*'. The assumption is made that by 'Typical Essex Clay', F23 means Hanslope Clay. For a brief description of the Hanslope series, refer back to figure 6.2. The farmer for farm four (F24) did not name a soil series for his soil but instead said the following;

> *'…ranging from fine sandy loam through to clay loams. And most the soils are shallow soils over chalk but we have a clay cap in the middle of the farm, and we have some soils overly gravely sub soils'.*

From looking at table 6.9 it is possible to see that farms three and four, whilst they largely have the same soil classification and clay percentage ranging from 15.7% to 26.4 % for farm three and 14.9% to 28.4 % for farm four, the percentages of the sand and silt fractions differ. Farm three had a range of 6.7% to 12.6% and 66.2 %to 74.0 % of sand and silt, respectively. Whereas farm four had a higher sand content with a range of 13.0 to 28.5% and silt range of 52.0 % to 59.0 %. It is to be expected then that the soil at farm four would be more coarse and sandy than that found at farm three. However as the clay percentages are similar, and the climate of the two farms are also similar, it can be assumed that the farms three and four can be compared to each other with regards to their organic C content. Figure 6.13 shows cores taken from farm four; demonstrating that the soil at this farm is sandier that those at farm three (figure 6.12).

A. Baseline

B. Non-inversion tillage, 7 years

C. Non-inversion tillage, 5 years, followed by conventional ploughing, 2 years

Figure 6.12: 50 cm cores taken from farm three. A: Baseline. B: Non-inversion tillage, 7 years. C: Non-inversion tillage, 5 years followed by conventional ploughing, 2 years.

A. Baseline

B. Conventional Ploughing, 1 in 3 years

C. Non-inversion tillage, 5 years

Figure 6.13: 50 cm cores taken from farm four. A: Baseline field. B: Core taken from a field with conventional ploughing every 1 in 3 years. C: Core taken from a field with 5 years of non-inversion tillage.

pH

Farm pair B demonstrated an increased in alkalinity in soils from the surface towards 50 cm depth across all six managements, as shown in table 6.9. Farm three had a greater range of pH from pH 7.3 to 9.2, compared to farm four which ranged from pH 7.4 to 8.3.

Table 6.10: pH levels for farms three and four (Farm Pair B) from 0 cm to 50 cm depth, across all three management types at both farms.

FARM PAIR B			
Farm 3	**Baseline**	**Management 1**	**Management 2**
Depth (cm)	*Permanent Pasture*	*7 years non-inversion tillage*	*2 years ploughed following non-inversion tillage*
10-0	7.3	8.7	8.5
20-10	7.7	9.0	8.5
30-20	8.1	9.0	8.2
40-30	8.5	9.2	8.4
50-40	8.0	9.1	8.8
Farm 4			
Depth (cm)	*Permanent Pasture*	*Ploughed 1 in 3*	*5 years non inversion tillage*
10-0	7.4	7.8	7.8
20-10	7.8	7.9	8.0
30-20	7.9	8.2	8.0
40-30	8.2	8.3	8.1
50-40	8.2	8.2	8.2

6.2.2 Farm Pair B; Carbon Analysis

Total Carbon

Total C was measured on all the first cores to be taken at each of the seven fields from both farms. Total C includes both the inorganic and organic fractions of C. Figure 6.14 demonstrates the average total C for all the first cores taken under each management at farms three and four.

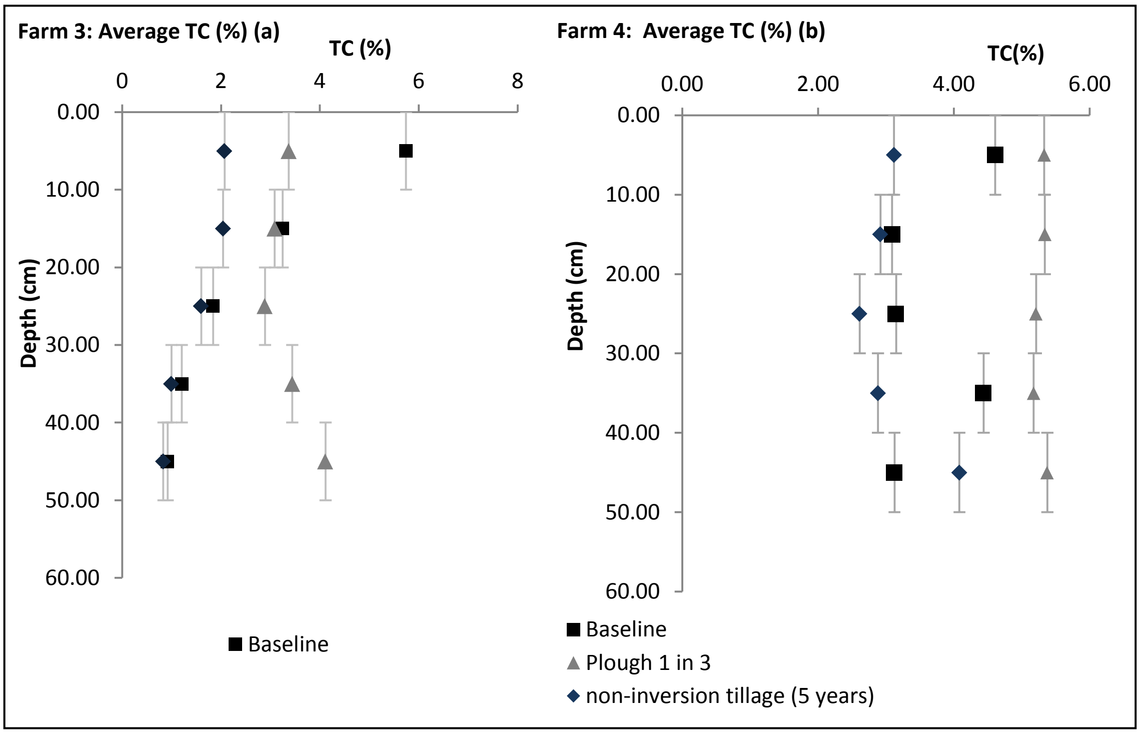


Figure 6.14: Average total C (TC) (%) for farms three and four (Farm Pair B), from 0 to 50 cm depth across all managements tested at each farm at 10 cm intervals.

At farm three, the highest levels of total C were found at the surface which then decreased through the soil profile. The exception is soil under 7 years of non-inversion tillage, whereby there is an increase in total C at 30 to 40 cm, and 40 to 50 cm, with the highest total C level for the soil profile at 40 to 50 cm with 4.1%. This is likely due to the presence of inorganic C. As figure 6.12, core B presents streaks of $CaCO_3$ towards the bottom of the core, which would increase the levels of the total C. The baseline field has the biggest difference between 10 to 0 cm and 40 to 50 cm with 5.7% and 0.9% respectively (figure 6.14). For farm four, all management types show an increase in total C levels towards the bottom of the soil profile with the exception of the baseline field where there is an increase at 40 to 30 cm (4.4%) and then a slight drop off at 40 to 50 cm (3.1%). The total C levels for soil which is conventionally ploughed one year in three; remain relatively high throughout the profile. Figure 6.13 demonstrates that core B has a high presence of $CaCO_3$ throughout the entire soil profile from around 20 cm. This would tally with the high total C levels found for this management type. $CaCO_3$ is also visibly present towards the bottom of the soil cores for other two management types as well.

Soil Organic Carbon

Following the removal of the inorganic C by HCl fumigation, the concentrations of SOC could be analysed. Figures 6.15 and 6.16 present the SOC levels in both percentages and kg/m^3 for Farm Pair B. SOC is presented in both units to provide information on the levels of SOC (%) and the concentration of SOC (kg/m^3). For farm three, the baseline field had the highest SOC % at the surface with 6.2%, almost double in soil under non-inversion tillage (figure 6.15, graph a). The baseline field also had the greatest difference between SOC % at the surface and at 40 to 50 cm with a difference of 5.3 % (6.2 % and 0.9 %). Soil under non-inversion tillage had higher SOC % than soil ploughed conventionally throughout the soil profile. At depths 0 to 10 cm and 10 to 20 cm, non-inversion tilled soils had levels of 3.2 % and 2.5 % respectively, compared to conventionally ploughed soil which had 1.86% and 1.6%. SOC kg/m^3 levels follow a similar pattern to that of SOC % with higher concentration at the surface compared to the greater depths. The baseline field once again had the highest SOC concentration with 58.22 kg/m^3 at 0 to 10 cm, compared to 32.61 kg/m^3 and 27.53 kg/m^3 for soil that is non-inversion tilled, and conventionally ploughed soil, respectively. Soil that is non-inversion tilled remains to have higher SOC concentration compared to conventionally ploughed soil throughout the soil profile (figure 6.16, graph a).

In comparison to farm three, soils under non-inversion tillage at farm four had lower SOC % levels compared to conventionally ploughed soil throughout the soil profile (figure 6.15, graph b). For example, at the 40 to 50cm depth, soil under non-inversion tillage has 0.7% SOC, whilst soil that is conventionally ploughed has 1.8 %. At the surface there remains the difference in SOC levels, with 1.8 % and 3.2%, for soil under non-inversion tillage and conventionally ploughed soil, respectively. The baseline field at farm four had the highest SOC % at the surface with 4.7 %. It also had the largest increase in SOC levels throughout the soil profile, increasing from 1.3 % at the 40 to 50 cm depth, to 4.8% at the 0 to 10 cm depth, a 3.4 % increase.

As figure 6.16, graph b, demonstrates, the highest level of SOC when presented as kg/m^3 is found in soils that are conventionally ploughed with 38.05 kg/m^3, although it is only just under 1 kg/m^3 greater than the baseline field which had 37.70 kg/m^3, both at 0 to 10 cm depth. With the exception of the 10 to 20 cm depth, soil which was conventionally ploughed had higher SOC levels throughout the soil profile in comparison to the baseline field and soils under non-inversion tillage. At 10 to 20 cm, the baseline field has a very marginal higher SOC level of 31.42 kg/m^3 compared to 31.36 kg/m^3 for soil that was conventionally ploughed. Soil that was under non-inversion tillage had the lowers SOC levels at all depths, starting at 10.9 kg/m^3 at 40 to 50 cm, approximately half of that that found in the other two managements (Figure 6.16, graph b). SOC levels increased to 28.01 kg/m^3 at 0 to 10 cm but remained approximately 10 kg/m^3 lower than the baseline field and soil that was conventionally ploughed.

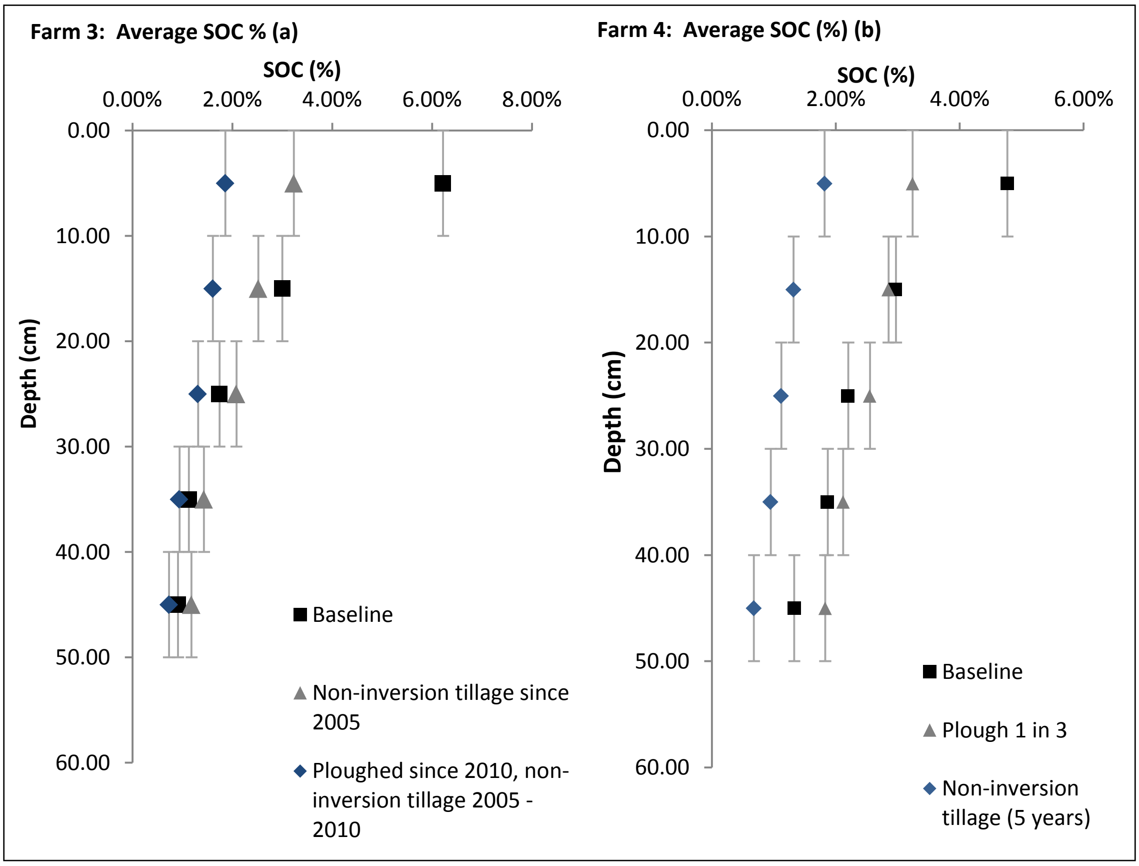


Figure 6.15: Average SOC (%) for farms three and four (Farm Pair B), across all three managements for each farm, from 0 to 50 cm depth.

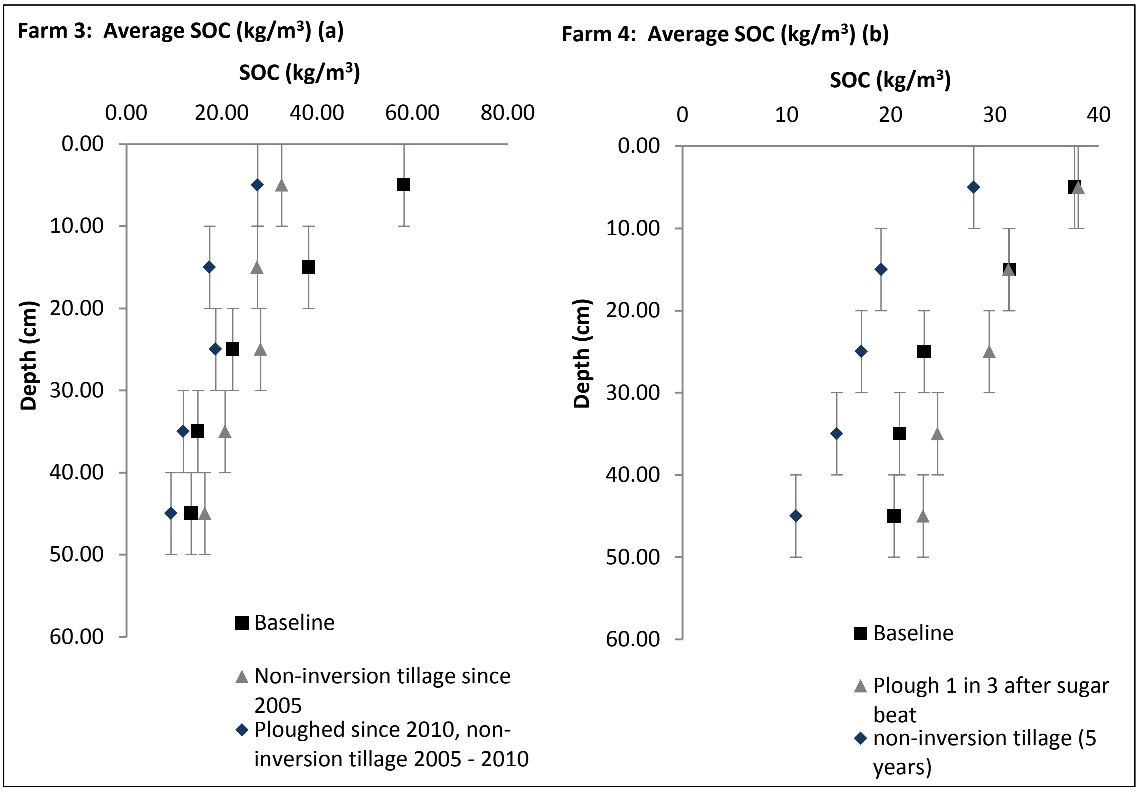


Figure 6.16: Average SOC (kg/m^3) for farms three and four (Farm Pair B), across all three managements for each farm, from 0 to 50 cm depth.

C:N Ratio

Table 6.11 shows the C:N ratios for farms three and four across all three managements at each farm, from 0 to 50 cm at 10 cm intervals. Soil under non-inversion tillage at farm three had a relatively high C:N ratio (26:1) at 0 to 10 cm. This suggests that the C measured here was not made up of animal muck or humus, which have low C:N ratios, but is due to older, more stable C. This is in line with management practice where the soil surface is less likely to be disturbed allowing for a build-up of SOC. Non-inversion tilled soil had a higher C:N ratio than conventionally ploughed soil from 0 to 30 cm. After which, non-inversion tilled soil has no C:N ratio due to N levels being low to be measured using the Elemental Analyser. The high C:N ratio at 20 to 30 cm (54:1) indicates that the C at this depth is in a more stable form and is probably mineralised rather than just OM. At farm four, unlike at farm three, N was at a high enough level to be measured in all samples throughout the soil profile, providing more data for the C:N ratios (table 6.11). The highest C:N ratio was measured at 40 to 50 cm under conventionally ploughed soil (32:1). In comparison to farm three, the conventionally ploughed soil at farm four had a higher C:N at all depths compared to the soil under non-inversion tillage.

Table 6.11: C:N ratios based on the organic C results for farm three and four (Farm Pair B), across all three managements at each farm from 0 to 50 cm depth with 10 cm intervals.

Farm 3	**Baseline**	**Management 1**	**Management 2**
Depth (cm)	**Permanent Pasture**	**Non-inversion tillage since 2005**	**Ploughed since 2010, non-inversion tillage 2005 - 2010**
10-0	15:1	26:1	12:1
20-10	18:1	24:1	11:1
30-20	0:1	54:1	12:1
40-30	0:1	0:1	14:1
50-40	0:1	0:1	19:1
Farm 4			
Depth (cm)	**Baseline**	**Plough 1 in 3 after sugar beet**	**Non-inversion tillage (5 years)**
10-0	10:1	17:1	13:1
20-10	13:1	16:1	11:1
30-20	9:1	17:1	11:1
40-30	10:1	23:1	19:1
50-40	11:1	32:1	22:1

Statistical Analysis

For farm three, the ANOVA test demonstrated that management has a significant impact from 0 to 30 cm. This means that the difference in SOC levels between the non-inversion tilled and the conventional tilled fields is caused by the two differing management types. When clay is considered in the ANCOVA tests, both management and clay are significant from 0 to 30cm, after which only clay is significant (table 6.12 and figure 6.17). The plough layer usually stops at around 20 cm, so it is likely that the biggest difference in SOC levels between the two management types will be seen at these depths. From this statistical analysis, it is possible to conclude that non-inversion tillage has promoted higher SOC levels in the upper layers (0 to 30 cm) compared to conventional ploughing at farm three.

For farm four, the ANOVA test found that management was only significant from 10 to 50 cm and not at the surface (table 6.12 and figure 6.18). Why this should be the case is unclear as between a field that is conventionally ploughed and one that is not, it is expected that there would be a difference at the surface in SOC levels as has previously been demonstrated. When clay is considered, both clay and management are significant throughout the whole soil profile. The fact that clay is significant is important here as the fields under conventionally ploughing have a higher SOC level than those under non-inversion tillage throughout the whole profile, which is not to be overly expected. Overall, the fields under the conventional plough had slightly higher clay % which could explain the difference. Higher clay contents may also suggest as to why the farmer was practising two types of tilling. The heavier soils with higher clay content may not have been as suitable for non-inversion tillage.

Table 6.5: ANOVA and ANCOVA analysis for SOC % for farms three and four, Significant to 0.95 confidence level. See table 6.5 for key.

Depth (cm)	**Farm No.**	
	3	**4**
0-10	** (+)	**
10-20	** (+)	** (+)
20-30	** (+)	** (+)
30-40	*	** (+)
40-50	*	** (+)

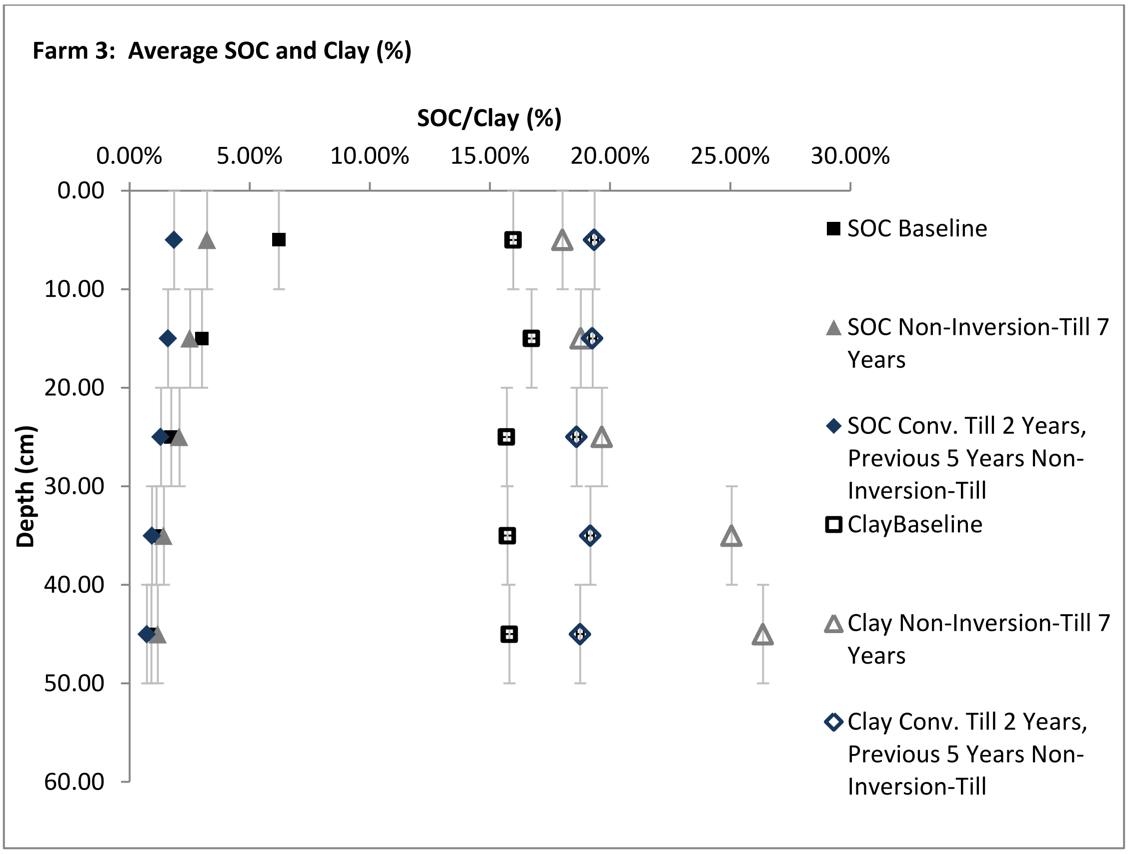


Figure 6.17: Farm three average SOC and Clay (%) across all three managements from 0 to 50 cm depth at 10 cm intervals.

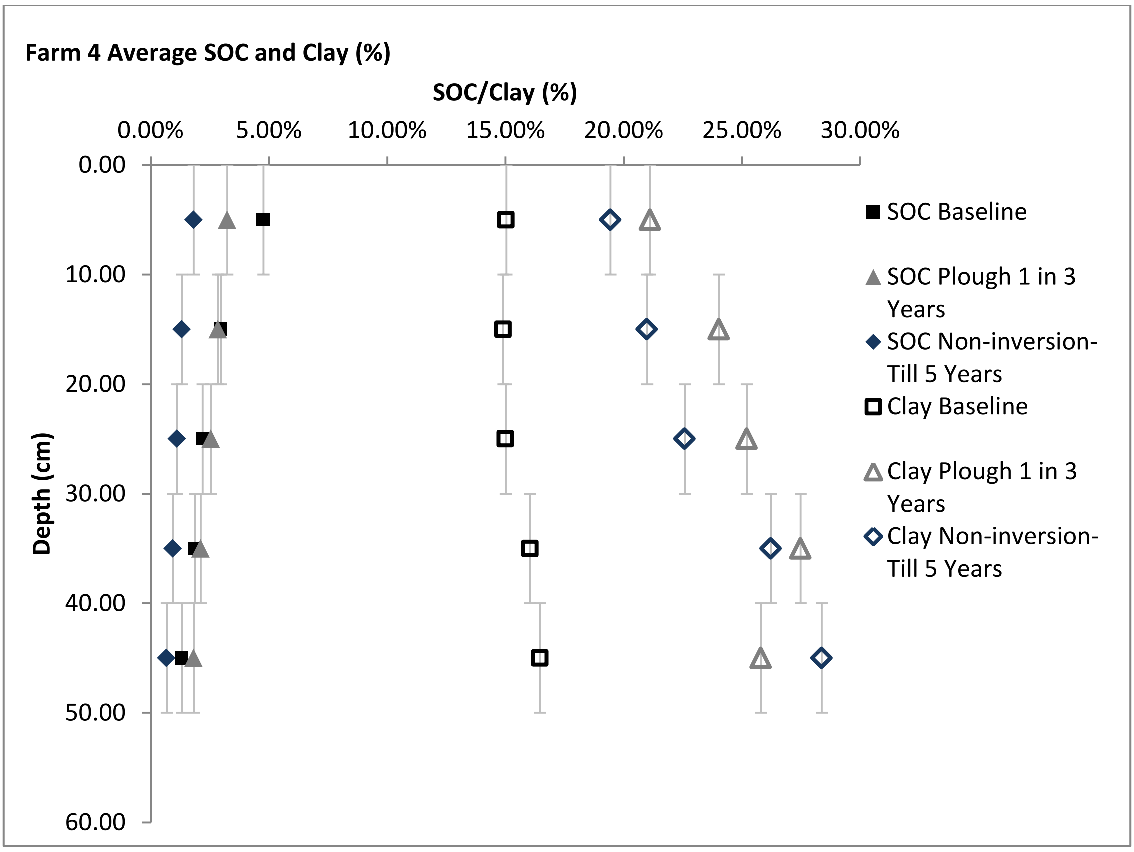


Figure 6.18: Farm four average SOC and Clay (%) across all three managements from 0 to 50 cm depth at 10 cm intervals.

Table 6.6: ANCOVA and ANOVA statistical analysis of Farm Pair B, comparing non-inversion till with conventional till SOC levels, and non-inversion till for 5 years with 7 years SOC levels. See table 6.5 for key.

Depth (cm)	Farm Pair B (Farm 3 & 4)	
	Non-Inv. Till vs. Conv. Till	Non-Inv. Till 7 Years vs. 5 Years
0-10	* (-)	** (-)
10-20	* (-)	** (+)
20-30	* (-)	** (+)
30-40	** (-)	** (-)
40-50	** (-)	** (-)

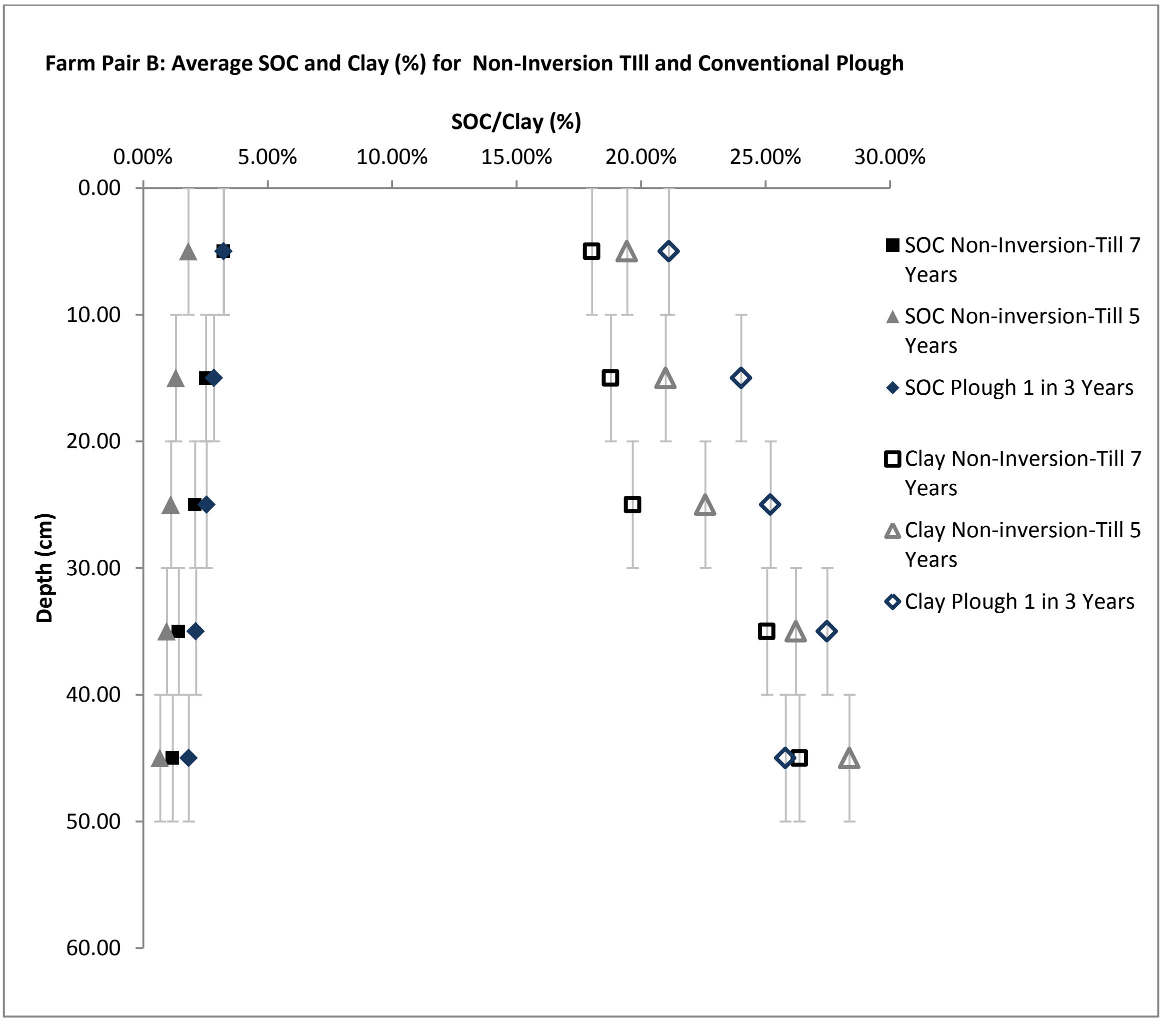


Figure 6.19: Farm Pair B: Average SOC and Clay (%) for non-inversion tilled and conventionally ploughed soil from 0 to 50 cm depth at 10 cm intervals.

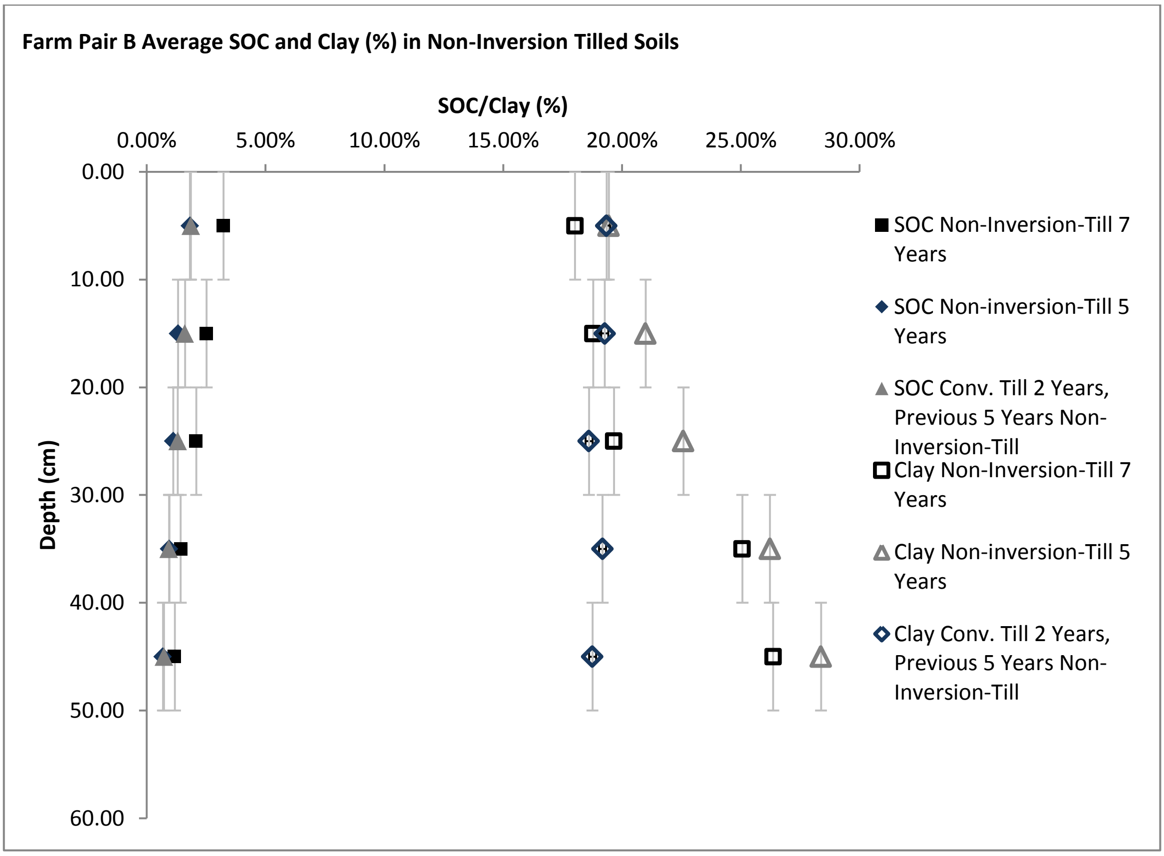


Figure 6.20: Farm Pair B: Average SOC and Clay (%) for soil under non-inversion tillage (5 and 7 years) from 0 to 50 cm depth at 10 cm intervals.

ANCOVA and ANVOA tests were applied to the different managements across the two farms, as table 6.13 demonstrates. When comparing the difference in SOC levels between fields under non-inversion tillage and those under conventional plough, management was not significant at any depths in ANOVA test (table 6.13 and figure 6.19). The ANCOVA test found that clay only was significant from 0 to 30 cm depth, but that both management and clay were significant from 30 to 50 cm depth. This may indicate why the different managements were chosen. Heavier land is not suitable for non-inversion tillage and may need to be cultivated more often than lighter soil in order to avoid compaction. It could for this reason that the farmers chose to practice the two different regimes on the land in order to achieve the best results.

The SOC levels from the fields under 7 years non-inversion tillage and those under 5 years non-inversion tillage were compared with each other (figure 6.20). The ANOVA test found management to be significant from 10 to 30 cm only (table 6.13). When clay was considered during the ANCOVA test, both clay and management were significant across all depths. This suggests that the higher SOC levels found under 7 years non-inversion tillage are a result of the management as well as the clay content. It indicates that non-inversion tillage encourages the increase of SOC levels but that clay content also has a significant role in the levels of SOC.

6.2.4 Discussion

Farms three and four were both largely classified as having silt loam soil. Given that the soil type, location and climate were similar, comparing SOC between the two farms was justified. At farm three, it was found that SOC levels were higher at all measured depths in soil that had been under non-inversion tilling for 7 years, compared to the soil that had been under conventional ploughing for 2 years, following 5 years of non-inversion tilling previously. The biggest difference in SOC levels were found at the 0 to 10 cm depth and 10 to 20 cm depth; the plough layer. At depths of 0 to 10 cm and 10 to 20 cm, non-inversion tilled soils had levels of 3.2 % and 2.5 % respectively, compared to conventionally ploughed soil which had 1.9% and 1.6%. This is to be expected non-inversion tillage does not turn the soil over, so crop residue and any other OM additions are left at the soil surface, increasing the SOC levels. Even though the soil that had been conventionally ploughed for two years had previously been under non-inversion tillage, any OM on the surface would have been lost as soon as the soil became disturbed again (see Manies *et al*., 2001; Freibauer *et al*., 2014). The turning over of the soil via conventional ploughing, leads to the burial of crop residues and other OM. This also encourages the faster decomposition and mineralisation of OM and C, meaning that more C is lost to the atmosphere in the form of Carbon Dioxide (CO_2). This proposition is further supported by the C:N ratio results. Soil under non-inversion tillage at farm three had a relatively high C:N ratio (26:1) at 0 to 10 cm. This suggests that the C measured here was not made up of animal muck or humus which have low C:N ratios but older, more stable forms of C. This is in line with management practice where the soil surface is less likely to be disturbed allowing for a build-up of SOC. In comparison, the C:N ratio in soil under conventional ploughing was approximately half at 12:1. Non-inversion tilled soil had a higher C:N ratio than conventionally ploughed soil from 0 to 30 cm. After which, non-inversion tilled soil has no C:N ratio due to N levels being low.

Statistical analysis found that management type was significant from 0 to 30 cm. This means that the difference in SOC levels between the non-inversion tilled and the conventional tilled fields is caused by the two management types, indicating that non-inversion tillage has led to increased SOC levels at this depth. However, when clay percentage was considered both management and clay are significant from 0 to 30cm, after which only clay is significant. The plough layer usually stops at around 20 cm, so it is expected that the biggest difference in SOC levels between the two management types will be seen at these depths. From this statistical analysis, it is possible to conclude that non-inversion tillage has promoted higher SOC levels in the upper layers (0 to 30 cm), compared to conventional ploughing at farm three.

In comparison to farm three, soils under non-inversion tillage at farm four had lower SOC % levels compared to conventionally ploughed soil throughout the soil profile. At the surface, where it would be expected to see the greatest difference in SOC levels between the two managements, soil under non-inversion tillage had 1.8% whilst conventionally ploughed soil had 3.2%. Why this should occur can perhaps be explained but the nature of the conventionally ploughed soil. The soil was only ploughed one year in every three, following a harvest of sugar beet. If samples were taken towards the end of the three year period just before ploughing was due, OM and SOC levels may have been relatively high. However, whilst this may explain higher SOC levels from 0 to 20 cm (the plough) it does not necessarily explain why the conventionally ploughed soil remains higher at 40 to 50 cm depth (Conventionally ploughed 1.8% SOC and non-inversion tilled soil 0.7%). The C:N ratios of soil under conventional ploughing were higher than those under non-inversion-tilling, again, very different to that found at farm three. This suggests that the SOC measured in conventionally ploughed soil was more stable, than that found in the non-inversion tilled soil.

Statistical analysis found that management was only significant from 10 to 50 cm and not at the surface. Why this should be the case is unclear as this would be where the greatest difference would be expected to be found given the nature of the managements. When clay is considered, both clay and management are significant throughout the whole soil profile. The fact that clay is significant is important here, as the fields under conventional ploughing have a higher SOC level than those under non-inversion tillage throughout the whole profile. Overall, the fields under the conventional plough had slightly higher clay % which could explain the difference. Soil with higher clay percentage is likely to have greater SOC contents due to the structural nature of clay particles. Higher clay contents may also suggest as to why the farmer was practising two types of tilling. The heavier soils with higher clay content may not have been as suitable for non-inversion tillage.

The statistical analysis of non-inversion soil and conventional plough between farms three and four, found that the management type was not significant at any depth in creating the difference between SOC levels. However, when clay content was considered, clay was found to be significant from 0 to 30 cm, and both management and clay were significant from 30 to 50 cm. This is further indication that the choice of management may have been dominated by the workability of the soil. Heavier land is not suitable for non-inversion tillage and may need to be cultivated more often than lighter soil in order to avoid compaction. It could for this reason that the farmers chose to practice the two different regimes on the land in order to achieve the best results.

The statistical analysis of comparing non-inversion tilled soils for 7 and 4 years from farms three and four, found that management was only significant from 10 to 30 cm depth. However, when clay was considered, both clay and management were significant at all depths. This suggests that the higher SOC levels found under 7 years non-inversion tillage, are a result of the management as well as the clay content. The results indicate that non-inversion tillage encourages the increase of SOC levels, but that clay content also has a significant role to play.

The results from this investigation reflect those found in published literature. At farm three, the results indicate that non-inversion tillage may lead to greater SOC levels, particularly from 0-30 cm depth, which is in line with what Barker *et al.* (2007) and Palm *et al*., (2014) found, with an increase in SOC near the surface. However, the same was not found at farm four, whereby conventionally ploughed soil had higher SOC levels than the non-inversion tilled which is similar to what Bhogal *et al.* (2009) stated, that there is limited scope to increase SOC levels from reduced tillage practices. Instead, the results do show the importance of clay content in the levels of SOC. Greater clay content may have been the decision behind why conventionally ploughing was conducted in certain fields rather than non-inversion tilling at both farms. Further testing is required in order to further qualify these results. The results from this study also highlight the importance of measuring SOC levels below the surface levels (>10 cm) particularly when considering the impact of different management regimes. This is an issue mentioned by Barker *et al*. (2007) in their study of the influence of tillage regimes on SOC levels, where it was suggested that sampling goes beneath 30 cm depth.

6.3 Farm Pair C

6.3.1 An introduction to Farm Pair C

Farm pair C consists of farms five and six, both situated in south Suffolk in the catchment area of the River Stour, approximately 2 miles apart from each other. Farm five was a conventional arable farm, with a 4-year rotation growing a combination of Oil Seed Rape (OSR), wheat and oats. The whole farm was under direct drilling, half of the land for 5 years and the remainder for 2 years. Farm six was again a conventional arable farm, growing a combination of winter wheat and barley and OSR. The majority of land was ploughed conventionally with around two thirds of the OSR being direct drilled with chicken manure applied annually. The farmer of farm five (F25) was very keen to see the results of the sampling as he had an invested interest in the direct drilling equipment that he was using. He was certain that his SOC levels would b higher than that of his neighbour as he had been direct drilling for longer. The farmer of farm six (F36) was also interested in the results, as he had begun direct drilling on some of land and wanted to see the difference between the direct drilled and the conventional ploughed land. He was also keen to see if the OM amendments he applied made a difference to his SOC levels. There was a feeling of friendly rivalry between the two farmers over who had the highest SOC levels.

Table 6.14: A summary of the management practices employed at farms 5 and 6 (Farm Pair C) which were analysed as part of this study.

Farm Number	Baseline (1 field)	Management 1 (3 fields)	Management 2 (3 fields)
Farm 5	Woodland.	Conventional arable, direct drilling for 5 years.	Conventional arable, direct drilling for 2 years.
Farm 6	Permanent pasture.	Conventional arable, conventional plough.	Conventional arable, direct drilled for 2 years with manure.

Particle Size

The soil at farm five was classed as silt loam using the UK classification (figure 6.1) in all three managements and across all depths. Farmer 29 of farm five described his soil as being mostly heavy boulder clay, with some areas being more 'loamy clay rather than boulder clay', which corresponds with the description of a silt loam (table 6.15) The soil at farm six was also mostly classed as a silt loam using the UK classification guidelines (table 6.15). The exception was under fields which had been direct drilled for 2 years at 40 to 30 cm depth, where the soil was classed as silty clay loam. This reflects the description the farmer provided for his soil describing as being, half Hanslope and the rest Melford series which he said was is more of a '*clay loamy sand*' (F36). The cores presented in figure 6.21 and 6.22 correspond with descriptions of Hanslope and Melford series in figures 6.2 and 6.3. Due to the proximity on location and similarity in soil composition, it can be assumed that the farms five and six are similar enough to be compared against each other with reference to SOC levels under different farming practices.

Table 6.15: Average sand, silt and clay percentages for farms five and six (Farm Pair C) and Textural Classification, across all three management types measured at each farm from depths from 0 to 50 cm with 10 cm intervals.

Farm No.	**Depth (cm)**	**Baseline**				**Management 1**				**Management 2**			
		Av. Sand (%)	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*	*Av. Sand (%)*	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*	*Av. Sand (%)*	*Av. Silt (%)*	*Av. Clay (%)*	*Av. Class*
Farm 5		**Woodland**				**Direct drilling for 2 years**				**Direct drilling for 5 years**			
	50-40	14.60	71.44	13.96	Silt Loam (SL)	9.74	65.13	25.12	Silt Loam (SL)/*Silt Clay Loam (SCL)*	12.25	67.84	19.91	SL/*SCL*
	40-30	16.54	69.32	14.14	SL	11.47	65.25	23.29	SL/*SCL*	5.65	67.45	26.90	SL/*SCL*
	30-20	16.77	70.06	13.17	SL	14.65	64.27	21.07	SL/*SCL*	6.64	68.99	24.37	SL/*SCL*
	20-10	12.20	73.00	14.80	SL	9.15	64.97	25.88	SL/*SCL*	9.35	69.56	21.10	SL/*SCL*
	10-0	11.94	73.32	14.74	SL	12.18	63.26	24.57	SL/*SCL*	10.91	69.68	19.41	SL/*SCL*
Farm 6		**Permanent Pasture**				**Conventional plough**				**Direct drilled for 2 years with manure**			
	50-40	12.74	63.69	23.57	SL/*SCL*	12.29	66.91	20.80	SL	11.16	62.07	26.77	SL
	40-30	15.01	63.25	21.75	SL/*SCL*	13.26	67.86	18.88	SL/*SCL*	4.84	67.27	27.89	SCL
	30-20	14.11	66.08	19.80	SL/*SCL*	14.58	67.10	18.32	SL/*SCL*	6.50	67.62	25.88	SL/*SCL*
	20-10	15.95	65.14	18.91	SL/*SCL*	16.51	65.92	17.57	SL	10.17	66.57	23.26	SL/*SCL*
	10-0	21.20	61.33	17.47	SL/*Sandy Silt Loam*	17.24	65.50	17.25	SL	13.73	64.63	21.64	SL/*SCL*

A. Baseline B. 2 years Direct Drilling C. 5 years Direct Drilling

Figure 6.21: Three 50 cm cores taken from Farm five. A: Baseline, B: 2 years direct drilling, C: 5 years direct drilling.

Figure 6 22: Three 50 cm cores taken from Farm six. A: Baseline, B: Conventional ploughing, C: 2 years direct drilling.

pH

Farm pair C had differences in the pH levels found at the two farms (table 6.15). Farm five had a smaller of range of pH 6.70 (0 to 10 cm, 2 years direct drilling) to pH 7.78 (40 to 50 cm, 5 years direct drilling). Farm six ranged from pH 6.93 (0 to 10 cm, baseline) to pH 8.57 (40 to 50 cm, conventional plough). Alkalinity increased with depth across all six managements. This could be due to the $CaC0_3$ found in the soil at these depths, as can been seen in figures 6.21 and 6.22.

Table 6.16: pH levels for farms five and six (Farm Pair C) from 0 to 50 cm depth at 10 cm intervals, across all three managements at each farm.

FARM PAIR C	Baseline	Management 1	Management 2
Farm 5			
Depth (cm)	*Woodland*	*2 years direct drilling*	*5 years direct drilling*
10-0	7.03	6.79	6.87
20-10	7.07	7.22	7.40
30-20	7.16	7.37	7.60
40-30	7.48	7.51	7.75
50-40	7.62	7.45	7.78
Farm 6			
Depth (cm)	*Permanent Pasture*	*Conventional plough*	*2 years direct drilled with manure*
10-0	6.93	7.88	7.88
20-10	7.50	8.21	8.13
30-20	7.90	8.32	8.36
40-30	8.26	8.54	8.52
50-40	8.27	8.57	8.49

6.3.2 Farm Pair C; Carbon Analysis

Total Carbon

As graph (a) in figure 6.23 shows, the baseline field for farm five has the highest amount of total C with 7.1% at 0 to 10 cm. The baseline field has a smooth transition from 1.6% at 40 to 50 cm up to the surface measurement. The total C for fields under direct drilling for 2 years changes very little throughout the soil profile. At 40 to 50 cm, average total C measures at 2.1% and only increases to 2.7% at 0 to 10 cm. Fields under 5 years direct drilling however demonstrates a less uniform concentration of total C in the soil profile. Average total C is highest at 40 to 50 cm with 5.0%, which then drops to 1.8% at 20 to 30 cm depth. In the top 10 cm of the soil, total C increases to 2.8%. The high average total C measured in the 40 to 50 cm of the soil profile is likely to be a consequence of the concentration of $CaC0_3$, which is visible in the soil core in figure 6.21.

The baseline field at farm six (figure 6.23, graph b,) has a smooth transition in average total C from the 0 cm to 50 cm, increasing from 0.9% to 6.4% (40 to 50 cm and 0 to 10 cm, respectively). Soil under the conventional plough has the highest average total C at 40 to 50 cm with 3.5%, which then decreases to 2.1 % at 10 to 20 cm, before rising slightly to 2.4% at 0 to 10 cm depth. Soil under 2 years direct drilling follows a similar pattern but with approximately 1% higher. At 40 to 50 cm, total C is measured at 4.6%, which decreases to 3.1% at 20 to 30 cm depth, before rising slightly to 3.4% at 0 to 10 cm.

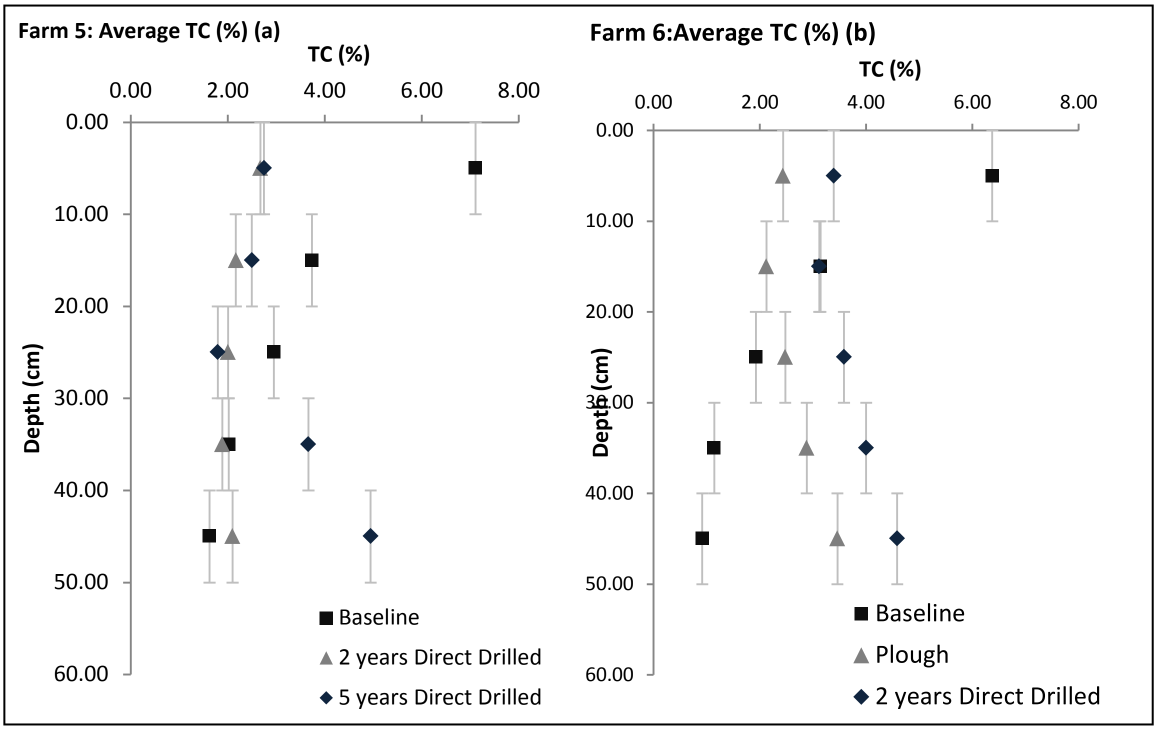


Figure 6.23: Average total C (TC) (%) for farms five and six (Farm Pair C), from 0 to 50 cm depth across all three managements at each farm.

Soil Organic Carbon

At farm five the highest SOC levels found throughout the soil profiles was in the Baseline field with 4.5 % at 0 to 10 cm and 1.2 % at 40 to 50 cm depth (figure 6.24). From 0 to 20 cm depth, soil under 5 years direct drilling had higher SOC levels than soil under 2 years direct drilling (2.0% at 0 to 10 cm compared to 1.9 %, and 1.5 % at 10 to 20 cm compared to 1.5 %. However from 20 to 50 cm, soil under 2 years direct drilling has higher levels of SOC than 5 years direct drilling.

At farm six, the baseline field had the highest levels of SOC from 0 to 20 cm with 3.5 % and 2.9 % %, but falls below both conventional ploughing and 2 years direct drilling from 20 to 50 cm, decreasing to 0.8 % at 40 to 50 cm (figure 6.24). Two years direct drilling had higher SOC levels compared the conventional ploughing throughout the whole soil profile, starting with 2.6 % at 0 to 10 cm and decreasing to 1.1 % at 40 to 50 cm depth. Conventional ploughing had 2.0 % of SOC at 0 to 10 cm and decreased 0.8 % at 40 to 50 cm depth.

When the actual SOC levels per area are examined, the baseline for farm five remains the highest throughout the soil profile; with 41.51 kg/m^3 at 0 to 10 cm, decreasing to 20.17 kg/m^3 at 40 to 50 cm, with a low of 16.60 kg/m^3 at 30 to 40 cm (figure 6.25). Soil under 5 years direct drilling remains higher than 2 years direct drilling from 0 to 20 cm, with 27.55 kg/m^3 and 21.94 kg/m^3, respectively (0 to 10 cm), and 22.86 kg/m^3 and 19.15 kg/m^3 respectively at 10 to 20 cm. At 20 to 50 cm depth, soil under 2 years direct drilling has a higher level of SOC compared to soil under 5 years of direct drilling.

At farm six, soil under 2 years of direct drilling has the highest level of SOC at 0 to 10 cm with 30.12 kg/m^3, although the highest level throughout the whole soil profile is found in the baseline field at 10 to 20 cm depth with 33.70 kg/m^3. Soil under 2 years of direct drilling has the highest SOC levels throughout the soil profile, except at 10 to 20 cm depth, decreasing to 14.50 kg/m^3 at 40 to 50 cm depth. Soil under conventional ploughing has the lowest SOC levels, starting with 24.09 kg/m^3 at 0 to10 cm and decreasing 10.45 kg/m^3 at 40 to 50 cm.

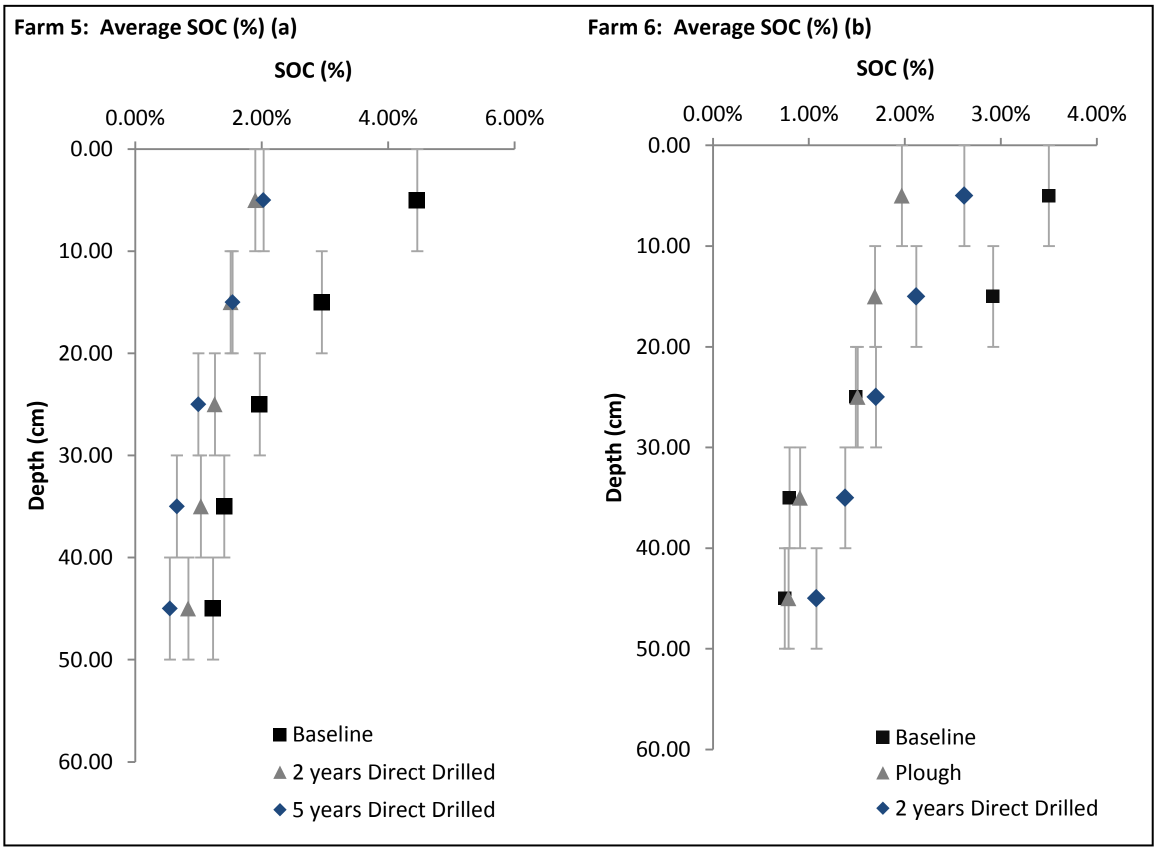


Figure 6.24: Average SOC (%) for farms five and six (Farm Pair C), across all three managements for each farm, from 0 to 50 cm depth.

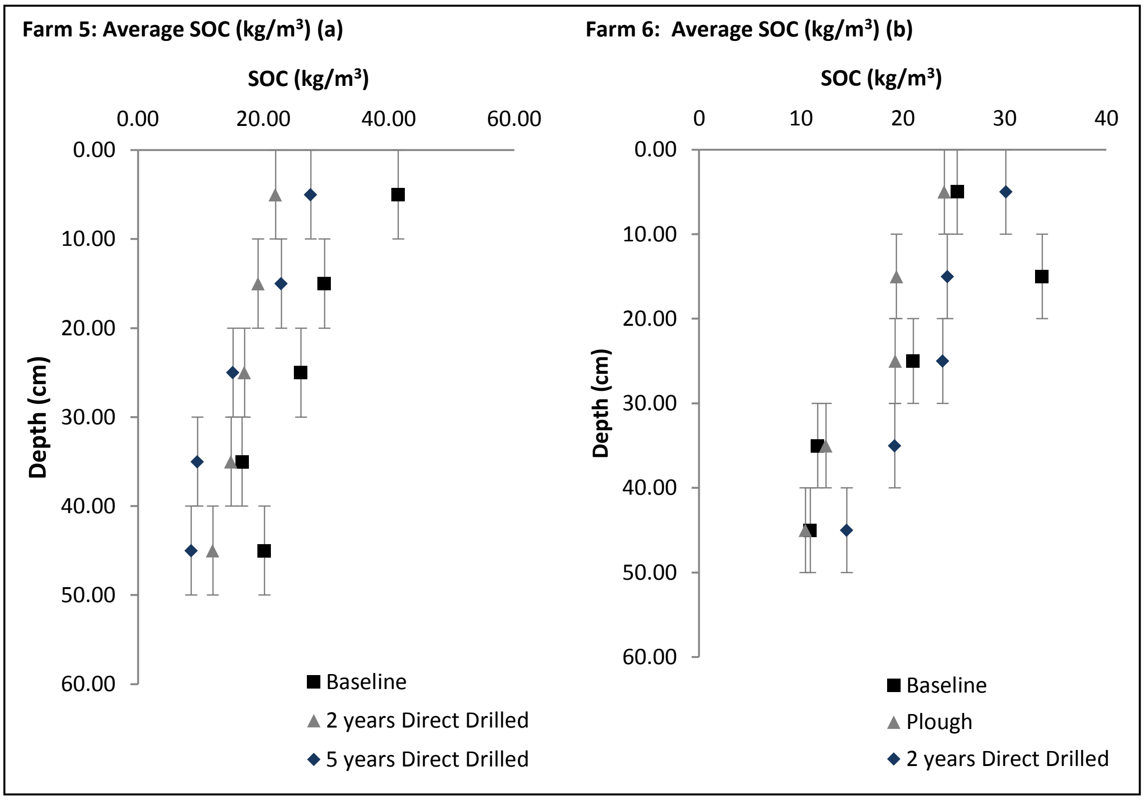


Figure 6.25: Average SOC (kg/m^3) for farms five and six (Farm Pair C), for each management type, from 0 to 50 cm depth.

C:N Ratio

The highest C:N ratio found at farm five was at 0 to 10 cm in soil under 5 years direct drilling with 73:1, over double found in 2 years direct drilling at the same depth (table 6.17). From 10 to 50 cm, no C:N ratios are displayed for the two managements at farm fiver, as the N levels were too low to be measured.

At farm six, the highest C:N ratio was in soil under 2 years of direct drilling at 40 to 50 cm with 70:1, over double that at 30 to 40 cm (1:30). Soil under conventional ploughing starts with a ratio of 12:1 at 0 to 10 cm, increased to 27:1 at 30 to 40 cm, jumping to 43:1 at 40 to 50 cm. The baseline has lower C:N ratios compared to the two managements at all depth. At the surface the C:N ratio was 6:1, and increases to just 14:1 at 40 to 50 cm (table 6.17).

Table 6.17: Average C:N ratios based on the organic C results for farms five and six (Farm Pair C), across all three managements and from 0 to 50 cm with 10 cm intervals.

Farm 5	**Baseline**	**Management 1**	**Management 2**
Depth (cm)	Woodland	2 years Direct Drilled	5 years Direct Drilled
10-0	16:1	30:1	73:1
20-10	14:1	0:1	0:1
30-20	14:1	0:1	0:1
40-30	11:1	0:1	0:1
50-40	15:1	0:1	0:1
Farm 6			
Depth (cm)	Permanent Pasture	Conventional Plough	2 years Direct Drilled
10-0	6:1	12:1	14:1
20-10	10:1	13:1	12:1
30-20	9:1	20:1	25:1
40-30	13:1	27:1	30:1
50-40	14:1	43:1	70:1

Statistical Analysis

The ANOVA test found that management was only significant at 30 to 40 cm depth for farm five, meaning that management is not significant in creating the difference in SOC levels between soil under 2 and 5 years direct drilling (table 6.18 and figure 6.26). When clay was considered in the ANCOVA test, management only was significant at 20 to 30 cm, with both clay and management significant at 30 to 40 cm. From 0 to 20 cm depth and 40 to 50 cm depth, neither clay nor management were significant.

At farm six, the ANOVA test found that management was significant from 0 to 20 cm depth (table 6.18 and figure 6.27). However, the ANCOVA test found that neither clay nor management were significant in the differences in SOC levels between 2 years direct drilling or conventional ploughing in all depths.

Table 6.7: ANOVA and ANCOVA analysis for SOC % for farms five and six, Significant to 0.95 confidence level. See table 6.5 for key.

Depth (cm)	Farm No.	
	5	6
0-10	-	- (+)
10-20	-	- (+)
20-30	***	-
30-40	** (+)	-
40-50	-	-

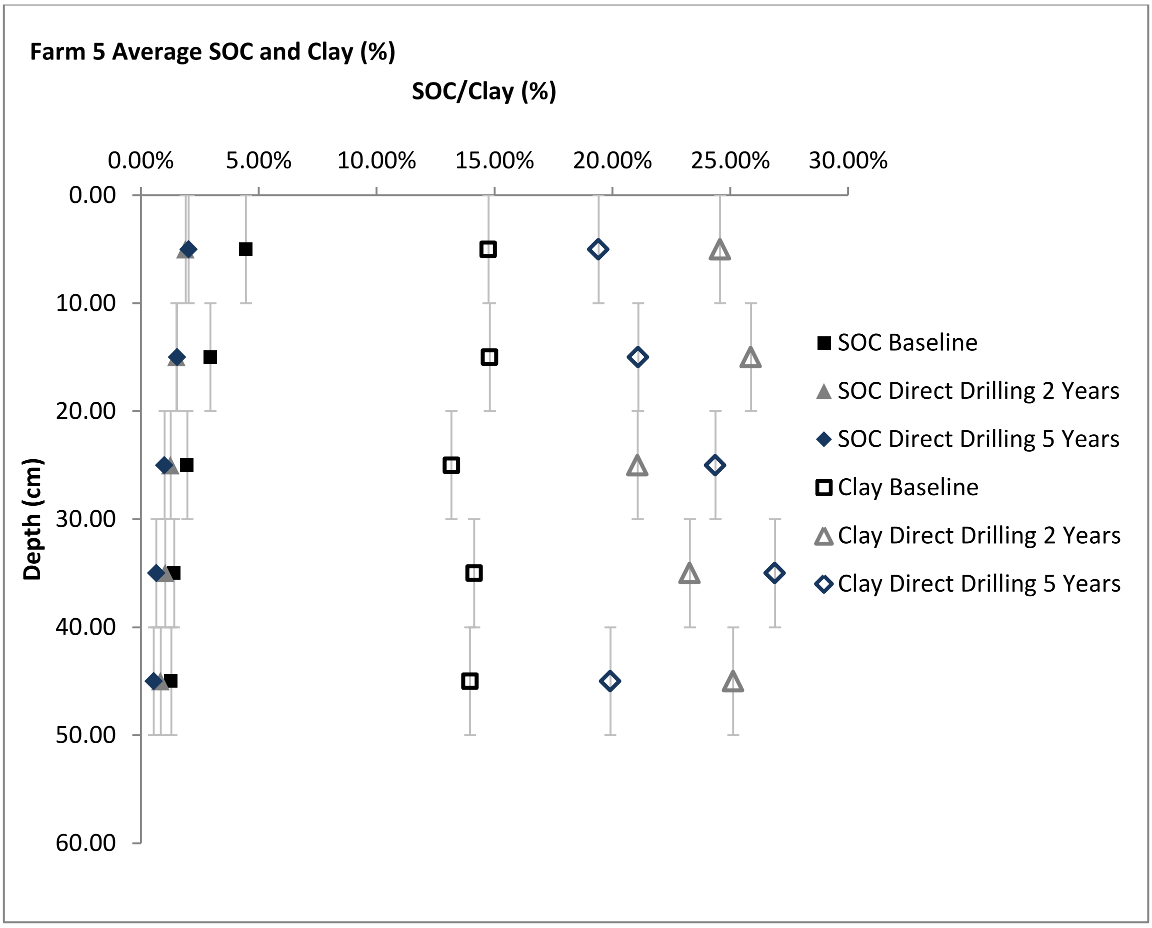


Figure 6.26: Farm 5 average SOC and Clay (%) for all three managements from 0 to 50 cm depth at 10 cm intervals.

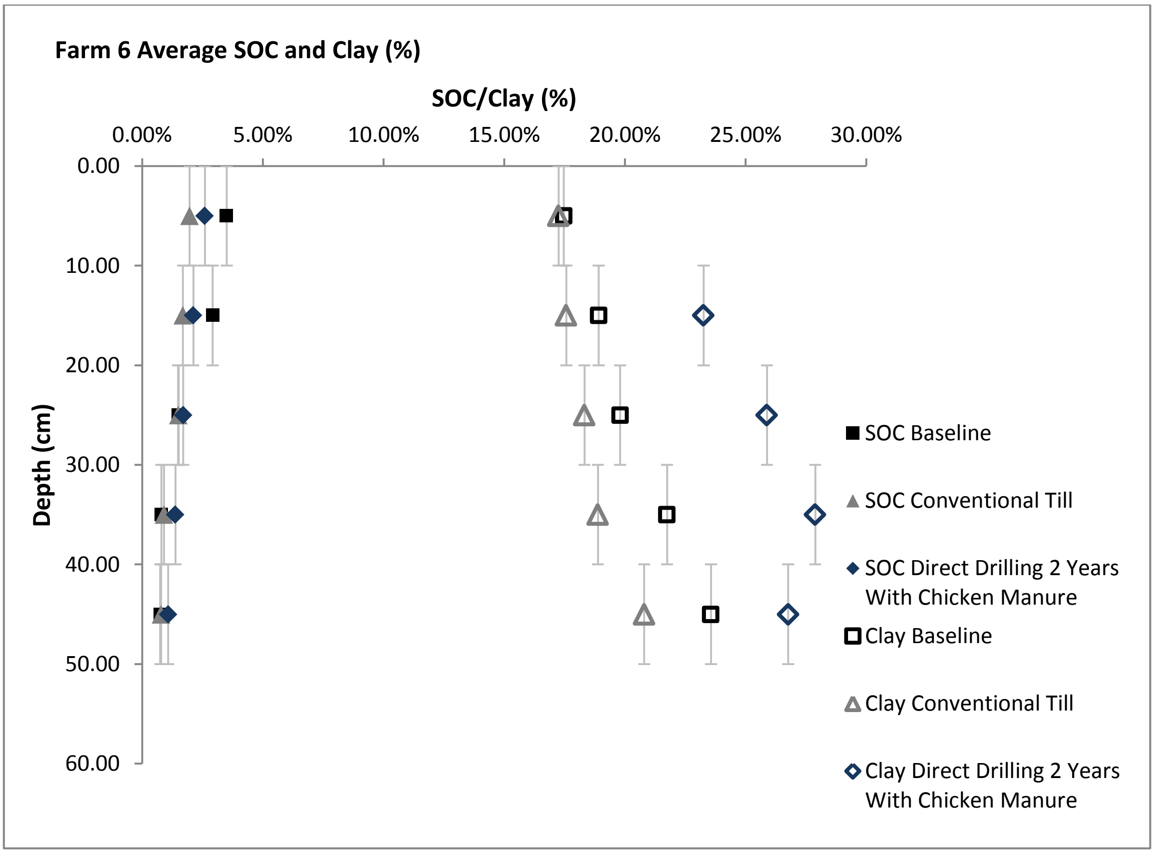


Figure 6.27: Farm six average SOC and Clay (%) for all three managements from 0 to 50 cm depth at 10 cm intervals.

Table 6.8: ANCOVA and ANOVA statistical analysis for Farm Pair C, comparing direct drilled SOC levels with conventional tillage, and direct drilled without manure, with direct drilled with manure SOC levels. See table 6.5 for key.

Depth (cm)	Farm Pair C (Farms 5 & 6)	
	Direct Drilled vs. Conventional Tilling	**Direct Drilled 2 years Vs Direct Drilled 2 years with manure**
0-10	- (-)	- (+)
10-20	- (-)	*** (+)
20-30	** (+)	- (-)
30-40	** (-)	- (-)
40-50	* (-)	- (-)

The SOC results for direct drilling under 2 and 5 years from farm five were pooled together and compared against the SOC levels from conventional ploughing at farm six, in order to test the significance between SOC levels of the two tilling regimes (table 6.19 and figure 6.28). The ANOVA test found that management was only significant at 20 to 30 cm, just below the plough layer. When clay content was considered, clay and management were both significant from 20 to 40 cm, with clay only being significant at

40 to 50 cm. From these results it would appear that the direct drilling and conventional ploughing have had an impact on the SOC levels between the depths of 20 to 40 cm, which is the area just below the plough layer. Clay only is attributed to the differences found at 40 to 50 cm (see figure 6.28).

The SOC results from soil under 2 years of direct drilling from farm five, and those under 2 years of direct drilling with additional chicken manure application from farm six, were compared against each other to assess the differences in SOC levels (table 6.19 and figure 6.29). The ANOVA test found that management was significant from 0 to 20 cm depth only. When clay content was considered in the ANCOVA test; neither clay nor management were significant at any depth. The statistical analysis suggests that the difference in SOC levels observed from 0 to 20 cm is result of the difference in management, in other words, that the additional manure application has led to increased SOC levels.

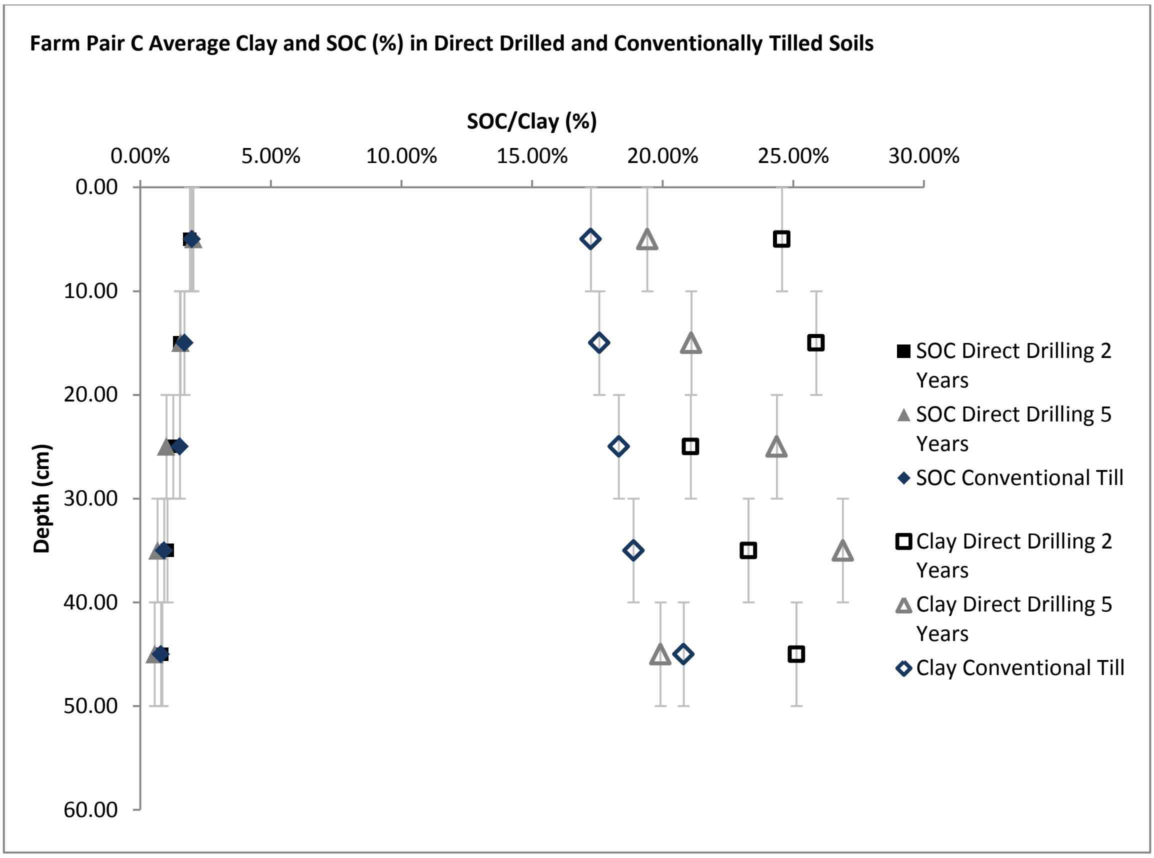


Figure 6.28: Farm Pair C: Average SOC and Clay for soil under direct drilling and conventional tillage from 0 – 50 cm depth at 10 cm intervals.

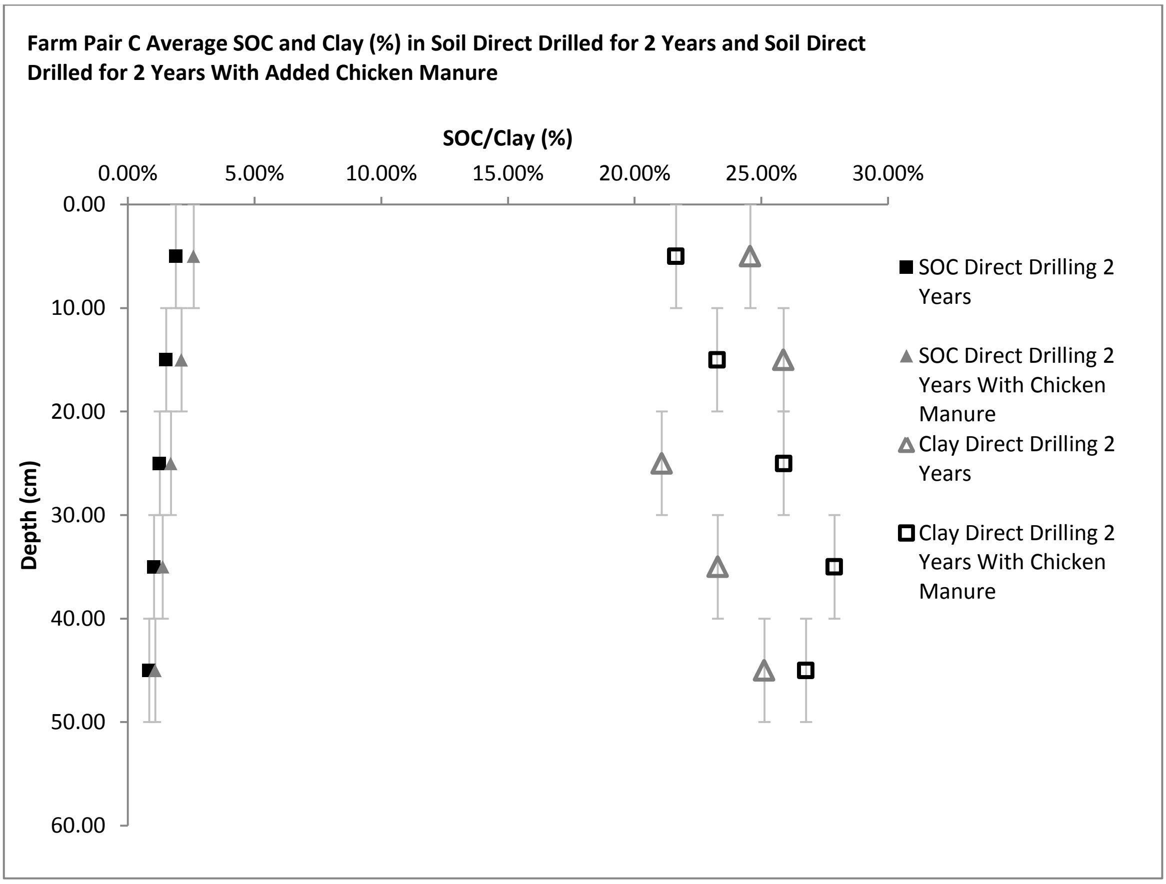


Figure 6.29: Farm Pair C: Average SOC and Clay (%) for soil under direct drilling for 2 years with and without manure additions from 0 – 50 cm depth at 10 cm intervals.

6.3.4 Discussion

At farm five, the baseline field had higher SOC levels throughout the whole soil profile compared to the two managements. At the surface layer, soil under 5 years direct drilling had higher average SOC levels than the soil under 2 years direct drilling (2.0 % compared to 1.9 %). However, from 20 to 50 cm, soil under 2 years direct drilling had higher SOC levels. It is to be expected that soil under 5 years direct drilling would have higher SOC levels at the surface due to a longer periods of crop residue being left and no substantial soil disturbance taking place. Why soil under 2 years of direct drilling may have higher SOC levels from 20 to 50 cm could be a result of stratification, whereby OM is staying at the surface levels in the soil under 5 years of direct drilling and not making its way down the soil profile. Another explanation could be down to soil variability. The fields under 5 years of direct drilling may have started out with less SOC than 2 years direct drilling and so the higher amount at the surface level could be an indication of an actual increase in SOC levels. The C:N ratio at 0 to 10 cm for soil under 5 years direct drilling was high at 73:1, over double that found in soil under 2 years direct drilling. This may suggest that the C is of a stable form, or that N levels were high due to artificial fertiliser application. The fact that N levels were too low to be measured from 10 to 50 cm depth for both of the management fields, may indicate that the soil is not turning over or mixing, so any fertilisers applied to the surface are staying there. Statistical analysis of the results found that there was not much significance between the SOC results. Management only was significant at 20 to 30 cm with both clay and management being significant at 30 to 40 cm during the ANCOA test. During the ANOVA test management was only significant at 20 to 30 cm. This may indicate that the lower levels of SOC found at these depths in soil under 5 years direct drilling is as a result of the lack of soil mixing (see Fernadez *et al*., 2007). The results here once again demonstrate the importance of sampling below the plough layer (20 to 30 cm), as management practices can have an impact below this depth, and offer further insight into the nature of SOC and C storage.

The baseline field at farm six started off at the surface with higher SOC levels than the two managements from 0 to 20 cm, but falls below both from 20 to 50 cm. Soil under 2 years of direct drilling with added manure has higher SOC levels throughout the soil profile compared to soil under conventional ploughing. Statistical analysis of the SOC levels found that management was significant in the difference between SOC levels from 0 to 20 cm when clay content was not considered. This suggests that at farm six, direct drilling with chicken manure has led to increased SOC levels in the plough layer, compared to soil under conventional ploughing. Whilst showing potential, SOC levels under 2 years direct drilling still has to increase by 2.6% to reach the surface levels of the baseline field. The reason why the baseline field may have lower SOC levels than both the managements at farm six could be due to its historical use. Approximately 30 years prior to the soil sampling, the permanent pasture was used to keep pigs. Pigs cause vast amounts of erosion as they turn up the soil quite dramatically. This erosion, would have led to topsoil loss, and perhaps encouraged the loss of SOC from the soil system. The lower SOC levels from 20 to 50 cm could perhaps indicate that the soil system is still recovering from this erosion.

When comparison was made between soil under direct drilling from farm five, and soil under conventional ploughing from farm six, management was only significant from 20 to 30 cm depth during the ANOVA test. This indicates that, similar to that found at farm six, that the two tilling regimes are likely having an impact below the plough layer. At this depth, soil under conventional ploughing has higher SOC levels than both 2 and 5 years direct drilling (figure 6.28), possibly suggesting that the lack of soil mixing in the direct drilling regime may be preventing OM and SOC from reaching lower layers of the soil profile. A study by Ferandez *et al*. (2007) found that direct drilling may cause stratified soil layers, which may be what is present here, whereby C is unequally distributed throughout the soil profile due to a lack of mixing mechanisms. When clay content was considered, both management and clay were significant from 20 to 40 cm further enhancing the argument that direct drilling and conventional ploughing are creating differences in SOC levels below the plough layer.

Soil under 2 years direct drilling from farm five and soil under 2 years direct drilling with added chicken manure from farm six were compared against each other to assess the impact of the additional OM input. Statistical analysis found that management was significant from 0 to 20 cm depth. This means that the higher level of SOC in soil with the added manure is due to the additional input of OM (figure 6.29). This significance is likely only to be found at the surface of the soil (0 to 20 cm) because, as previously mentioned, a lack of soil mixing from direct drilling would mean that any OM applied to the soil would be left on the surface.

The results from farm pair C have indicated that whilst direct drilling may encourage greater SOC levels at the soil surface, the lower depths (below 20 cm) do not receive this benefit due to a lack of soil mixing. The addition of manure to the soil, further increases the SOC levels, but again only at the surface due to the lack of mixing. What these results have indicated though is the importance of soil sampling below the plough layer, so as to assess the full impact of a farm management regime, something which has also been highlighted by Baker *et al*. (2007). The work by Ferandez *et al*. (2007) and Giobergia *et al*. (2013) have both indicated unequal distributions of C as a result of direct drilling and stratification, and also strongly promote deeper sampling depths in order to understand the effect on the whole soil profile.

Upon receiving their results both F29 and F36 were surprised. F29 said that 'I was not expecting that' relating to the lack of clarity in the increase of SOC from direct drilling. However, neither were disappointed and both said they would continue with direct drilling as they had recognised structural improvements in the fields.

6.4 Conclusion

From this study it is possible to draw several conclusions about SOC and different management regimes;

- Organic farming at farm one demonstrated the potential to increase SOC levels and potentially C sequestration at greater depths, below the plough layer. Not only when compared to conventional arable farming, but between soil under 12 years organic farming and soil under 4 years organic farming.

- Clay content had a greater significance than management between SOC levels found under 15 years minimum tillage, 6 year minimum tillage and conventional ploughing at farms one and two.

- Soil under non-inversion tillage for 7 years had higher SOC levels compared to conventional ploughing, due to the difference in management at farm three, from 0 to 30 cm (plough layer).

- Conventional ploughing one year in every three had higher soil SOC levels than soil under non-inversion tillage for 5 years at farm four. Both clay content and management were found to be significant in causing the differences in SOC levels between the two managements. It is likely that the higher clay content in fields under conventional ploughing had a greater impact in SOC levels than the management type and may explain why two regimes were in operation at farm 4.

- Statistical analysis of SOC levels between soil under non-inversion tillage and connectional ploughing at farm pair B indicated the importance of clay content when considering the impact of different managements. Clay only was found to be significant in the difference between SOC levels from 0 to 30 cm, with clay and management significant between 30 and 50 cm.

- Statistical comparison between soils under 5 and 7 years non-inversion tillage from farms three and four demonstrated that both clay and management were significant in the differences between SOC levels at all measured depths. This indicates that non-inversion tillage encourages the increase of SOC levels but that clay content also has a significant role to play.

- Evidence of possible stratification from direct drilling at farm five based on the management only being significant in SOC levels at the plough layer depth. This is potentially caused by a lack of soil mixing. Further evidence for this was found in the comparison between direct drilling at farm five and conventional ploughing at farm six, whereby management was only significant below 20 cm depth indicating that direct drilling and conventional ploughing are creating differences in SOC levels below the plough layer. This also highlights the importance of sampling below the top 20 cm of soil in order to fully assess the impact of management on SOC levels.

- At farm six, direct drilling for 2 years with the addition of chicken manure had led to greater SOC levels from 0 to 20 cm compared to soil under conventional ploughing.

- The additional of chicken manure to a direct drilling regime compared to direct drilling, caused higher SOC layers from 0 to 20 cm at farm pair C.

- Direct drilling appears to only improve SOC at the surface rather than encouraging SOC increases at deeper depths at farms five and six.

With these results in mind, the following chapter will discuss recommendations on how to improve or maintain SOC levels using appropriate farming practices, policy measures and the previously discussed interview data. The results found here complement those found in published literature, as highlighted in the discussion for each investigation. Whilst this was not a large-scale investigation into SOC levels under different farming systems and practices, the results are of great value as they feed into the wider studies on SOC levels. They are representative of those farms which took part in the sampling.

CHAPTER 7: RECOMMENDATIONS TO IMPROVE SOIL ORGANIC CARBON LEVELS IN AGRICULTURE

The purpose of this chapter is to draw upon the previous literature reviews and results chapters, and discuss potential recommendations on how soil organic carbon (SOC) levels could be maintained or improved in UK agriculture. The specific objectives are:

Objective 3a: *Drawing on outcomes from objectives 1 and 2, identify on-farm management strategies for maximising SOC levels.*

Objective 4c: *Create recommendations based on the outcomes of objective 2a and the analysis of the farmer and farm advisor interviews, to form a policy environment that is conducive to increasing/maintaining SOC levels through effective farm management practices.*

These objectives can be achieved by analysing the interview data with farmers and farm advisors (FAs) (Chapter 5), most of whom had an opinion on how the current policy and advisory environment could be improved. These results combined with data from the literature reviews (Chapters 2 and 3), can lead to suitable ways forward of improving SOC levels.

Whilst examining these recommendations, there are a number of methodology limitations to consider. First, the size of the study means that the results generated cannot be considered representative of the whole farming community, or the farming practices and systems investigated. Soil is naturally very variable, and any documented change in SOC that could be perceived to be from a result of a particular management or land use, will need to be verified by extensive monitoring. Secondly, the social science methods undertaken in this research have, as mentioned in Chapter 4, certain restrictive elements. For example, the use of a case-study approach, considered suitable for the overarching aims of this thesis, can be criticised due to the lack of the ability to generalise from the relatively small, in-depth studies, to broader, more general contexts. Additionally, interviews too have their criticisms as a methodology approach. Interviews record 'what people say' rather than what people do or think, with reality continually under construction during the interview process (Holstein and Gubrium, 2006). There is also the risk that the interviewee will withhold information if they think it will portray them in a negative light, or alternatively, they may say what they think the interviewer wants to hear to present themselves in a positive *manner. These recommendations are not supposed to be representative of the national situation, but are based instead on the issues highlighted in the investigations undertaken in this thesis.*

7.1 Introduction

During the interview process with the farmers and FAs, it became apparent that many of them had strong views and opinions on how agri-environmental policy could be altered to improve their own experiences of farming. Some of these suggestions fell beyond the remit of this thesis, but a number were related to the management of soil and SOC. The examination of these suggestions, within the context of the previous literature reviews and results chapters, provides a solid baseline from which to hypothesise how current systems could be improved to facilitate the improvement or maintenance of SOC levels. The following recommendations chapter presents and discusses the suggestions made by the interviewed farmers and FAs, and offers potential mechanisms to put some of these in place.

Based on the suggestions made by the farmers and FAs in the interviews, this chapter examines the following areas for improvement; research and development, policy and agri-environmental schemes (AESs) and lastly, communication mechanisms. The chapter ends with a brief summary of these recommendations and how they could be implemented within the current environment. By exploring these topics, it is hoped that recommendations can be made on how to improve or maintain SOC at the farm level and within the current policy environment.

7.2 Improved Research and Development

The most common response from the interviews on how to improve SOC advice and information was to have better research and development (R&D) guiding the advice. Many of those interviewed, both farmers and FAs, felt that the R&D in English agriculture was not necessarily fit for purpose.

Improved Unbiased Research and Greater Accessibility

It was repeated that unbiased, scientific based research was needed in order to demonstrate the benefits of increasing SOC and soil organic matter (SOM). For example, FA11 (East, self-employed) was not convinced of the benefits of SOM, saying that more evidence was required to prove the claims, as in their own experience, it had appeared to have had very little effect on crop yields or soil quality;

'Well we grow potatoes, onions or something, high value crops, we feed the soil with the nutrients, we supply water and we get very good crops, so does the organic matter actually matter that much? It doesn't appear to does it? If somebody came along and said 'Well, you can improve your organic matter by 2% if you do this, this and this; then people might turn around and say 'Well, we'll give it a go', but when the [in-field] evidence is that incorporating straw, incorporating manure, doing all these things, doesn't actually make a huge amount of difference...'(FA11) (East, self-employed).

Others emphasised that there was room for improvement in R&D and a general improvement in the scientific understanding of the soil system and SOC was required;

'I think there's room for improvement in the science, and the understanding. I really believe that' (FA17) (SW, government body).

This is especially true given the quote by FA11 (East, self-employed) above and, as highlighted by FA7 (East, self-employed), improved SOM and SOC levels are not going to have the same benefit in all areas of agriculture or on all soil types, due to the large variability. He states that unbiased trials are required in order to provide a true picture for farmers;

'...what wants to be established is some really sensible trials looking at the pros and cons, accepting that it's not always a winner and so there's some real impartial advice required and unfortunately whoever funds the advice is wanting a particular answer to come out' (FA7) (East, self-employed).

However, it was commented by both FA2 (SW, charity) and FA20 (SW, consultancy) that more funding was needed to increase the amount of applied R&D. Without more funding, improvements in the understanding of SOC cannot occur;

'And that's something we pick up, criticism and a lack of investment in R&D' (FA2) (SW, charity).

*'...we're in desperate need of money being spent on applied R&D...I would come back that we need more applied R&D really. You know, you need figures to put to people rather than hear say. I mean **** and I, being old age, we're more used to whatever we said was based on experiments, whereas I wouldn't say that's true now, so [back to my] hobby horse, we need R&D' (FA20) (SW, consultancy).*

A couple of the farmers commented that they felt R&D in England was lagging behind the USA and Australia. Farmer 28 (East, conventional arable) was very keen on research being undertaken in North America and Australia and was frustrated that the same level of research was not occurring in England, or at least the information associated with such research was not publically available to farmers. He got a lot of information on biological activity in soil over the internet, largely from North American and Australian sources, but felt that such research should and could be going on in England and the rest of the UK;

'A lot of the things I read and the information I get comes from America or Australia, clips on YouTube of American extension agencies who give advice to farmers and it's really focused at zero-tillage and using the best fertilisers and taking into consideration the biological activity within the soil and that's really where our...where I focus my attention for that sort of thing and I've never heard anything about that from UK soil scientists or people who advise farmers talking about how the biology in the soil can structure it and improve the water holding capacity and improve how it can support the weight of vehicles and things like that. We always seem to be down the mechanical route of improving your soil with a cultivator' (F28) (East, conventional arable).

He also mentioned that whilst he was at University, there was not huge amount of focus on soil biological life and how to have a healthy balanced soil system;

'We had lectures on it at University but not very many, not very detailed; just saying these are the organisms that live in your soil...They never talk about how to try and have, you know, create a natural balance so the predator and prey relationship in the soil, helps keep it healthy and balanced' (F28) (East, conventional arable).

Farmer 33 (East, conventional arable) echoed the same sentiment as farmer 28, stating that the UK is behind North and South America in terms of agricultural research;

'Yes, there should be masses more but I think, people that are providing the information need to get themselves up to date first. Because quite a lot of what we read; comes out of, it's a bit naive really and not really very good. And we're quite behind in this country compared to a lot of the rest of the world, America and South America; they're sort of 10 or 15 years ahead of us really. And so a lot of the information I get comes from those sorts of people' (F33) (East, conventional arable).

Farmer 38 also felt that there could be room for improvement within AESs, with more scientific information being presented;

'...because it seems some of the advice we get on ELS (Entry Level Stewardship) is...doesn't have enough scientific grounding, it's just some is more theoretical rather than practical' (F38).

FA19 (East, self-employed) commented that a more co-ordinated approach would benefit the industry in terms of R&D, stating that many organisations conduct their own research, but do not necessarily collaborate their data or consequential advice with other organisations;

'Certainly one would like to know what the position was. That's the trouble since ADAS and all the organisations like that have disappeared, you know, one doesn't have the continuity of data. You know it would be interesting to back and go through some of the old data and see what they were finding in the 60's and 70's' (FA19) (East, self-employed).

In addition to this, the FA also highlighted that each organisation or institution has 'tunnel vision' of what they feel is the most important current issue, resulting in conflicting advice, and possibly legislation;

'...you know, everyone sees their own little tunnel vision problems, like the Environment Agency are looking at stopping pollution, you know, they can see themselves as the policeman of that sort of beat but they don't see the other side of it...'(FA19) (East, self-employed).

This is perhaps an area where academic institutions could play a more prominent role in agricultural advice and information. Research at Universities is likely to be unbiased due to how the research is funded. A fertiliser company or a company trialling a new piece of tilling equipment will want a positive result for their product in terms of good soil husbandry, which may lead to bias in the presentation of the results. However, if farmers and FAs had access to unbiased research that presented results in a fair and open manner, highlighting the positive and negative impact of practices, then they may have more faith in the research as well as being able to make better informed decisions.

Whether the UK is behind other countries in terms of its agriculture research is debatable. However, it has been highlighted by several authors that there is a lack of comprehensive data on SOC levels across the UK, particularly with regards to changes in land use and management, as highlighted by the lack of understanding of the response of SOC levels to changes in set aside legislation (Defra, 2006; Bell *et al*., 2011 and SAC and AEA Technology, 2011). There may also be relic effects from the privatisation of ADAS, which used to be a government organisation that provided free advice to farmers. It has been noted that the privatisation caused a fragmentation of the advisory system (Read, 1987; Labarthe and Laurent 2013). The result of this was that many farmers, especially small-scale farmers, no longer received advice as they were priced out of using the service.

However, the main reason that these farmers may feel the UK is behind in it agricultural research, is likely to do with accessibility, and the promotion of information and research being conducted in academic institutions. Information networks between scientists, academics and farmers, 'horizontal communication' (Garforth *et al*., 2002) should be improved in order to increase the amount of information transferred between the parties, as well as a comprehensive database and monitoring system of SOC levels, particularly with regards to changes in land use and management.

Critical Levels and Soil Organic Carbon Testing

Specific research areas that needed to be improved were mentioned by a number of FAs. Critical levels of SOC came up a number of times. FA2 (SW, charity) felt that an improved understanding of the potential for increased SOC levels was needed;

'Yeah, it's poorly understood really what the potential is for increasing soil organic carbon. At what point the soils reach equilibrium, at what points the soils, the soil

> *carbon is going to match the land use. You know if you've got an arable system, there's going to be a limit as to how much carbon you can cram into the soil, and whether things like biochar and things like that, whether they actually have the benefits they are potentially claiming to have...So everything in the soil has evolved to feed on carbon in the soil isn't it? So there must be something that's going to break it down, so yeah more research into really understanding that' (FA2) (SW, charity).*

Critical levels were also mentioned by FA14(East, consultancy);

> *'...it would be nice to find out critical levels for different soil types, but it's going to vary depending upon rainfall, it's going to be a factor of soil type and rainfall quite honestly' (FA14)(East, consultancy).*

FA14 also touched upon the difficulty of potentially finding critical levels of SOC due to the variability of soil and climates. The FA went on to comment on the impact of different OM additions and which material is the moist suitable at increasing SOC levels;

> *'...so then we've got to say different levels of organic manure additions, is there really a difference? It looks like compost might be the longer lasting one because of its high lignin content. Is it the right organic matter that's being applied? Should I be polysaccharides rather than lignin for example? I shall be out of my depth very quickly I'm afraid, but that's the sort of thing that does need investigating I think' (FA14)(East, consultancy).*

Soil testing was raised in a number of interviews, particularly in response to the question 'how do you think soil organic carbon advice needs to be improved?' The main issue appeared to be that the basic soil analysis, which farmers have completed on an annual basis, did not include C or OM analysis. The lack of C analysis inhibits peoples' understanding and hides it as an issue, as it does not demonstrate whether there is an improvement in SOC levels, or a decrease as FA3 (East, charity) demonstrates;

> *'...most people don't test for it and if you didn't measure it you don't know whether it's improving or not' (FA3) (East, charity).*

FA16 (East, consultancy) said that most farmers would not be able to quote a figure regarding their SOC levels;

> *'It's [carbon] is not a figure I would think most people will know anything about...I bet 99% of the farmers wouldn't quote a figure' (FA16)(East, consultancy).*

One advisor admitted that he had not done any soil C analysis for a long time;

> *'....I haven't looked at soil organic matter in...I mean I haven't done any analysis for years, decreased. If I thought there was a real problem, I might, but actually we'd rather than doing the analysis just get some sewage sludge' (FA19) (East, self-employed).*

One of the reasons given for the lack of SOC and OM testing was the cost of including it within the annual testing as stated by FA21 (SW, consultancy);

> *'The costs to analyse carbon are expensive so where it's £10.50 to measure five things, when it's carbon it's about £50. It's not cheap' (FA21) (SW, consultancy).*

The main issue however was the lack of a reliable method to test for SOC and SOM as highlighted by FA11 (East, self-employed);

> *'It would just be nice to have the simple things, like a validated excepted test for organic carbon'...tests for organic matter don't agree. There are about, well I know of three or probably four [ways] of doing organic matter and I have seen data which shows that different tests give different results and that's a problem' (FA11) (East, self-employed).*

This highlights a need not only to refine the methods used to measure SOC, but also to make the tests more accessible and more affordable so it becomes part of the standard soil analysis. A reason for this is it allows targeted use of manures;

> *'...people could then target the available manures and nutrients, additional carbon products at the fields that need it most, whereas at the moment, they tend to throw it on the field and if it happens to fit in with the rotation they just happen to put it in whatever field' (FA16)(East, consultancy).*

Having an accessible test would increase farmers' awareness of SOC and SOM and make it more visible. It would also help encourage farmers to farm their soil in a sustainable and holistic manner, taking into account a wider perspective of the soil ecosystem, especially if tests for soil micro-organisms were conducted too. In theory, having a readily available and inexpensive test for SOC and SOM is an easy way to bring them more to the forefront in soil and farm management. However, as indicated in the methodology chapter (Chapter 4) of this thesis, there is no robust or standard method of testing for SOM and SOC with different tests producing varying results. This indicates that further research is required in order to develop and produce a test that is reliable and accessible, which could become the industry standard.

Improved Understanding of the Economic Value of Soil Organic Carbon

Another area which requires more attention is the economic value of conserving OM and increasing SOC levels. In order for farmers to conserve their SOC levels, there needs to be an economic profit which needs to be made clear and backed up with solid evidence as FA20 (SW, consultancy) stated;

> *'Yes, they'll often want evidence to show that if you're going to advise them to change, it's not going to leave them out of pocket' (FA20) (SW, consultancy).*

FA15 (East, consultancy) comments on the difficulty of putting a value on increase SOM levels;

> *'I mean as a result of our long term straw experiment which is now 30 years old, increasing that has had a very small benefit on organic matter but a huge benefit in soil workability it would appear. I mean how do you put a value on that? I don't know. But certainly it would be nice to put a value on it' (FA15) (East, consultancy).*

FA15 (East, consultancy) comments that OM had shown little increase in a long term straw experiment, whereby straw was incorporated into the soil, but that workability improved. In order to quantify this benefit in terms of profit, several factors need to be considered. The most prominent will be the amount of fuel used by machinery when working the field. If workability has improved, it can be assumed that fewer passes up and down the field will have be made, and perhaps less energy used to break up the soil if ploughed. Such calculations will need to be done on a case by case basis due to variability and will also rely on accurate records of fuel use.

Review of Research and Development

Improvement in the research and development underpinning SOC and SOM advice, will lead to an improvement in the quality of that advice. Research and development can be improved by seeking to ascertain the critical or ideal levels of SOC and SOM in the soil, allowing farmers to have some figures to aim for. Additionally research should be more focused, in a similar way to that from the US and Australia. To allow the figures developed by possible R&D work to be utilised by farmers, an effective SOC test will need to be developed, that can be utilised to simply and quickly test the SOC levels accurately.

Finally, and in many ways of most importance, is the communication of advances in knowledge out of the academic arena, so that it can be accessed by farmers and FAs. This can be done through an improved relationship between academics, soil scientists and farmers, ensuring that the information transferred efficiently. What is needed to achieve these aims is a national forum where farmers, scientists and policy makers can converse and share information, similar to what Palmer *et al*. (2006) proposed. The authors suggested a soil management information gateway, as a means to facilitate a central pool of resources available to all farmers. Information and contacts for organisations with the best available soil management information could be made available to farmers through such a forum. Updates on soil management training events could also be made available to farmers, informing farmers and advisors of all upcoming training opportunities. There is, at present, farmer centred research activities, such as that being undertaken by the HGCA (Home Grown Cereals Society) and the AHDB (Agriculture and Horticulture Development Board) monitor farms (AHDB, 2015; HGCA, 2015). However, these forums were not mentioned by the interviewed farmers, who, as previously highlighted, were likely to be the more 'forward-thinking' farmers and actively engaged in current research. This suggests that such approaches have yet to be fully exploited to maximise their potential. Given the vast improvement in communication technology and the development of social media, this is a vital resource which needs to be researched and developed to maximise the full potential that the agricultural industry could redeem from it. Such a forum as suggested by Palmer *et al*. (2006) could easily be set up and could potentially reach a wide audience if promoted by farming media.

A national monitoring programme or at least regional monitoring of SOC level changes needs to occur, particularly in response to land use and management changes. This can occur on research farms, or if a suitable test is manufactured, can be done by farmers themselves. The information from which should be stored by central government, a national research consultancy or a national academic institution for monitoring purposes.

7.3 National Policy and Voluntary Programmes

7.3.1 Current Issues with National Policy and Voluntary Programmes

Programmes such as the Catchment Sensitive Farming (CSF) and Environmental Stewardship (ES) reach a wide audience and impact a high percentage of farmers in England. For example, at the beginning of 2011, there was approximately 6.3 million ha in ES agreements in England, equating to 68.8% of the utilisable land (Courtney *et al*., 2013). This was reflected in the interview population, where all but one of the farmers was involved in an agri-environmental scheme (AES) at the time of interview. Many of the FAs and farmers commented on how they felt AESs fell short of their aims, or how they could be improved to enhance their impact. Given the importance of AESs as a communication method, it is a problem that many criticised this platform. It was repeatedly highlighted that continuity in programmes is often lacking, due to frequent updates or reshuffles. As a consequence, AESs do not always offer the full extension that farmers require in order to make positive changes to their managements;

> *'...and the funding doesn't often allow, doesn't often provide for follow up. So there is a bit of lack of feedback as to how the advice is taken up' (FA1) (SW, self-employed).*

FA1 (SW, self-employed) felt that due to a lack of funding, follow up visits to farmers do not always occur. Without full extension services from the advisory system, it is hard to evaluate how successful the schemes are, as well as potentially preventing farmers from achieving the best results; as there is not enough guidance to follow up after initial contact. However, it was largely the inconsistency and, as many commented, the frequency with which the schemes are altered, as the main failing point of the AESs. FA2 (SW, charity) expressed his annoyance with the lack of consistency, stating that better use of the schemes already in place is what is required rather than new schemes;

> *'...I think it's a question of having some consistency in the way these things are promoted and delivered (schemes and extension). Because there's sometimes the urge to go 'ah no, this doesn't work, we need something new', and then you end up with something with new logos, new people and new materials, and actually it just needed making better use of what we already had' (FA2) (SW, charity).*

Farmer 30 (SW, organic beef/poultry) commented that there were too many top-down farming projects coming and going, with a lack of continuity, with changes in formats and different people involved;

> *'...it's project, project, project, so things come and go...what I see as a problem is continuity or, you know, 'it's flavour of the month', the same themes come up but it's just in different formats so you've not got, and then there's going to be different people involved in each project, you've not got any really continuity of...you know, one minute they're saying this is the main thing to do, the next minute it's something else' (F30)(SW, organic beef/poultry).*

Farmer 30 (SW, organic beef/poultry) also mentioned that farmers were being 'grant led', in that they were only doing work or taking additional responsibilities on because there is a grant available and not necessarily for the merits of the scheme;

> *'You've got farmers who are being grant led on what they want to do and projects that are switching their priorities whereas the underlying principles, in terms of something like soil management, you've got new developments and people doing research but the underlying principles are the same, so why does the project have to change every five seconds' (F30)(SW, organic beef/poultry).*

In addition to this, farmer 30 also commented that although the projects change, the underlying principles of the schemes remain the same, questioning why the projects therefore need to be altered.

At present, AESs and CSF do not directly mention SOC. However, as illustrated in tables 3.5 and 3.6 (Chapter 3), a number of the options do have an indirect impact on SOM and SOC. For example, ES encourages the use of buffer strips and arable land to be reverted to grassland, both of which have been shown to enhance SOM levels (Bhogal *et al.,* 2009). The use of winter cover crops was the only mechanism listed under ES that may enhance C storage. CSF had a number of mechanisms too, including cultivating in spring rather than autumn and reducing livestock stocking densities, both of which maintain SOM levels. CSF also encouraged the adoption of reduced tillage systems and using more manure, which according to the several authors (Haynes and Naidu, 1998; Stoate *et al*., 2001; Lal, 2004a; Bhogal *et al*., 2007; Bhogal *et al*., 2009; Palm *et al*., 2014) may enhance soil C storage. This is also partly demonstrated in the results of the investigations in the previous chapter (Chapter 6). However, due to the issues highlighted by the FAs and farmers, the schemes do not appear to be creating any changes in farming practice and are falling short of their aims due to a lack of consistency and changes.

Due to the way in which national agri-environmental policy is funded and set out, there is not a vast amount of control the UK government has upon how laws and legislation are altered or updated, as this occurs at the European level. However, the message from these FAs and farmers is clear. Instead of creating brand new schemes every time the Common Agricultural Policy (CAP) is reformed, bringing in the new objectives into existing schemes may be better and more user friendly. It would mean the names of the schemes remain the same, as well as the people or agencies who advise on them, although there would of course need to be room for new experts to be bought in if the updates to the schemes scope required. It would also mean, that any land use or management changes brought about by the schemes, would be maintained for longer and allow for more long-term management, which if SOC levels are to be increased, is required.

7.3.2 Improvements in Current National Policy and Voluntary Programmes

Many of the farmers and FAs, when asked, suggested ways in which current programmes and advice could be improved. With regards to SOC, it was commented by two of the interviewees that more direct information was needed to improve SOC levels and awareness. FA15 (East, consultancy) felt that Defra should provide more practical information;

> *'I think just a general statement by Defra that organic matter levels are too low, lets increase it, is a totally worthless statement as far as I'm concerned because they don't say how do you increase it, over what time scale, what level of increase do you need to make a difference, is it just soil organic matter or is it also associated bio fungal biomass, which I believe it is, and therefore we need positive messages other than the value of P and K' (FA15) (East, consultancy).*

As can be seen above FA15 felt that the level of information provided by Defra, needed to be more detailed, backed up with practical ways of working and with solid, hard evidence that farmers will pay attention too. Farmer 24 (East, conventional arable) echoed this sentiment, stating that in regards to educating farmers; more could be done in terms of increasing SOC levels as farmers do not actually do very much about SOM or SOC levels;

> *'Well on the basis that I would like to think that I'm reasonably well informed and I suspect you've met lots of farmers who will equally feel they're reasonably well informed, at the general level they're aware of it [SOC] but don't actually do very much about it then clearly it's an area that is ripe for a little further exploration' (F24) (East, conventional arable).*

The farmer then went on to explain what he felt was needed with regards to good SOC information emphasising that target levels were required as well as highlighting the cost and profitability that could be potentially associated with improved SOM management. Profit was a theme which reoccurred throughout the interviews and appeared to be the underlying driving force for many, if not all, farm management decisions, as farmers are businessmen;

> *'I think clearly to establish you what we're talking about, what the target levels and the effects of increasing or improving that level on profitability, ease of working, cost saving, you name it, it's all part of the sort of job of raising the profile' (F24) (East, conventional arable).*

Not only is more practical advice needed on to how to increase SOC levels, but the information needs to be framed in a way in which will grab farmers attention, informing and educating as appropriate. Using profitability would likely be a very useful tool in this goal. The Soil4Profit scheme in the SW of England had this particular focus and was relatively successful (Natural England, 2010b). The scheme provided grants for farmers wishing to undertake work or purchase equipment which would improve the quality of their soil. However, the scheme is no longer in operation, but it is hoped that further schemes similar to this are rolled out at the national level.

Certain groups of farmers felt that the information regarding SOC could be more specific to farming types and locations, rather than just general advice. Farmer 22 (East, organic arable), who farms organically, commented that there is need for more long term information regarding soil management for organic farmers. At the time of interview, most of it was engaged with conversion from conventional to organic farming, rather than long term organic farm management;

> *''Think Soils', which actually is a fantastic resource, it really is. Other than that which is a great document, there is very little advice out there...Well the difficultly is, because there's so little advice for organic farmers other than conversion advice, which obviously we're beyond that, I think that you know, the advice should be given...much more advice should be given on long term management of farms. I think it's all very, very short term...So I would say, personally, we need more long term advice, I mean five years plus, I mean that's not even long term, that's short term. I would say that it's irresponsible not be looking 10, 20 years*

> *into the future and that must mean concentrating on rotations and soils' (F22) (East, organic arable).*

As the results from Chapter 6 indicate, organic farming could play a role in increasing SOC levels in English farming, potentially leading to soil carbon (C) sequestration. It is therefore perhaps key that more information on SOC and soil more generally, is available to organic farmers for long term management. A dairy farmer in the SW also felt that the advice regarding soil was not useful for his situation;

> *'We're just grass really so we're not really trying, impacting the soil greatly. If we have to turn the soil to re-seed it, min-till isn't a very good option here...<u>We have tried haven't we? But we end up having to plough anyway [Farmer's son]</u>' (F42) (SW, conventional dairy).*

Farmer 42 (SW, conventional dairy) implied that as a dairy farmer, their farming practices did not impact the soil that greatly and rather that pollution and nitrate levels were their main concern. He also went on to say when they have to re-seed their grass; it is done using the plough, as the area and soil type is not conducive for minimum-tillage. These factors emphasised his point that advice and information needs to be more specific to location and farming practice. He went on to use the Soil Protection Review (SPR) as an example;

> *'...things have to specific to the area where they work don't they? You can't just say on a broad spectrum like down here we are very wet and very clayey and grassy. You have to be specific. But sometimes I do pick up, like the other day I picked up my Soil Review, I filled that, and a lot of that is totally irrelevant to us down here' (F42) (SW, conventional dairy).*

The main way in which SOC advice and information can be improved in regards to AESs, is to be more specific. This can be done by outlining optimum SOC levels, providing more practical information on how to improve those levels, including the practical benefits of doing so, with an emphasis on profitability, and also to ensure that the advice is not too vague, with it being tailored to suit different farming regimes and locations. Improvement in AES and other programmes could be achieved if, as outlined earlier, improvements in research and development were made which would improve the understanding of SOC in agricultural systems. Critical or ideal levels need to be agreed upon, a suitable test to measure SOC levels, as well as further information on the economic impact of increasing SOC levels.

7.4 Improved Communication

7.4.1 Communication Mechanisms

There are many different ways in which advice can be communicated; workshops, farm walks, one-to-one farm visits and written information (leaflets, publications, manuals, email etc.). The FAs, when interviewed, had various opinions and experiences as to which method was the most effective at communicating and engaging with farmers. Events such as farm workshops and farm walks, which are usually held on a farm and centred around a certain topic, such as soil erosion or tillage practices, were generally seen as effective due to the examination of managements in the field, the ability to openly discuss ideas with other farmers and the positive effects of peer pressure.

A number of FAs felt that the best way to communicate with farmers was in a practical manner. FA 18 (East, consultancy) suggested that the best way to communicate advice and research to farmers was through '*farmer field schools'* whereby a group of local farmers are taken out to a farm and practically shown new ideas and research. The reasoning for this more practical approach was that sending publications would be a waste of time, and a classroom setting would fail to engage with them;

> *'Sitting farmers in a room or sending them publications is a waste of time. They either fall asleep at the back of the room or never get time to read the publication. They enjoy going out kicking dirt, kicking tyres, that's the way they learn' (FA18) (East, consultancy).*

FA10 (SW, consultancy) and FA12 (East, government body) also mentioned practical demonstrations as the best way to engage with farmers;

> *'...actually in the field is better than just sitting in a room talking about it' (FA12) (East, government body).*

> *'...so digging soil pits, and you're actually, once you have the farmer alongside you and you dig a hole in the field, he can see the soil structure problems, then you've got them hooked' (FA10) (SW, consultancy).*

In addition to practical demonstrations and workshops, many FAs agreed that group settings were the best way in which to communicate advice. FA12 (East, government body) provided a good example of this where a workshop in the East was run and was focused on SOM;

> *'...focused entirely on soil organic matter and why it is so important in terms of erosion, run-off and water quality and also in terms of building up the carbon reserves within the soil and the impact on climate change and those sorts of things' (FA12) (East, government body).*

Initially two workshops were run, but due to oversubscription a third one was organised which meant over 50 farmers attended the workshops in total. Whether the popularity of these workshops was due to their more practical format is unclear, but it does send out a positive image of both the workshop as a viable means of communication and that such a topic is quite so popular. FA12 (East, government body) said that the farmers were more interested in SOM than other subjects that had also been offered;

> *'…it was interesting because the farmers were more interested in that [SOM] as a topic than they were in some of other stuff we offered at the same time. So we were quite pleased and surprised' (FA12) (East, government body).*

Farmers too, felt that group meetings were also a good way in which to communicate advice between themselves and FAs as F34 (SW, conventional poultry) states;

> *'Small group meetings around the kitchen table' (F34) (SW, conventional poultry).*

Other suggestions by farmers for ways in which to improve communication included more practical workshops (F37) (SW, conventional dairy), as well as meetings at appropriate times (F39) (SW, conventional dairy/sheep). Farmer 39 (SW, conventional dairy/sheep) emphasised that having a good incentive for farmers to attend such workshops and meetings was also important, as well as making sure the events were correctly timed i.e. not at busy times of the year, such as silage time. Incentives wise, free lunch was suggested, as well as for points to be awarded towards Catchment Sensitive Farming (CSF). Additionally the workshops or events need to be on engaging topics that will actually interest and add value to the farmers, as outlined by farmer 40 (SW, conventional dairy);

> *'But it needs to be interesting enough to get people to go' (F40) (SW, conventional dairy).*

In addition to having attractive workshops or events in which to provide advice or information on schemes, with good incentives to attend, the FA or the person running the event also needs to be successful at communicating their message. The advisor therefore needs to be able to tailor the advice to each individual farmer. As FA18 (East, consultancy) states, advice is not a blueprint, and it needs to be tailored depending upon the context;

> *'...working with farmers is very much a two-way process...good advice is not a blueprint, it's taking what works well on one farm and where it's appropriate transferring it to other farms in the right context...I guess it's an evolving process. It doesn't change, it evolves' (FA18) (East, consultancy).*

This suggests that advice should change naturally depending on the circumstances on the farm, the farmer and the current political agenda. It is taking what is written down in the legislation and guidance and applying it to the 'real world'. An example of how the advice has changed with regards to political circumstances is demonstrated in the quote below; where the FA is speaking about ADAS, a large consultancy that was once government run but was privatised in the mid-1990s. Farmers now have to pay for the advice and the training provided for new entrants to the company is not as in-depth as it once was, as there is now that there is a greater need to make money;

> *'In those days, in my early days, everything I did Katherine was entirely for free. I would take soil samples, I would produce reports, I would go out to farmers, we would dig holes with them, I would produce a report afterwards...Nowadays...they have to charge farmer. And because they have to charge, they have to earn money, the new entrants within these advisory groups, they haven't got the time for a lot of training. They have to begin there at the deep end and start selling...there isn't the time to train people nowadays as there was when ADAS was owned by the Ministry of agriculture...farmers didn't have to pay for it. It was therefore just that bit easier than it is nowadays' (FA14)(East, consultancy).*

Farmer 26 (East, conventional arable), after saying that there is '*a lot of confusion out there, a lot of mixed messages*' regarding soil information, felt that there could be improvements in the way advice is provided; by developing the routes of information transfer and the organisations that are providing the advice:

> *'I think it's a huge shame for the farming industry that ADAS disappeared, effectively, to all intents and purposes. We lack a...the worry is for all farmers is that people like NIAB tag, well intentioned as they are, they are always at risk of vested interest with sponsorship. Whoever is sponsoring wants a result and it's always in the back of your mind. It would be wonderful if...Defra would be the best place to get advice. To be absolutely frank with you the soil stuff we get from Defra is patronising in the extreme really' (F26) (East, conventional arable).*

FA14 (East, consultancy) and F26 (East, conventional arable) have highlighted the change in advice following the privatisation of ADAS; which, as they have indicated, has reduced the amount of free information available to farmers. The way in which improvements in the effectiveness of current and suggested new advice should be managed, according to FA9 (East, charity), is through voluntary measures rather than through legislation;

> *'...I think the advice is there it's just getting people to commit to take it up really but obviously you want to get them to do that voluntarily rather than through some regulatory means' (FA9) (East, charity).*

Communication Mechanisms Review

Based on the interview data, it can be surmised that the best way to communicate with farmers is to engage with them and understand their requirements. This can be done through adapting the forum that the advice is communicated through to more practical demonstrations and briefings in small groups. Practical demonstrations are useful because a lot of the briefing can be done out in the field, showing farmers what they would see in the soil under various circumstances. This has been shown to be more useful than simply providing information on a piece of paper (Palmer *et al*., 2006). These demonstrations can be encouraged through more funding for workshops, twinned with ensuring that the subject is tailored to meet the farmers' interest and with attendance incentives. At present just over half of farmers receive technical advice via events and demonstrations (59%) and by discussion groups, farm walks or workshops (52%) (Defra, 2013d). This data demonstrates that there is a room to increase the numbers using such mechanisms, if the attendance can be encouraged. Briefings in small groups are advantageous as the farmers can be directly engaged, with understanding being confirmed in a way that is not possible in larger briefing environments. This method however, does place an increased burden on the FA to independently organise and support the briefings.

In order to encourage farmers to attend briefing events two methods can be used to ensure the subject is engaging and useful to the farmers. Firstly, incentives can be used; such as using the events as some sort of professional development scheme, where points are accrued against AESs and schemes, the supply of a free lunch, and finally combing the briefing with a social event. Secondly many briefings and conferences can be expensive to attend, so access to free or discounted prices would encourage farmers to seek that advice. In addition easily accessible and free advice at the point of contact should also be available.

Whilst this subject has not directly dealt with SOC, the improvement in communication is critical if SOC levels are to be increased in agricultural soil. As Ingram (2008) found in her study, less than half of the interviewed advisors felt that farmers were well informed about soil management, demonstrating that there is a real need to improve the information available to farmers. If farmers are actively engaging with the advisory system, they are likely to come into contact with more information and ideas, which they will then implement. Facilitation in any scheme or programme is incredibly important, as it is more likely to have long-term effects and be successful, resulting in more informed farmers and practical implementation (Garforth *et al*., 2002). In terms of increasing SOC levels, the profile of SOC needs to improve, which can be achieved through improved communication mechanisms in combination with improvements in R&D and policy and voluntary programmes.

7.4.2 Delivery and Source of Communication

The delivery of advice is very important. FAs, as they communicate directly with the farmer, have an important job in translating policy into practical advice and information and their level of knowledge is just as important as the farmers' (Ingram and Morris, 2007) It is therefore very important that the FA is knowledgeable and helpful as well as free from bias as much as possible. If a FA who is briefing the farmer on matters of policy is not knowledgeable in that subject, nor an engaging speaker, it can have a potentially negative impact on the success of the communication. This success of communication is dependent on a number of factors. Firstly, it depends on the advisors background, whether they are from a particular scheme or company, or whether they are completely independent, as well as their own skill level in effective communication. As FA1 (SW, self-employed) commented, FAs may place a particular spin on subjects to suit the scheme or organisation they are representing;

> *'[A possible issue is]...how different advisors are putting their point of view across. It depends on what...most of the advice that farmers are taking on soil management is being taken under schemes which will often have a different slant on where they're coming from, what they're trying to achieve and also on the skill level of the actual advisors as well' (FA1) (SW, self-employed).*

Secondly, is the importance of the skills and knowledge of the FA regarding the subject topic. FA17 (SW, government body) emphasised that it is key for the advisor to fully understand the material being briefed and to come across in a confident way, to gain the farmers trust and attention. For example, when asked about how receptive farmers are to advice, FA17 (SW, government body) replied that it is key for the FA to know what they are talking about;

> *'Very receptive...one provision is that you come across as knowing what you're on about really. Farmers are very, like anyone, very quick to spot someone who doesn't really know what they're talking about. But if you come across as someone who has a bit of authority then they'll listen to you and providing you don't preach to them...' (FA17) (SW, government body).*

The importance of the educational background of the FA was raised as an issue several times. If the advisor is well-informed, then they will spread their knowledge onto their farmers. One advisor suggested that refresher courses in soil and water management would be beneficial, when combined with greater emphasis of the importance of SOM in BASIS[14] training. One FA suggested that a stronger link between FAs and soil scientists was needed, as he felt a combination of skill sets is needed to improve current advice.

---

[14] BASIS is a qualification in crop protection

In addition to this point, two FAs noted the importance of a good relationship between the farmer and the advisor. Due to the present structure of AESs and the use of private consultancies and government regulatory bodies, farmers do not always have one point of contact. This is especially the case with personal points of contact moving as people within these different organisations jobs alter, as organisations change. FA2 (SW, charity) highlighted this by saying;

> *'It's good to have some consistency as it takes a while to build up that relationship and confidence' (FA2) (SW, charity).*

The same sentiment was echoed by FA1 (SW, self-employed), who felt that farmers need a single point of contact;

> *'I just feel that the sooner the farmers have got a single point of contact again, whoever it's from, the better' (FA1) (SW, self-employed).*

Communication extends further than the relationships between the FA and the farmer, and also includes the links between the academic community and the farming community (farmers and FAs). FA6 (SW, government body) commented on the lack of soil scientists working within the advisory system as a negative. He suggests that whilst FAs are better as communicating with farmers, they struggle with the soil science, whereas the soil scientist would struggle with the communication side of things;

> *'There isn't any good soil scientists working in terms of farm advisor...You've probably got soil scientists who know all the ins and outs and you've got advisors who can speak to farmers and get the basic[s] but having the interaction of the two, I'd say probably a good soil scientist would struggle with the practices of the farming side whereas the farm advisor would struggle with the scientific stuff, like the carbon and nitrogen ration...'(FA6) (SW, government body).*

Delivery and Source of Communication Review

In conclusion, FAs are highly important in the education of and support to farmers in all aspects of farming policy and guidance, in particular in the understanding of soil and SOC. For FAs to be effective they need to be well informed, like any professional job. FAs need to be up to date with the latest scientific and technological knowledge, understanding its application to farms in their area. They must also have links with current research which can be passed onto the farmers. Additionally they must seek to maintain an unbiased approach to the advice that they give. Farmers need to believe that the advisors are credible and knowledgeable in their subject (Garforth *et al*., 2002). If the farmer perceives the advisors to be knowledgeable and there is solid communication between the two parties, then there is likely to successful knowledge implementation.

In addition to the current FA structure it has been suggested as part of this research that more soil scientists and specialist academics support FAs delivery of advice to farmers, especially in regards to SOC. This science driven involvement will lead, firstly, to the advice being better grounded, improving its application to farms, and secondly will aid in the explanation of the reasoning behind the advice to farmers, highlighting the reasons for it.

7.5 The Next Steps

Having presented and discussed the recommendations suggested by the interviewed farmers and FAs, the following section will review these suggestions, placing them into the current policy, advisory and R&D context.

7.5.1 Research and Development

First and foremost, in order to achieve the majority of the recommendation suggested, advances in R&D are required. As highlighted by a couple of the interviewees, more funding and a greater focus and understanding of SOC in agricultural systems is required. As demonstrated throughout this thesis, there are gaps concerning the knowledge and conflicting results of certain land use and management approaches on SOC levels. Comprehensive and long-term monitoring of SOC levels is required, particularly with regards to land use and management changes. If, through greater R&D an inexpensive and efficient test can be produced which can measure SOC, farmers could undertake regular SOC measurements of their fields at the same time as collecting samples for their standard soil testing. A regulation to monitor SOC levels would be required in order to enforce this. Such results could then be collected by Defra, or another agency such as the Environment Agency. This pathway is likely to take time to develop and may be expensive in terms of its development. There is also the risk that farmers will not appreciate having to take part in another form of regulation or having to undertake more paperwork, as such a system would require. Alternatively, large scale monitoring could occur via the use of collaborations between farmers and organisations such as ADAS, Rothamsted and the National Soils Research Institute (NSRI), whereby regular monitoring of SOC levels could be undertaken and stored centrally. This would require less work for farmers and would also strengthen the relationships between farmers and research institutes, something which also needs to be addressed. Whilst many research farms have conducted their own research into SOC levels in a controlled environment, due to the variable nature of soil and therefore SOC, the more data that is available (such as the Rothamsted farms and the HGCA and AHDB monitor farms), the clearer the picture is. It would also be beneficial to map

SOC changes in response to legislation changes, such as the implementation and consequential removal of set-aside, which research farms are likely not to be affected by.

In addition to this, more research is required in terms of the economic benefits of improving or maintaining SOC levels could have for English farmers. Whilst there is information and studies on the potential impact SOC could have, via C sequestration, on climate change mitigation, these are not factors that are considered by the average farmer whilst undertaking management decisions. As reflected in the interview data, farmers need to consider business profitability when undertaking management decisions. Therefore, comprehensive data is required to demonstrate any financial incentives for conducting practices that may increase C storage, such as reduced tillage systems and a greater application of OM. Such research could be undertaken within academic institutions, with sponsorship by Defra, in order to circulate any results.

7.5.2 Agri-Environmental Schemes

At present, AESs do not address SOC directly, however, as they reach a wide farming audience, they are well placed to maintain or improve SOC levels through effective mechanisms. ES promoted the use of winter cover crops, which was highlighted by Bhogal *et al.* (2009) as being a potential way to increase C storage. However, as has been demonstrated within the interview data and Chapter 2, AESs largely, do not create actual changes in farming practices or managements, instead facilitating good environmental behaviours which are likely to have been undertaken in their absence. Whilst CSF promoted the use of reduced tillage systems which has also been shown to potentially increase C storage, the project is not available nationally so its impact is restricted. What is required, is an AES which clearly promotes and facilitates managements and systems which enhance C storage (reduced tillage systems, cover crops, crop residue incorporation, increased use of manures and organic farming) and creates actual management change. What has been demonstrated through this investigation, is that farmers want greater scientific evidence for the managements promoted by AESs and the benefit they are supposed to have. If through improved R&D and communication networks (discussed further on), farmers can increase their understanding of why they are being asked to undertake certain measures, they may create more significant changes in their management approaches. To summarise, AESs need farmers to do more in terms of undertaking methods to improve SOC levels but in order to do so, they require evidence that doing so will create a positive benefit, not just for the environment, but also economically.

It is likely, that to achieve greater changes in management and farmers opinions, greater flexibility is required in AESs. As has been highlighted by a number of farmers in the SW, the AESs at the time of the interviews were generally focused on the land types in the East and not necessarily suitable for the whole country, as one size does not fit all. Such issues can be rectified in the design of the scheme, allowing for variations in requirements.

As has been highlighted earlier in these recommendations, there has in the past been bureaucracy around the development and implementation of changes to the AES framework. Governments have generally developed new schemes if a political change is brought about, such as the CAP-reforms, rather than improving those schemes that already exist. It is better to improve existing schemes as it ensures there is continuity in personnel, reducing skill loss, and allows lessons learnt to be carried forward. Again, these changes need to occur in the development of any future AESs.

7.5.3 Communications

The discussion on improved communications here is two-fold. Firstly is the communication in the wider sense, between academics, scientists, FAs and farmers, and secondly, the system by which information is passed on to the farmers.

As has already been highlighted, there is a great need to improve communication and relationships between academic institutions, research farms, agricultural organisations, FAs and farmers. At present, there is no key, identifiable way for these groups to communicate with each other. If such communication networks were in place, farmers would be aware of the R&D currently occurring in academic environments and at research farms, but also, research could be designed to suit the needs and requirements of the farmers. What is required is a forum where information can be shared. The development in communication technology and social media is open to be exploited in terms of making such a forum a reality and successful. Such a forum as suggested by Palmer *et al*. (2006) could easily be set up and could potentially reach a wide audience if promoted by farming media. Palmer *et al.* (2006) suggested that a soil management gateway was required, however the potential benefits of such a mechanism go beyond that of soil management. Such a platform could have central forums on topics, as well as regional discussion groups. Whilst there are a number of forums and platforms similar to this suggestion (for example the HGCA, NiabTag, and Twitter accounts such as @AgriChatUK), they have the potential to be further exploited. What is of the greatest importance though, is the availability and communication of current research. This is especially true in the case of SOC where uncertainties lie regarding the best approaches to take in order to increase levels.

Communication of advice and information to farmers regarding SOC can be improved in a number of ways. FAs are highly important in the education of and support to farmers in all aspects of farming policy and guidance, in particular the understanding of soil and SOC. Farmers need to believe that the advisors are credible and knowledgeable in their subject (Garforth *et al*., 2002). If the farmer perceives the advisors to be knowledgeable and there is good communication between the two parties, then there is likely to successful knowledge implementation. It was also mentioned several times during the interviews, the importance of the knowledge of the FA, and that in the opinion of a number of the interviewees, this can be improved. FAs need to be up to date with the latest scientific and technological knowledge, understanding its application to farms in their area. They must also have links with current research which can be passed onto the farmers. The knowledge of FAs with regards to SOC could be improved by the communication mechanism mentioned previously, with improved access to R&D occurring in universities and other institutions. FAs, particularly the self-employed or agronomists, are already qualified with FACTS and BASIS, both of which are required to be updated on a regular basis, therefore it is too much to ask FAs to undertake further qualifications or examinations.

As already highlighted, AESs have the potential not only to improve farmers' understanding of SOC but also to impact levels though the promotion of correct management approaches. However, this is dependent upon alterations being made to the current AES systems and on greater R&D. In terms of effectively communicating information with farmers, it was felt that practical demonstrations were the best forum to achieve this. With just over half of farmers receiving technical data via events, demonstrations, discussion groups, farm walks or workshops (Defra, 2013d) there is room to increase the number of farmers using these mechanisms. AESs are well placed to achieve this as they already reach a wide audience and have the potential to receive funding to hold such events. Such events can be conducted at various levels; national, regional and catchment, allowing for an array of topics to be covered. In terms of SOC, practical demonstrations are key, as farmers will be interested in the physical, visible impacts of have grater SOM, as well seeing demonstrations of the use of reduced tillage systems. However, whilst considering these recommendations, it is important to recognise that whilst improvements in communication may increase awareness of SOC, it does not guarantee change in farmer practice. This is due to the complicated nature of farm management decisions and farmers' beliefs and attitudes, as previously highlighted in Chapter 3. To create a change in farmer practice, a thorough understanding of how farmers make decisions is required which then needs to be intertwined within the design of agri-policy and schemes, as highlighted by Escobar and Buller (2014).

7.6 Conclusion

The interviews have demonstrated that there is a belief that R&D conducted in England is not as extensive or effective as it should be. This is especially the case for R&D associated with SOC, in particular regarding the response of SOC to changes in land use and management. The most likely reason for this impression of the UK's R&D environment is that the information is generally held within institutional silos. This information will need to be promoted if the perception of R&D is to improve.

The development of an effective and accessible test for SOC and SOM, would allow farmers to conduct testing and increase their awareness of SOC and SOM levels. Such a test would also allow for greater monitoring of SOC levels on a wider, national scale, something which is currently missing but which would prove invaluable in terms of improving the understanding of SOC.

Improvement in the R&D underpinning SOC and SOM advice would lead to an improvement in the quality of that advice, especially if reflected in national policy and voluntary programmes, including AESs. Many of the farmers and FAs interviewed stated that AES fell short of their aims or suggested improvements. It is an issue that so many of those interviewed criticised AES, as they have the potential to influence farming management and decision making, as they reach a wide audience. There are no schemes currently in place which focus on SOC and SOM improvement and maintenance, with only particular elements of ES and CSF touching on methods that would have a positive effect on SOC and SOM. With improved R&D and a re-designing of current schemes, AESs could have a greater focus on SOC and SOM, as well as requiring farmers to take greater actions in their farm management and actually create management changes.

Once policy and AESs have been developed to support an improved SOC management regime it is important that this information is effectively communicated to FAs and the links from FAs to farmers are fully developed to aid implementation. Communication between academic, agricultural organisations, FAs and farmers needs to be improved. This can be achieved through the development of an information forum and effective use of communication technology, such as the use of social media.

In terms of improving communication between FAs and farmers, practical demonstrations and workshops have been highlighted as the most appropriate form. It is envisaged that these can take place under current AESs and other programmes. It is also important that the knowledge of the FA remains up to date to maintain professional relationships with the farmers. This can be achieved by the previously suggested improved communication between academics and the wider agricultural industry.

By using the data collected throughout this thesis, it has been possible to suggest recommendations to create a conducive policy and advisory environment to improve or maintain SOC levels. Although, care must be taken when considering these recommendations regarding those limitations of the methodology approaches and data sets outlined in the forward of this chapter. It has not been possible to identify on-farm strategies for maximising SOC levels. Whilst certain approaches have highlighted their potential to increase C storage or enhance/maintain SOM levels, due to uncertainty and a lack of consensus in published literature and in the results of Chapter 6, no solid conclusion can be drawn upon. However, it is recommended that further R&D is conducted to improve the current understanding of SOC levels in relation to changes in land use and management changes. The following chapter will summarise these conclusions in relation to the previous chapters as well as suggestions for further research.

CHAPTER 8: CONCLUSIONS

The following chapter reviews and concludes the main points to have emerged from this thesis with reference to the original research questions and objectives as outlined in Chapter 1. In addition to this, a brief discussion of ways in which the work could be extended further, as well as the challenges in conducting an interdisciplinary project is presented.

The research conducted within this thesis has taken the relatively unexplored topic of soil organic carbon (SOC) in English agriculture from an interdisciplinary point of view. The use of twin methodologies has allowed for the exploration of both the social and the soil science aspects concerning SOC and its management. The social science methodology addressed the current policy framework, the advisory network and the personal views, understanding and implementation at the farm level conducted by farm advisors (FAs) and farmers. The soil science methodology addressed the lack of consensus regarding various farming practices and their impact on SOC. As a result of the twin methodologies, this research has provided rich empirical qualitative data combined with scientific analysis of SOC from paired farms with different management practices. Taking this interdisciplinary approach is a novel approach to researching SOC, and has provided a wider picture of the current situation. This work therefore has contributed new understandings to the body of knowledge on this subject, as well as a greater insight into interdisciplinary research and methodologies.

8.1 Research Question 1

> *What are the optimum management approaches for the maintenance and enhancement of SOC levels in order to uphold a balance between farmer satisfaction and minimal environmental degradation?*

To address research question one, the following objectives were adhered to:

***Objective 1a:** Conduct a thorough review of related science literature to synthesise best knowledge of the impact of different farming practices (ranging from conventional, high carbon input/organic and no-till regimes) upon SOC levels and their rate of change.*

***Objective 1b:** Construct a sample of farms from two contrasting regions of England representing a range of farming practices.*

***Objective 1c:** Measure SOC levels in soil samples for paired sites, representing different farming practices, comparing and contrasting variations between management approaches.*

In order to address research question one, a literature review of scientific research was conducted in order to synthesis the best knowledge of the impact of different farming practices upon SOC levels. Whilst it is estimated that currently 30% of anthropogenic Green House Gas (GHG) emissions that drive climate change come from agricultural practices (Smith and Gregory, 2013), it is also understood that agricultural soil offers a significant mitigation contribution with the potential to sequester 20 to 30 Peta grams (Pg) Carbon (C) over the next 50 years globally (Paustian *et al*., 2000). Increasing SOC levels has a multitude of positive benefits, including a reduction in CO_2 emissions, reducing the vulnerability of soil to climate change, as well as improving agricultural sustainability through improved soil fertility, soil structure, water holding capacity and soil biodiversity, creating a win-win-win scenario (Lal, 2004a; Lal, 2004b; Janzen, 2006; Smith *et al*., 2008; Trumbore and Czimczik; 2008; Wang *et al*., 2011).

One of the main contributors towards SOC depletion was found to be the conversion of agricultural land (Pretty, 2008). However there were a number of agricultural practices identified to have the potential to increase SOC levels. These included reduced tillage systems, crop residue management, effective use of organic matter (OM) amendments, set-aside/grassland management, optimal livestock densities, as well as measures to reduce soil erosion such as cover crops and buffer strips (Smith, 2008; Smith *et al*., 2008; Bhogal *et al.,* 2009; FAO, 2011a). On the basis of these suggested practices, and the work by Gattinger *et al*. (2012), it was decided to investigate, in further detail, the impact on SOC from reduced tillage regimes, organic farming, and OM amendments. Many of the other practices mentioned are covered in agri-environmental schemes (AESs), of which the impact on SOC was addressed elsewhere.

A sample of farms was selected based on the farming practices being undertaken and it was ensured that they covered the three practices mentioned above. In total six farms were chosen to sample, and were placed into 'pairs' creating three distinct investigations. For each pair, 'opposite' practices were chosen to measure, for example, an organic farming system and a conventional farming system. It was found that organic farming demonstrated the potential to increase SOC levels, and potentially sequester C at greater depths, below the plough layer. This was demonstrated not only when compared to conventional arable farming, but between soil under 12 years organic farming and soil under 4 years organic farming. These results are in line with what has been noted in the published literature. The Soil Association (2009) and Gattinger *et al*., (2012) both found that organically managed soils generally had higher SOC levels when compared to non-organic soils.

Analysis of SOC levels under non-inversion tillage regimes and direct drilling, however, did not indicate a clear improvement in SOC levels when compared to conventional ploughing. This too is in line with published literature on these practices. Whilst results at one farm indicated that non-inversion tillage may lead to greater SOC levels, the same was not found at its neighbouring farm, where conventionally ploughed soil was found to have higher SOC levels than the non-inversion tilled. Instead, the results demonstrated the importance of clay content in the levels of SOC. The results from soil under direct drilling indicated that whilst direct drilling may encourage greater SOC levels at the soil surface, the lower depths (below 20 cm) do not receive this benefit due to a lack of soil mixing. The addition of manure to the soil, further increases the SOC levels, but again only at the surface. The work by Ferandez *et al*. (2007) and Giobergia *et al*. (2013) which have both indicated unequal distributions of C as a result of direct drilling and stratification, also strongly promote deeper sampling depths in order to understand the effect on the whole soil profile.

As the literature review and sampling demonstrated, soil is highly variable, and what may encourage improved SOC levels in one area, may not in another. It can therefore be concluded that an optimum management approach will vary depending on the location, soil type and farming system in place. However, in general, good management which involves the use of OM amendments and practices which minimise soil erosion and disturbance should be high up the agenda of a farmer wishing to increase their SOC levels. Whilst organic farming demonstrated the potential to increase SOC levels in this study, it cannot be promoted as a method to increase agricultural SOC levels, as more research and data is required to support these results. As highlighted in Chapter 2, the reason for an apparent increase in SOC levels, is not yet fully understood.

8.2 Research Question 2:

> *What are the mechanisms of policy measures and farm management advice regarding SOC management and what is the level of adoption of the advice?*

To address research question two, the following objectives were adhered to:

Objective 2a: *Identify and evaluate current information, policy and farm management advice regarding SOC, tracing the agricultural advisory pathway.*

Objective 2b: *Assess current policy and farm management advice regarding SOC and the practical impact it has on farm management decisions by conducting interviews with farm advisors.*

***Objective 2c:** Analyse farmers receptiveness to SOC related policy and advice through conducting interviews.*

To address research question two, a critical review and synthesis of current SOC related policy at the global, European and national level was conducted. In conjunction with this, interviews with FAs and farmers were conducted to evaluate policy and advice in relation to SOC. The review examined the various national, European and global policies and schemes, summarising their key points and how SOC and soil management as a political issue have been affected. The key conclusion from this was that SOC is mentioned at the global level, particularly in publications by the Food and Agricultural Organisations of the United Nations (FAO), but that it rarely appears in European or national polices. The Soil Framework Directive (SFD) at the European level may well have drastically improved the policy underpinning the management of soil throughout the European Union (EU). However, its withdrawal demonstrates that there was, at the time, a lack of appetite for direct soil regulation.

The EU, its regulation and the Common Agricultural Policy (CAP), provide the framework within much of the national agricultural policy is formed. SOC does not feature heavily in any national polices, however measures under cross-compliance and AESs encourage good SOC management. However, a main criticism of these measures is that they do not necessarily change management practices at the farm level, but instead facilitate normal management practices that would be occurring in their absence. This means that any potential the mechanisms under AESs have in improving SOC levels may not be realised as changes in management will not occur. This was reflected in the interviewed with farmers and FAs as well as in the reviewed literature, reflecting that there is room for improvement. The Soil Protection Review (SPR), which forms part of the cross-compliance, was seen in an overwhelmingly negative light by all of the interviewed farmers. The farmers stated that it was simplistic, was common sense and did not achieve its aims due to limited scope. As the SPR is one of the few direct measures to address soil, it is a shame that it was seen as pointless by the farmers. Although it demonstrated that Defra is attempting to improve the management of the England's soil, it did not achieve the impact it was after, indicating that a greater understanding of how farmers' knowledge of their soils and how they manage them is required.

From the conducted interviews it was possible to conclude that farmers and FAs considered SOC to be important although they were more aware of the terms soil organic matter (SOM) and OM. The benefits of SOM were well known by farmers and FAs, however there was a lack of knowledge amongst farmers on the particular methods and management practices needed to improve and manage SOC levels. This lack of knowledge shows that there is room for improvement in many aspects of the advisory system. As previously mentioned, many of the measures promoted through AES's can lead to enhanced SOM and SOC levels, however, as they are not portrayed as having this impact, farmers may remain unaware of the additional benefits these measures could bring.

8.3 Research Question 3:

> *What mechanisms or factors inhibit or promote the adoption of farm level advice, relating to SOC maintenance or improvement?*

To address research question three, the following objectives were adhered to:

Objective 3a: *Drawing on outcomes from objectives 1 and 2, identify on-farm management strategies for maximising SOC levels.*

Objective 3b: *Through interviews; explore the responses of farmers and farm advisors, to the policies and management strategies identified, evaluating if current policy measures and advice pathways are effective.*

To address research question three, interviews with farmers and FAs were conducted with the purpose of exploring their responses and experiences regarding policies and advice on SOC and associated management practices. These interviews were undertaken with the informed knowledge from the previously conducted literature reviews on the social and soil science aspects of this research. Overall, all of the interviewed farmers and FAs recognised and understood the importance of SOC, although there were a number of farmers who stated that they did not know how to manage it to maximise its benefits. It was also recognised that the importance of SOC will vary depending upon location, soil type and farming practice. Organic farmers were perceived to be the most concerned with SOC, as they cannot use artificial fertilisers and so rely on alternative nutrient sources. Farmers on either very light or very heavy land were also more concerned with SOC, due to the soil structure benefits it provides.

In terms of the previously highlighted methods and approaches that may enhance SOM or SOC, a number of these were being employed by the interviewed farmers. In particular, a high number were using reduced tillage systems, the success of which was highlighted as being largely down to the weather and soil type. The uptake of this practice was primarily because of the reduction in fossil fuel use and therefore cost, although it was recognised as a method that increased SOM levels. Additionally, the use of crop residues and cover crops were regularly commented on as being used, as they were recognised for increasing SOM levels, improving soil structure, and reducing soil erosion.

The use of OM amendments demonstrated the biggest difference between the interviewed farmers, with huge contrasts between the South Western (SW) and Eastern farmers. This was caused by the differences in availability of OM, a result of the specialised farming in each region. The eastern FAs outlined the scarcity of OM in the region, mostly due to the lack of livestock farmers, with green waste and poultry manure being utilised instead. The limiting factor behind the lack of FYM use in the East is the cost of transportation due the distances between the farmers and a FYM source. The use of OM amendments has been highlighted by several authors (Smith, 2008; Smith *et al*., 2008; Bhogal *et al.,* 2009; FAO, 2011a) as way to increase SOC levels, however, the addition of OM was largely driven by the benefits it brings in terms of its nutrient value and improving soil structure.

As previously mentioned, whilst the current policy environment may encourage good soil management, which may lead to enhanced SOM or SOC, these policies do not focus directly on SOC, nor do they create changes in actual farm management practices. This issue, combined with the lack of understanding from farmers on SOC and the scarcity of OM in regions of England, can be seen as factors which inhibit the maintenance or improvement of SOC levels.

8.4 Research Question 4:

> *What current levels of SOC are found under different farming practices and systems, and what is the scope for improving these levels, when using different management and policy approaches?*

To address research question four, the following objectives were adhered to:

Objective 4a: *Analyse SOC levels in soil samples for paired sites representing different farming practices (ranging from conventional, high carbon input/organic and no-till regimes) in England.*

Objective 4b: *Draw conclusions based on the farmer and farm advisor interviews, and their responses to SOC management and current policy and advice.*

Objective 4c: *Create recommendations based on the outcomes of objective 2a and the analysis of the farmer and farm advisor interviews, to form a policy environment* *that is conducive to increasing/maintaining SOC levels through effective farm management practices.*

Addressing research question four involved the creation of recommendations on how to improve and maintain SOC based on the outcomes from soil sampling, the interview data and literature reviews. One area, in which a number of the farmers and FAs felt that there was scope for improving SOC, was to improve the research development underpinning current understanding. Whether more spending is required to improve and expand current research, or that current research is not being communicated to farmers as it remains within academic and policy maker circles, is unclear and beyond the realms of this thesis to research. However, both of these aspects have scope for improvement. A particular aspect of research and development that was flagged was the need to develop an effective and accessible test for SOC and SOM. Such a test would allow farmers to conduct testing alongside their regular and annual soil testing. This would also allow for greater monitoring of SOC levels on a wider, national scale, something which is currently missing but which would prove invaluable in terms of improving the understanding of SOC.

Advancements in the understanding of SOC would lead to an improvement in the quality of advice, as it would be reflected in national policy and voluntary programmes, including AESs. AESs have the potential to influence farming management and decision making as they reach a wide audience, so if they were to focus more on SOC, even by outlining the benefits many of the current mechanisms have on SOC, an improvement in farmers' understanding would occur. Additionally, AESs could improve SOC levels by requiring farmers to take greater actions in their farm management and actually create management changes.

There is need to improve the communication between academic, agricultural organisations, policy makers, FAs and farmers. As present there is not an effective forum for these parties to share information. An information forum could be developed with the effective use of communication technology including social media. Such a forum would improve the understanding farmers have of SOC, as well as being more aware of the research that is being undertaken. They may also have a greater appreciation of reasoning behind certain polices. Besides from an internet-based forum, local partnerships could be encouraged and networks between farms at the local scale and links with universities and research centres could be developed. The sharing of information and knowledge is vital if improvements in SOC are to be made. At the farm level, communication between FAs and farmers can be strengthened with greater use of practical demonstration and workshops, which can occur within the framework of AESs. Again, connecting with local universities and research consultancies could aid in these events as these actors would provide a greater insight into scientific understanding.

In addition to the recommendations made above, it was highlighted by a number of interviewees that the regularity with which schemes are altered, have their names and who manages them change, is a hindrance. Instead of creating new schemes every time the CAP is reformed, bringing in the new objectives, set out as part of the reforms, into existing schemes would be more efficient, effective and user friendly. This would mean that the names of the schemes remain the same, as well as the people or companies who advise on them, although there would, of course, need to be room for new experts to be bought in if the updates or reforms required additional expertise to embed into the AES. This would allow farmers to build professional relationships with those delivering the schemes, as well as limiting confusion.

8.5 Further Research

In order to extend this research, there are several options to take. Firstly, it is necessary to extend the data set. As has been highlighted, the sample size used within this research means that there has been limited scope to expand the results to a boarder, more general scale. Greater soil sampling is required, including farms in the SW, as well as repeat sampling, to see if there is a change in the observed SOC levels after a longer period time under the management practice. Greater sampling concerning tillage and direct drilling regimes is also required, due to the uncertainty in the results demonstrated in this study, as well as in published literature. It will also be critical to conduct sampling below the surface levels (>10 cm), as demonstrated by the results found in this study and highlighted by Barker *et al*. (2007). Extension of the social science data set is also required to apply the results to a wider scale and to produce more conclusive and detailed results. This can take the form in increasing the number of farmer and FAs interviewed within the two regions, or expanding the study to cover the whole of England, to fully assess the policy environment and understanding of SOC across a wider geographical area.

Secondly, the most recent CAP reform will undoubtedly have an impact on AESs and other polices. It is too early in its lifecycle to consider or assess what changes the new CAP will bring to the national level. However, as there will be even greater emphasis on the environment under the new policy, it would be beneficial to re-interview the FAs and farmers from this study, to see what impact the new CAP has had on them, once it has been installed. Also it is necessary to assess the new policy with reference to

SOC and whether or not the profile of SOC as a management issue has been increased.

Finally, this thesis has examined the communication mechanisms used within the farm advisory system, and their potential to deliver information on SOC. This study has remained within the realms of traditional methods, written reports, face-to-face contact with FAs, workshops, farm walks. However, in recent years, the use of social media has increased across many sectors including agriculture. It may therefore be beneficial to assess the appropriateness and effectiveness of the use of social media, such as Twitter, as an information tool, and its potential capacity to promote information on SOC. Unlike advice and information in the printed form, social media has the ability to inform a relatively large number of farmers quickly, across a large geographical area with up to date information. Social media may also be a good platform for farmers to interact with academics and soil scientists with regards to their research needs and outcomes, specifically SOC.

8.6 Interdisciplinary Challenges

The execution of this thesis has been challenging. Combining both soil and social sciences, has, at times, been incredibly difficult. Firstly, the author's background was in physical geography and soil science. From the outset of the thesis, I have had to learn new material regarding the social sciences. The challenge was to ensure that neither the soil nor social aspect of the thesis was of better quality than the other. This has led to more significant time being spent on the social aspects of the PhD to ensure the quality of the work was at a high level. I had to learn how to interpret social data as well as get to grips with new material. Another issue was that soil and social science work is presented in very different formats. The language is very different as is the structure of the projects. In physical sciences, it is common to conduct literature reviews before stating the aim and objectives, basing them on the findings from the reviews. However, in social sciences, the aims and objectives are stated prior to the literature reviews, as the reviews form part of the data gathering. Deciding on which presentation was most suited for this project was difficult and resulted in many discussions and structural changes of the thesis.

It was critical that the PhD was seen as one whole project, rather than two projects running side by side. The inclusion of sampling from farms where I had previously interviewed farmers, helped to ensure the combination of both parts. However, as mentioned previously, coming from a physical geography background I am well aware that if this were soil science study only, then far more sampling and analysis could have been conducted. The same could probably be said regarding the social data set. However, time constraints' would not allow for further exploration of the soil data.

The supervisory team consisted of a human geographer and a soil scientist to reflect the interdisciplinary nature of this thesis. Whilst it was of great value to have both, ensuring that both sides of the project received equal attention, sometimes their feedback clashed. It was at times challenging to decipher which was the best way forward.

Although the nature of this PhD provided many challenges and difficulties, the value of the interdisciplinary approach far outweighs these issues. By addressing SOC in agricultural soils from both a political and social perspective, combined with the scientific understanding, it has been achievable to provide information on what factors are currently inhibiting SOC levels, both from a policy perspective as well as farming practices. Issues in farming regarding practices need to be addressed from a policy and personal level, as well as the scientific. Farmers are people, and the way in which they perceive SOC, and how they manage their soil and negotiate the advisory and policy system are key in understanding SOC as an agricultural issue and how best to improve its profile in agricultural advice. If, as has been highlighted by several authors (Mettzger and Zare, 1999; Steele and Stier, 2000; Defra, 2008; Miller 2013; Fazey *et al*., 2014), the use of interdisciplinary research is to be increased and fully exploited to address and solve global and environmental issues, a greater appreciation and understanding of the nature and challenges facing such studies is required. This would help improve facilitation within academic institutions and enable greater, more valuable research to be undertaken.

APPENDICES

Appendix I: Summary of FAO Publications

Soil Carbon Sequestration for Improved Land Management (2001)

The FAO development of SOC advice started in 2001. The World Soil Resources Report entitled 'Soil Carbon Sequestration for Improved Land Management' (2001) discusses and presents the case for soil carbon sequestration, analysing the various scenarios under which C could be sequestered (FAO, 2001). The report estimates that soils have the potential to sequester around 20 Pg C in 25 years, accounting for more than 10% of anthropogenic C emissions. It also recognises the ecosystem benefits that sequestering C can bring due to the fact that it will entail greater organic matter (OM) inputs and levels. In particular, it emphasised that dryland farming communities have much to gain from the win-win benefits of carbon sequestration. The report's conclusion states that governments need to recognise these win-win benefits and to initiate pilot studies of C stocks and fluxes under different sites. It also, critically, concludes that conservation agriculture is needed for soil carbon sequestration to be successful, which will be easier to instigate in developing countries due to the severity of land degradation in these regions. The authors use Brazil and Argentina as examples, where the development of new farming practices, including no-till and direct drilling, is rapidly occurring. The report acknowledges that at the time of publishing, there were significant knowledge and data gaps associated with the quantitative analysis underpinning the projections made. It was also stated that soil carbon sequestration efforts would be more successful if the efforts were to build upon existing institutions, initiatives and organisations (FAO, 2001). The report nevertheless judged that soil carbon sequestration is a viable mechanism to improve land management due to the many ecosystem benefits that it could bring. However, it also highlights that further research was needed to fully understand soil carbon sequestration. In addition, the emphasis was on dryland environments, in particular those in less developed countries.

Assessing Carbon Stocks and Modelling Win-Win Scenarios of Carbon Sequestration through Land Use (2004)

In his report entitled '*Assessing carbon stocks and modelling win-win scenarios of Carbon sequestration through land use change*', Ponce-Hernandez, (2004) states that the synergies between the UN conventions on biodiversity and desertification and the Kyoto Protocol could be exploited in order to promote land use change and land management practices that prevent land degradation, enhance carbon sequestration and enhance or conserve biodiversity in terrestrial ecosystems. One of the main problems is the technical issue of not having a standard set of methods and procedures for the inventory and mentoring of C stocks or sequestration in current and potential land use and management practices. The report investigates win-win options to address poverty alleviation, food security and sustainable management of natural resources by enhancing land productivity through diversification of agricultural systems, soil fertility management and carbon sequestration in poor rural areas.

The report used models and software tools, including Roth C-26.3 and CENTURY (V.4.0), to create land use change scenarios for identifying the land use options and land management practices that would maximise food and biomass, soil carbon sequestration, biodiversity and minimise land degradation, simultaneously. The methodologies, models and software tools were developed and tested in pilot field studies in Cuba and Mexico. The results of the study demonstrated that soil represents a larger pool of terrestrial C than biomass, concluding that carbon sequestration in soils is of great importance in mitigating GHG concentrations. It was also found that land management practices have the strongest effect on the fate of SOM and on carbon sequestration, or on its release to the atmosphere as CO2. The publication presents the technical information needed to assess the potential for soil SOC, indicating that SOC at this point, has become a factor acknowledged by policy makers. However, the case studies still remain in parts of the world with different climates to that find in the UK.

A Review of Carbon Sequestration Projects (2004)

The 2004 report, 'A Review of Carbon Sequestration Projects' (FAO, 2004) reviews those projects where carbon sequestration has been implemented around the world. The report's main output was to provide a knowledge base for enabling policy support for ongoing and further funding for cooperation programmes aiming at enhancing carbon sequestration and reversing desertification. One of the report's objectives was to provide information, support and policy options for the use of C sinks, overall enabling articles of the Kyoto protocol and other C initiatives. The report reviewed past and ongoing projects on carbon sequestration as part of the wider knowledge base for the programme. A total of 16 projects on carbon sequestration were reviewed from the developing world; four in Latin America, six in Africa, five in Asia and one international project. Whilst encouraging that soil carbon sequestration is becoming more prominent and recognised, the focus still remained in less developed countries with warmer climates than those found in the UK and NW Europe.

The FAO Soils Bulletin

From 1965 to 2005, the FAO has published a Soils Bulletin on a regular basis. There have been 80 publications in total, covering various aspects of soil management. The focus of the bulletins was largely on soils in arid and dryland environments, as well as tropical climates in countries such as Africa and Latin America. Each bulletin covered a specific topic, ranging from conservation measures in specific areas to soil laboratory methods. OM, here known as organic materials, made a number of appearances as bulletin headlines during the publication dates. In 1975, bulletin number 27 was entitled 'Organic Materials as Fertilisers', 1977, number 35 'Organic Materials and Soil Productivity', 1982, number 45 'Organic Materials and Soil Productivity in the Near East', to the most recent in 2005, number 80 entitled 'The Importance of Soil Organic Matter: Key to Draught Resistant Soil and Sustained Food Production'. Environments found in Europe were never the focus of these publications, with developing countries as the key focus. Whilst it shows that OM has been a long considered component of the soil system, SOC is missing from these bulletin subjects.

The Importance of Soil Organic Matter: Key to Drought Resistant Soil and Sustained Food Production (2005)

The FAO Soils Bulletin 80, is entitled 'The Importance of Soil Organic Matter: Key to Drought-Resistant Soil and Sustained Food Production' (Bot and Benites, 2005). The bulletin discusses the dynamics of SOM in cropping soils, or in other words, how stocks of OM are depleted in agricultural soils and the impact that this can have. In response to this issue, a number of practices were reviewed which have potential to increase OM content and the benefits this could bring. The bulletin is far more science focused than the previous reports by the FAO that have been discussed so far. The authors discuss the sub-pools of C and the effect that they may have on soil physical stability, discussing the differences between the labile and non-labile C fractions. Subjects covered in the bulletin include the following; OM decomposition and the soil food web, natural factors influencing the amount of OM, practices that influence the amount of OM, creating drought-resistant soil, key factors in sustained food production and the role of conservation agriculture in OM deposition and carbon sequestration. The chapter entitled 'Practices that Influence the Amount of Organic Matter' was the longest and covered anthropogenic influences on SOM. It covered practices that decrease SOM, as well as the decrease on OM supply. Practices which were discussed as decreasing SOM included; the increased use of monoculture crops and pastures, burning of natural vegetation and crop residues, removal of crop residues, tillage practices, increased use of fertiliser and pesticides, overgrazing and a reduction in OM supply. The latter half of the chapter discussed practices which could increase SOM levels including the use of cover crops, protection from fire (in dry, arid areas), reforestation and afforestation, crop residue management, decreased decomposition rates, reduced or zero tillage, and an increase in OM supply (animal manure, other C rich wastes and the use of compost and mulch) (Bot and Benites, 2005).

Soil Carbon Sequestration in U.S Rangelands (2009)

In 2009, the FAO produced a report entitled 'Soil Carbon Sequestration in U.S Rangelands' as an Issue Paper for Protocol Development. This is the only FAO publication, easily found, that focuses on a developed country. It is stated that grazing lands, including managed pasturelands in the U.S have the potential to remove an additional 198 million tonnes of CO_2 from the atmosphere per year for 30 years until saturation is reached (Flynn *et al*., 2009). This would offset 3.3% of U.S CO_2 emissions from fossil fuels (Flynn *et al*., 2009). The publication outlines project actions for soil carbon sequestration including changes in land use and land management. Project actions highlighted for increased carbon sequestration included the following; conversion of abandoned and degraded croplands to grassland, avoiding conversion of rangeland to cropland or urban development, adjustments in stocking rates, integrated nutrient management, introduction or reintroduction of grasses, legumes and shrubs on degraded lands, managing invasive species, shrubs and trees, reseeding grassland species, addition of trees and shrubs for silvopastoralism, riparian zone restoration, and introduction of biochars into soils.

The State of the World's Land and Water Resources for Food and Agriculture (2011)

In 2011, the FAO published the 'The State of the World's Land and Water Resources for Food and Agriculture' (SOLAW) summary report (FAO, 2011a). The SOLAW analyses options for solving problems and improving resource management for both land and water. It is an 'advocacy' report, to be published every three to five years, and targeted at senior level decision makers in agriculture as well as in other sectors. It compliments other 'State of the World' reports which are published regularly (FAO, 2011a).

As part of the SOLAW publication, background thematic reports were conducted prior to publication which formed the basis of the information presented. The report 4B is entitled 'Soil Carbon Sequestration' (FAO, 2011b). The report describes the global C cycle and the basics of carbon sequestration, before outlining the details and practicalities of carbon sequestration and the benefits it could bring. The report finished with a section on policy implications.

Climate Smart Agriculture Sourcebook (2013)

In 2013 the FAO produced the 'Climate Smart Agriculture (CSA) Sourcebook' (FAO, 2013). The sourcebook intends to be a reference tool for planners, practitioners and policy makers working in agriculture, forestry and fisheries at national and sub national levels, dealing with the effects of climate change (FAO, 2013). The sourcebook was created due to the challenges found in implementing CSA, due to a lack of tools and experience. Implementing CSA practices is highly location specific and knowledge intensive meaning that considerable efforts are required in order to make CSA a reality.

CSA was defined and presented by the FAO at the Hague Conference on Agriculture, Food Security and Climate Change in 2010. It integrates the three dimensions of sustainable development; economic, social and environmental, by jointly addressing food security and climate challenges. The main three pillars of CSA are; sustainably increasing agricultural productivity and incomes, adapting and building resilience to climate change, and reducing and/or removing greenhouse gas emissions where possible.

CSA is required for several reasons according to the FAO. The CSA Sourcebook states that world population is due to increase by a third by 2050 (an additional two billion people), most of which will be seen in developing countries. The FAO has estimated that agriculture will need to increase output by 60% to satisfy increased population. The addition of the effects of climate change will make this challenge even greater. To meet this challenge, and achieve food security and agriculture development goals, adaptation to climate change and lower emissions intensities per output will be necessary. This change must be done without depletion of the natural resource base. By reducing greenhouse gas emissions per unit of land and/or agricultural product and increasing C sinks, these changes will contribute significantly to the mitigation of climate change.

Module 4 of the sourcebook is entitled ‘Soils and their Management for Climate Smart Agriculture’. The sustainable soil management options presented are described as win-win-win strategies that sequester soil C, reduce GHG emissions and help intensify production, all the while enhancing the natural resource base. Emphasis is placed on practices which increase SOC through OM. A brief summary of soil science and the role OM has in various aspects of the soil system is given. The module is divided into four sections with the titles;

- Principles of soil health, key functions and soil: plant-water interrelations
- Challenges of climate change to soils
- Soil principles for climate change adaptation and mitigation and enhancing resilience in different contexts
- Successful examples of soil management practices for climate-smart agriculture with a focus on resilience.

Under these titles, is the discussion of how best to manage SOM for carbon sequestration, as well as the benefits that SOM can bring to the soil system. In the conclusion of the report it is recommended that a shift away from specialised high-input systems towards more integrated production system is needed, reducing inorganic fertiliser use and therefore associated GHG emissions. Such systems would also reduce vulnerability to climate change.

Appendix II: Summary of Previous AESs

Environmentally Sensitive Area Scheme 1986 - 2003

The ESA scheme was a UK-wide AES and was the first AES within the EU (Dobbs and Pretty, 2008). The ESAs targeted areas of high landscape of ecological value and encompassed 14% of total UK agricultural land. There were 43 designated areas in the UK, 22 of which were in England. The ESA offered 10 year voluntary agreements for farmers and land managers. The scheme paid farmers to carry out environmental management that aimed to help improve bird habitats, biodiversity, landscape beauty and historic preservation. The prescriptions of the scheme were successful in halting the intensification of farming occurring at the time, but did not require, nor encourage, the farmer to revert to a less intensive level (Dobbs and Pretty, 2008). However, although the ESA and Countryside Stewardship Scheme (CSS)(introduced two years later), were successful in bringing over 500,000 ha into management agreements by 1993, extending the conservation estate in the UK (Morris and Potter, 1995), neither had specific reference to SOC.

During the 1990s, a considerable amount of research was undertaken on farmer responses to these voluntary environmental initiatives which, for the first time, paid farmers for the delivery of environmental goods. Surveys of farmers' opinions of the ESA scheme concluded that the agreements enabled them to carry out environmental practises that they would not otherwise be able to afford (Dobbs and Pretty, 2008). However, Wilson (1996) found that many of the farmers who were in the early ESA agreements did not see the scheme as being about environmental protection and landscape conservation (see also Morris and Potter, 1995) . Wilson (1996) argued that this reflected that way in which the scheme was 'sold' to the farmers, with emphasis on the financial benefits in order to get them to sign up. Today, some twenty years on, farmers are well aware of the conservation or environmental reasons behind the schemes. The ESA was largely concerned with the landscape, and conservation, rather than specific parts of the ecosystem. From a soils perspective, the halt in intensification, particularly from an arable view point, was a positive step. However, as the scheme did not necessarily encourage farmers to reverse past intensification, the environmental capital was being maintained but yet nothing was being given back to the environment. To continue in this fashion would cause issues for soils as they became less and less productive. This approach was not conducive for encouraging sustainable farming. Dobbs and Pretty described the ESA scheme as 'greening the edges' of farming which is effectively all the scheme achieved.

Countryside Stewardship Scheme 1991 - 2003

The CSS was introduced in the UK in 1991, shortly before the 1992 CAP reform when AESs became mandatory for Member States. Similar to the ESA, the CSS was a voluntary grant scheme where farmers and land managers were provided with payments for integrating conservation into everyday farming practices. The agreements lasted for 10 years, with the last being made in 2003.

The aims of the CSS were to sustain the rural landscape, preserve wildlife, conserve historic features, restore neglected land or features and create new habitats. The latter two of these aims are where the CSS and ESA differ. This perhaps presents that improvements were being made based on the issues highlighted from the ESA, where an attempt was made to give something back to the rural landscape, rather than just stopping the intensification of farming. Alongside the CAP reform, the CSS demonstrated a shift from production orientated policies to policies that support the stewardship of the land and social concerns (Dobbs and Pretty, 2008). The scheme was popular and was regularly over-subscribed (Morris, 2004). Participation in the scheme was straightforward and it did not entail the farmers doing much more than what they would otherwise have done. Morris (2004) argues that some farmers may have accepted the agreements due to the ‘before-hand conditions’, making it easier for them to comply with the scheme.

Assessments of the scheme showed that CSS appeared to have had little impact of agricultural land (Dobbs and Pretty, 2008). Funding for management practices for arable farming was limited to arable reversion, field margins and projects for selected species. There was very little focus on crop rotations and other measures for the purpose of building soil health (Dobbs and Pretty, 2008). Some farmers referred to the ‘blanket prescriptions’ of the scheme, questioning why there was set of prescriptions applied in a situation or land use context (Morris, 2004). In 2003, the final year when new enrolments to ESA and CSS were allowed, nearly 1.2 million ha, (over 10%) of England’s agricultural land was enrolled in one of the schemes (Dobbs and Pretty, 2008), doubling the area of the previous decade. Whilst this may indicate that ESA and CSS were successful, Lobley and Potter (1998) pointed out that policy makers set relativity low conditions to recruit as many farmers as possible into the schemes. Having such low requirements to qualify entry into the schemes, meant that farmers often had to do very little to participate. Therefore, although 1.2 million ha were in an AES, there is little evidence to suggest that positive environmental changes occurred as a result of the schemes. Or, as Lobley and Potter (1998) stated there is; *’little evidence of environmental additionality due to the scheme - changes that would not have taken place without the scheme*’. It may be doubted whether, given the limited impact of both CSS and ESAs in those areas for which they were specifically intended, that it has a positive impact on increasing SOC levels in agricultural soil. In terms of impact on SOC, set aside which was made compulsory in the 1992 CAP reform is likely to have a had a greater positive impact on SOC levels.

Appendix III: Response of Farm Advisors to Interview Questions.

Who/Where do you work?

FA No.	Gov Body	Large Consultancy/Company	Charity	Small Consultancy (local)	Self-employed	Other	Duration	Prev. Job	Specific Area
South West									
1					Y		20+	ADAS	Devon/Cornwall
2			Y FWAG				5		Somerset
4					Y MGA				Devon
5	Y (NE - CSF)						3	Recent Cranfield graduate	Devon (Exeter)
6	Y (NE - S4P)						2	Farmer (recent graduate?)	Devon (Exeter)
8			Y SA				1	Different role at SA	SW (Bristol
10				BIP					Devon
17	Y EA						22		Devon
20		Y ADAS					35		Somerset
21				Y Tamar Organic Group			23	Farmer	Devon
East									
3			Y FWAG						Bedfordshire (Cambridge/Hertfordshire to a lesser extent)
7					Y AICC + MGA		40+		Suffolk/Norfolk
9						LEAF			Cambs (Nationwide)
11					Y AICC			ADAS	Suffolk
12	Y (EA - CSF)						5	Recent Cranfield graduate	Suffolk (Ipswich)
13					Y AICC		30	ADAS	Suffolk
14		Y ADAS					40+		Cambs (Bedfordshire, Hertfordshire, Essex to a lesser extent)
15		Y TAG						ADAS	Cambs (Bedfordshire, Hertfordshire, Essex to a lesser extent)
16		Y TAG						ADAS	Essex (Hertfordshire to a lesser extent)
18		Y Abacus Organics					15	Engineer	Cambs (Nationwide)
19					Y - AICC		30+	ADAS	Suffolk/Essex

Do you give SOC Advice?

FA No.	*No advice given on SOC*	*Yes advice given on SOC forming part of or via the following subjects;*											
FA No.	**Reason**	**Manures/Slurry[15]**	**Soil Fertility**	**Soil Structure**	**Fertiliser Advice**	**WHC**	**Microbial Life**	**Improved Yields**	**Water Quality**	**C Storage & CC**	**Grass-land (Leys)**	**Cross-Compliance**	**General Soil Management**
South West													
1		Y		Y					Y				
2										Y	Y		Y
4		Y									Y		
5			Y	Y				Y	Y				
6		Y				Y							
8										Y			
10		Y									Y		
17	Doesn't see the need for it												
20		Y											
21			Y										
East													
3	Doesn't come up as a problem												
7		Y											Y
9			Y										Y
11		Y									Y	Y	
12				Y					Y	Y			
13													
14			Y	Y		Y		Y					
15								Y					
16		Y	Y	Y		Y							
18			Y	Y		Y	Y						
19			Y	Y	Y	Y							

[15] sourcing, storage, application & compost

Do you have a formal responsibility regarding SOC advice?

FA	No	Yes	Comments
South West			
1		Y	In relation to the Soil Protection Review
2	N		
4		Y	In relation to RB209
5	N		
6	N		
8	N		Except for cross-compliance.
10	N		
17	N		
20	N		
21	N		
East			
3	N		
7		Y	Part of cross-compliance.
9		Y	Forms part of their advice.
11	N		
12	N		
13	N		
14	N		
15	N		
16		Y	Implied responsibility - if not giving advice on OM will be a dereliction of duty.
18		Y	Part of the job to provide information on soil management (including OM)
19	N		

Has the advice provided changed at all?

FA No.	*Yes, advice regarding SOM/SOC has changed. (Reason)*	*Yes, advice has changed but not to do with SOM/SOC. (Reason)*	*No, advice has not changed. (Reason)*
South West			
1		Change in advisory and extension programmes.	
2		More interest in soil management, greater priority on grassland farms, and min-till.	
4	Manure and slurry advice has become more technical. More interest because fertiliser prices have increased.		
5		CSF has evolved - developing more into the biology/soil carbon side.	
6			Have only been working in this sector for 2 years
8			Hasn't been working in the sector for very long
10			None given
17		Become more refined - shift from water to soil	
20	Mentions the benefits of Organic Manures more	Emphasis on production to more environmental concern	
21	Actively looking at ways to enhance SOM for the past 3-4 years		
East			
3			Not in terms of soil
7		Farmers' knowledge levels are dropping as the next generation come through - basic soil management techniques have not been trained at college.	
9			Perception of the farmer/grower has changed rather than the *advice per se*
11		More environmental concern, previously greater emphasis on production.	
12			Only been working in the sector for 5 years
13	Problems with FYM have changed with closed periods for application.		None given
14	More awareness of OM, farmers taking greater account of it and seeing and understanding the benefits.		
15	Previously great emphasis on modern technology and artificial inputs, now the trend is reversing.		
16		Spray less, changing the crops they grow - less chemicals are now available.	Has been advising on Organic Manures for a long time
18	Has become more sophisticated in terms of how Organic Manures are used		
19			Pretty much the same

Has your experience with farmers altered the way in which you communicate your advice?

FA No.	Yes, my experience has altered the way in which I communicate with farmers. (Reason)	No, my experience with farmers has not altered the way in which I communicate my advice. (Reason)
South West		
1	N/A	
2	Came from a science background and had to learn the importance of social science on the job, tailoring advice to suit each farmer	
4	Learning how to communicate the right information correctly in a way the farmer will find interesting and relevant.	
5	Advice changes on event, or what key message is trying to get across, either environmental or economic.	
6		Comes from a farming background so automatically tailors the information in way farmers will listen and take note.
8	Learning to tailor the advice to each farmer.	
10		Change has occurred through changing in funding not experience with farmers.
17	Has become less theoretical and more practical.	
20		No reason given
21		Tends to give advice in workshop scenarios rather than one-to-one.
East		
3	Tailoring advice to suit each farmer	
7	Changed with experience	
9	Tailor advice depending on the competence of the farmer.	
11		Has established relationships with farmers who have worked with for a number of years.
12	Learnt that field demonstrations are better than in the classroom, and making the advice relevant to them.	
13		No reason given.
14		Not in the way it is communicated - one-to-one advice still occurs and is still the most effective.
15	Communicating advice has changed radically	
16		No, although modern technology has helped - emails etc.
18	On-going process, it's a two-way system and good advice is not a blueprint, adjusting an idea for each farm/farmer.	
19		Has established relationships with farmers who have worked with for a number of years.

How receptive are farmers to advice on SOC?

FA No.	Ver y	Very, once they understand	Increasingly receptive	Somewh at	Not very	Comments
South West						
1				Y		Depends upon the driver
2			Y			Takes a while for things to build up momentum. Benefits of certain practices spread by word of mouth.
4	Y					Interested in terms of reduced fertiliser costs.
5	Y					Depends on the groups of farmers - some more forward thinking than others.
6			Y			Beginning to see it as more important, see it as a 'free source'.
8		Y				Organic farmers are more receptive.
10	Y					
17	y					Advisors need to come across as confident with authority.
20	Y					Arable farmers without livestock
21		Y				
East						
3				Y		Varies. Most receptive when there is some financial incentive, otherwise it's down to people's personalities.
7				Y		More evidence is needed in order for the farmers to take the advice on board, currently getting high yields on low OM levels.
9	Y					The farmers in this group are all like-minded, forward thinking.
11				Y		Yes, but depends on the cost of OM, transporting it and spreading it.
12	Y					Mostly the forward thinking farmers, some are lagging behind.
13	Y					
14	Y					Mainly the younger to middle-aged farmers.
15			Y			Want to breakthrough current ceiling in yield output. Problems have arisen with erosion
16		Y				Need to speak in their terms e.g. increased yields. Won't understand SOC.
18	Y					Recognise the importance but don't necessarily know what to do with it.
19				Y		See OM as cheap fertiliser and nutrients - probably wouldn't understand it in detailed terms.

How important do you consider SOC to be?

FA No.	Very important	Depends on soil type and location	Increases yields	Not as important as other parts of the soil system	Improves crop quality	Increasingly more important	Not very
South West							
1	Y						
2	Y		Y		Y		
4			Y		Y	Y	
5				Y			
6	Y						
8	Y						
10	Y	Y					
17				Y			
20		Y					
21	Y						
East							
3	Y		Y		Y		
7				Y			
9	Y						
11							Y
12		Y					
13		Y					
14		Y	Y		Y		
15						Y	
16	Y				Y		
18	Y						
19		Y	Y				

Why do farmers take up the advice provided?

FA No.	Financial	Environmental Concern	Increased Efficiency (Crop growth ect.)	Legislation	Other
South West					
1				Y	
2	Y				
4	Y			Y	
5	Y		Y		
6	Y				
8		Y	Y		
10	Y	Y			
17	Y				
20			Y		
21			Y		Seeing the benefits.
East					
3				Y	Sense of achievement
7	Y		Y		
9	Y		Y		
11	Y				
12		Y	Y		Makes them look good (CSF)
13			Y		
14			Y		
15	Y		Y		
16	Y				Better looking crops
18	Y	Y	Y		
19	Y			Y	

What practical impact does the advice have?

FA No.	Positive and fast	Positive but slow	Hard to say/ measure	Reluctant until they've had enough evidence	Use more OM because they understand the value	A better understanding of soil management in general	Seen as extra work	Greater sourcing of OM	Greater uptake in soil loosening machines.	New practices tried	Other Comments
South West											
1			Y								Advice usually given as a one-off so doesn't go back for a repeat visit.
2			Y								Difficult to say because there's no accurate way of measuring changes in practices.
4	Y				Y						
5	Y										
6	NA	NA		NA	NA	NA	NA	NA	NA	NA	Project hasn't started fully running yet
8										Y	
10									Y		
17	Y										
20				Y	Y						
21		Y									
East											
3		Y									Peer pressure has a big influence.
7	Y					Y					
9	Y			Y							
11	Y						Y				Follow advice but it makes things more complicated if more OM is added.
12	Y						Y				Stressful - understand the importance but can't deal with it.
13						Y					
14		Y									Sourcing OM is a limiting factor.
15	Y			Y							
16	Y							Y			Pay for advice so if not used, it's a waste of money. Farmers who relied on ADAS' free advice won't or can't pay for advice.
18	Y				Y						
19	Y			Y	Y		Y				

What blockages are there?

FA No.	Farmers not part of the advice circle	Succession of the farm business	Lack of OM available	Lack of farmer knowledge/ awareness	Lack of Time	Economics	Practicality	More R&D & evidence	None
South West									
1	Y								
2		Y							
4				Y					
5				Y					
6					Y	Y			
8				Y		Y			
10				Y		Y			
17					Y				
20							Y	Y	
21				Y					
East									
3			Y		Y				
7					Y	Y			
9							Y		
11			Y			Y	Y		
12							Y		
13									Y
14			Y			Y	Y		
15						Y	Y		
16							Y		
18						Y	Y		
19				Y					Y

Does SOC advice conflict with any other advice or legislation?

FA No.	No	Fertiliser Use	NVZ	Pollution	AES's	Practices	Market
South West							
1			Y				
2	N						
4	N						
5							Y
6						Y	
8	N						
10	N						
17	N						
20			Y				
21		Y					
East							
3					Y		
7		Y					
9							Y
11	N						
12			Y				
13						Y	
14		Y					
15		Y					
16						Y	
18			Y		Y		
19				Y			

Are farmers aware of their role in mitigating against climate change?

FA No.	No	Yes	Forward-thinking farmers only	Sceptical	Fossil fuel reduction	Environmental	Financial	Alternative Energy	Environmental	C seq	Actively sequestering C
South West											
1	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA
2	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA
4	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA
5	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA
6			Y		Y	Y					
8			Y	Y	Y		Y				
10		Y			Y		Y				
17				Y			Y	Y			
20			Y		Y		Y				
21		Y								Y	Y
East											
3	NA	NA	NA		NA	NA	NA	NA	NA	NA	NA
7	N						Y	Y			
9			Y								
11			Y	Y	Y		Y				
12			Y	Y	Y					Y	Y
13	N				Y		Y				
14			Y		Y		Y				
15	N				Y		Y				
16	N										
18		Y			Y			Y			
19				Y			Y	Y			

Do you think advice regarding SOC needs to be improved?

FA No.	Standardise advice	Greater Consistency	More R&D	More testing of SOC	Better communication between FA & soil scientists	More emphasis on economic benefits	More advice in general	Bring it into voluntary schemes	Make it an integrated issue	More practical demon-stration	Find critical levels	Better educate the FA	Less emphasis is needed
South West													
1	Y												
2		Y	Y										
4	Y		Y										
5	Y	Y											
6		Y			Y								
8	Y	Y					Y	Y					
10								Y		Y			
17			Y										Y
20			Y			Y							
21			Y	Y									
East													
3			Y	Y									
7			Y			Y							
9								Y	Y				
11			Y	Y									
12			Y				Y						
13			Y					Y					
14	Y						Y				Y	Y	
15			Y			Y				Y			
16		Y	Y	Y									
18			Y							Y		Y	
19		Y	Y								Y		

Appendix IV: Farm Advisor Interview Schedule

1. *What is your role/job? (title, who they work for, and briefly what it involves)*

2. *What advice, if any, do you provide on SOC?*

   - *What are your dealings with SOC as an issue?*
   - *Is there general advice on SOC? If so, what? Who/where does it apply to?*
   - *Are there specific areas of advice linked to specific programmes (e.g. stewardship)?*

3. *Has the advice you provide changed?*

4. *Has your experience with farmers altered the way in which you communicate advice?*

5. *Do you provide advice only to farmers and land managers? Or are there other parties you also advise?*

6. *What is your formal responsibility regarding advice on SOC?*
   - *What statutory advice do you have to provide on SOC, if any?*
7. *How receptive are farmers to advice on SOC and related issues?*
   - *Is there resistance, perceived as not a priority, or as something they already do?*

8. *What are the reasons farmers take up the advice provided?*
   - *Money? Fines? Environmental concern?*

9. *What practical impact does the advice have on farm management practice?*
   - *Do farmers readily change their practices and/or views after receiving advice or information?*

10. *What blockages stop farmers doing more to protect soil?*
    - *Lack of awareness, profit?*

11. *Does SOC advice conflict with any other advice?*
    - *Or schemes, practices and environments?*

12. *Are farmers aware of their potential role in mitigating climate change? Including both fossil fuel reduction and carbon sequestration?*
13. *How important do you perceive SOC to be?*

    - *Is its management an issue? Production benefits? Climate change and carbon sequestration*
    - *Is there an issue of production vs. protection? Biodiversity vs. SOC?*
    - *Issue of visibility (can't see SOC but can see birds)?*
    - *Issue of timescale (SOC takes decades; biodiversity much shorter therefore has greater rewards?)?*

14. *Is there room for improvement regarding SOC advice?*
    - *Are there gaps in available information? Is more research needed?*
    - *Are there issues that aren't covered that should be? Or issues that are covered but do not need to be?*

15. *Is there anything else you would like to add regarding the discussed topic?*

Appendix V: Farmer Responses to Interview Questions

Size and Type of Farm

Farmer No.	Conventional	Organic	Size	Arable	Vegetables& other	Grassland/pasture	Fodder	Livestock
South West								
30		Y	90 acres			44 acres	5-7 acres oats & wheat. Has to buy in any way as area is too small to produce enough bedding.	Suckler herd of Red Ruby cattle, 600 laying hens, 450 game geese for Christmas, mountain sheep for grazing.
34	Y		500 acres	Maize	Rotational potatoes	Grassland		Chickens
35	Y		350 acres	220 acres winter wheat, spring barley and winter oats		50 acres		Beef
36	Y	Used to be organic but stopped 1 year ago	1000ha	900 acres wheat, OSR, maize	100ha of potatoes on 5/6 year rotation,			150 dairy herd
37	Y		2000acres over 5 farms	250 acres wheat, plus grass, silage and maize				1000 dairy + 650 young stock
38	Y		2800 acres	wheat, winter wheat, winter barley, winter oats, OSR			Maize	750 sheep and single suckle herd
39	Y		105 ha			50 acres grassland	25 acres maize, 25 acres under sown whole crop - spring barley.	200 dairy cows, 180 followers. 200 sheep over winter.
40	Y		900 acres	100 acres of maize				450 milking cows and 300 hedder followers
41	Y		294 acres			250 acres grassland	Silage for fodder.	120 dairy cows, 90 followers
42	Y		570 acres	490 acres of grass. 80 acres of wheat, rotated with rye grass.				220 dairy cows
East								
22		Y 10/11 years	1700 acres	1500 acres: 18 months clover - winter wheat - winter barley - winter bean - either wheat or barley undersown with clover - clover for 12 months				
23	Y		360 ha	3 year rotation: wheat - wheat - OSR . Barley on 20 ha on lightland				
24	Y		2000 acres	Winter wheat, OSR, Sugar beet	Dried peas, potatoes, carrots			

25		Y 12 years	167 ha	6 year rotation: 2 years of grass & clover - wheat - beans or borage, wheat - spring barely undersown with grass & clover.				4 years of cattle with some sheep s in late 90's
26	Y		540 ha split between 3 farms; 300ha, 200ha and 40ha	Sugar beet, winter wheat, spring barley, occasionally winter barley				
27	Y		150 acres			39 acres grassland, 100 acres grazing	10 acres Maize	Cattle: beef
28	Y		370ha	185 acres: Wheat. 185 acres split: Borage (Spring) - OSR (Autumn)				
29	Y		400ha	4 year rotation: OSR - wheat - oats - wheat				
31	Y		1600ha	800ha - Wheat. OSR	Peas, Pharmaceutical crops: borage, camellia, eccium & seed crops for farmers to use in HLS.			
32	Y		710 acres	355 acres: winter wheat, 177 acres: OSR, 177 acres: winter barley				
33	Y		400 acres	wheat - winter beans, peas and linseed.				

Soil Type

Farmer No.	Main	Secondary	Tertiary	What difference does it make
South West				
30	Culm measures			
34	Sandy clay loam			
35	Clay	Sandy, silty loam		Different cultivation techniques and timings of crops you can grow. Some fields aren't suitable for arable.
36	Medium loam with some silt	Heavy clay on floodplain	Silty sand on top of farm	
37	Loam over sandstone	Cotswold Brash	Denchworth (heavy)	Location of grassland and crops
38	Medium sandy loam			
39	Heavy clay			
40	Sandy loam	Heavy over shillet		
41	Culm measures			
42	Culm measures			
East				
22	Hanslope clay	Melford clay		Crop die off in melford areas in a dry year
23	Hanslope clay	Light sandy gravel soils		Sandy soils suffer if there's a moisture deficit.
24	Shallow soils over chalk	Fine sandy loam to clay loam with a clay cap in the middle		
25	Medium loam			
26	Hanslope Clay	Some patches of light land		Causes differences in yield & moisture
27	Heavy clay	Some sandy soil		
28	Sandy loam	Medium clay		Black grass pressure changes depending on soil.
29	Heavy boulder clay (Hanslope?)	Pockets of gravel		
31	Silty clay	Sandy clay loam with a chalky boulder clay subsoil		Effects inputs and outputs.
32	Hanslope Clay	Melford series		
33	London clay			

Cultivations/special measures to help soil

Farmer No.	Conventional	Min/zero tillage	Compaction	Erosion	Cultivations	Cropping
South West						
30	N					
34		Min-till - 6 years				Changed cropping
35		Started min till but difficult as gives neighbour straw which he then puts back - not sure what is worth more				
36		Min-till	Fatter tyres			Stopped sugar beet - 12 years
37	Y	Have min-till cultivator but didn't use it this year because of the weather so used plough instead. Only been using it a year so no noticeable difference yet.				
38		Mainly min-till, still plough when weather doesn't allow for min-till, for 5 years				
39	Y		Don't flat lift			
40	N					
41			Avoid poaching and keeping stock off when wet. Concerned about pans.	Uses a slitter to provide some air - goes down 7 inches.		
42	Y		Try not to make a mess when ground is wet.			
East						
22		Min till as much as possible	Low ground pressure tyres, large tractors are on tracks, combiners are on tracks		Drill seeds	
23		Non-inversion tillage (4-5 years)	Avoid compaction at all costs. Heavy set of discs for sub-soiler			
24	Y	Min till in some fields	Low ground pressure tyres. Sub soiler use tramlines		ploughing 1 in 3	
25		Trying to do min till				
26		Min till for 15 years. Only plough after sugar beet and before	Mole drain, flat lift or subsoil to a depth of 12 inches especially after sugar beet			
27			Sub soil			
28		Trying to do zero tillage	Direct drilling			
29			Direct drilling - 10 years			
31		Non inversion tillage. 10 to 5 years				
32	Most is conventional		Low ground pressure tyres		Two thirds of OSR is direct drilled	Stopped sugar beet (running around too late in the season)
33			Direct drilling			

How high do you rate your soil?

Farmer No.	Very important	Important	Important but not over-arching	Becoming more important	Comments
South West					
30	Y				Fundamental to the system
34		Y			
35	Y				Soil is everything
36		Y			Can't do much without it.
37				Y	
38	Y				It's key
39	Y		Y	Y	Spend more time looking after dairy cows than about a corner of field but are more conscious of it compared to previous years.
40		Y			
41		Y			
42		Y			
East					
22	Y				Rate it above everything else
23		Y			
24	Y				An integral part of the system
25				Y	
26	Y				
27	Y	Y			
28	Y				
29	Y				Main asset - if you don't look after it, then you haven't got a business
31	Y				If we mess up the soil, then we've messed the business up.
32	Y				
33	Y				

Do you think the OM content of your soil is important?

Farmer No.	Y/N	Why N?	Improves structure, workability	Improves moisture retention	Improves nutrients	Improves soil life	Improves yield	Is it an issue?
South West								
30	Y							N - grassland only
34	Y		Y	Y			Y	
35	Y		Y					
36	Y		Y		Y			
37	Y				Y	Y		
38	Y			Y				
39	Y		Y			Y		Not something they need to worry about because of the slurry
40	Y			Y				
41	Y				Y	Y		
42	Y							Got a lot of OM so don't need to worry so much
East								
22	Y		Y					
23	Y							Would like to improve it further but need someone nearby with livestock
24	Y		Y					Don't do much about it
25	Y							
26	Y		Y			Y		
27	Y							
28	Y							
29	Y							
31	Y		Y	Y				
32	Y			Y				
33	Y							

Do you have your soils tested?

Farmer No.	Y/N	How often?	What?	Who by?	Why?	Is it worth it?
South West						
30	Y	Sporadically	P, K, Mg, pH		Only had it done because it was free of charge.	Always useful but the cost adds up
34	Y	1 in 3	P, K, Mg, pH		Too see what needs to be applied	Saves money on fertilisers
35	Y	1 in 3 (3rd of farm every year)	P, K, Mg, pH	SOYL	Financial saving	Value for money
36	Y	1 in 3 (3rd of farm every year)	P, K, Mg, pH	SOYL	Test to see if there are any deficiencies.	Expensive to get equipment, but now using less fertiliser
37	Y	1 in 1	P, K, Mg, pH		Would be difficult to manage without that information	Value for money
38	Y	1 in 1	P, K, Mg, pH		Stops blanket applying.	Saved a fortune in fertiliser.
39	Y	1 in 3	P, K, Mg, pH		Doesn't value it that high as doesn't do it that often.	Not a quick job to take the samples. Useful but usually tells him what he already knows.
40	Y	1 in 3	P, K, Mg, pH		Check status of phosphate, potash and lime	Valuable exercise, and is worth the money.
41	Y	1 in 3	N, P, K, Mg, pH	Biogas test soil.	Base future fertiliser purchases on results rather than just guessing.	Y
42	Y	1 in 3	N, P, K, Mg, pH	Biogas test soil.	Can see what needs doing.	Y
East						
22	Y	1 in 3	P, K, Mg, pH		Test because there's a requirement but would do it anyway.	Having the basics tested is not costly
23	Y	1 in 1 (1/5 at a time)	P, K, Mg, pH	NRM Labs	It's a requirement but also did before it was	Not too costly
24	Y	1 in 1 (1/5 at a time)	P, K, Mg, pH	SOYL	Need to monitor soil nutrition to get most out of it.	Y
25	Y	1 in 3	P, K, Mg, pH, N and micro nutrients		Only recently started testing	Info only really useful if explained. Value for money.
26	Y	1 in 3 (3rd of farm every year)	P, K, Mg, pH	SOYL	Essential to test as either chucking money away or starving your fields	Y
27	Y	1 in 3	P, K, Mg, pH		Save fertiliser.	Not cost effective as farm is very small
28	Y	1 in 3	Albrecht test	Albrecht test	Improve the soil, save fertiliser.	Thinks it's value for money but hasn't been doing it long yet
29	Y	1 in 3 (3rd of farm every year)	P, K, Mg, pH	SOYL	Potential financial savings.	Not sure if it's value for money yet. Yields seem to have responded well to variable rate applications.
31	Y	1 in 3 (3rd of farm every year)	P, K, Mg, pH	SOYL	Potential financial savings.	Not sure if it's value for money yet. It's costly but can save money in the long run regarding inputs and outputs.
32	Y	1 In 4	P, K, Mg, pH	LandCrop	Test to know what nutrients are needed to save money - max yields with min input, and to prevent leaching	Good value for money
33	Y	1 in 3 but has some done in Spring and others done in Autumn	Albrecht test	Albrecht test	Thinks just having N, P and K is useless.	Value for money

Do you add organic matter?

	Y/N	*What organic material is applied?*			*Why is it applied?*				
Farmer No.		***Animal muck etc***	***Crop residue***	***Other***	***To get rid of it***	***Fertiliser & Nutrients***	***Structure & Moisture (Workability)***	***Improved yield***	***No visible effect***
South West									
30	Y	Muck produced from the cows.			Y	Y		Y	
34	Y	Poultry litter				Y	Y	Y	
35	Y	FYM		Neighbour takes straw at harvest, beds animals on it over winter, then gives it back and it is applied.		Y			
36	Y	Slurry from dairy - split into solid and liquid, occasionally chicken manure.	Y but not if selling is worth more.			Y	Y	Y	
37	Y	Slurry from dairy			Y	Y	Y		
38	Y	Some FYM		Green waste compost - 5000 tonnes a year.		Y	Y	Y	
39	Y	Cow slurry	Y		Y	Y			
40	Y	Cow slurry			Y	Y	Y		
41	Y	Cow slurry			Y	Y			
42	Y	Cow slurry		Digestate from Biogas. Sand bedding.	Y	Y		Y	
East									
22	Y	Import poultry manure - 8 - 12 tonnes a ha (approx 20 miles away)	Y	Import Limex as soil conditioner (approx 8 miles away). Import green waste - 30 tonnes a ha rotationally on all fields (approx 8 miles away)		Y	Y	Y	
23				Sewage sludge			Y	Y	
24	Y	FYM on small area of organic only	Y			Y			
25	Y	Cattle & poultry muck		Green waste		Y	Y		
26	Y		Y	Bio solids provided by Thames Water		Y	Y		
27	Y	Cow slurry					Y	Y	
28	Y		Y	Makes own compost from local FYM. Composts it to increase biological activity					Y
29	Y		Y				Y		
31	Y		Y				Y		
32	Y	chicken manure to 30 acres of land	Y			Y	Y		
33	Y		Y	Makes compost out of horse manure.			Y	Y	

Would you consider taking further steps to increase your SOM?

Farmer No.	Y/N	What?	Why?
South West			
30	Y	Only if he was told they were low and only through management. Wouldn't buy anything in.	
34	Y		Can never stop learning.
35	Y		For profit
36	Y	Wouldn't do organic	Likes to farm responsibly - concerned about the broader environment but isn't too concerned with what he kills within fields
37	N		
38	Y	Would consider zero-till, will stop selling straw if incorporating it adds up as financially better option	
39	N		Does quite a lot already with slurry management. Min-till isn't practical for soil and weather.
40	N		Would need to change cropping and weather is too unreliable for min till
41	N		Doesn't know what else to do as a grassland farmer.
42	N		Doesn't know what else to do as a grassland farmer.
East			
22	Y	Anything within financial reason	
23	Y	Looked at taking compost in but depends on cost.	
24	Y		Y but with an aim based upon evidence of yield or cost saving.
25	Y		Only if it was helpful and not costly. Drivers: environment, planet, extra yields, easier management, less weeds and soil easier to work.
26	Y		Soil health would be the driver to take further steps
27	N		Would never do min tillage. Wouldn't add sewage sludge or council waste because you don't know what's in it
28	Y	Wants to do zero tillage. Interested in Controlled Traffic Farming.	
29	Y		If it was cost-effective and conductive to better cropping
31	Y		Needs to be practical. Distance from OM is a problem
32	Y		Not sure about min-tilling though. Not sure about the effect on soil structure. Also, it is relying on good weather.
33	N		Feels he is doing as much as he can at the moment

What soil conservation practices do you use?

Farmer No.	None	Conventional Plough	Min/Zero Tillage	Compaction Elevation	Cultivations	Cropping
South West						
30	Y					
34			Y (6 years)			Y - Changed cropping
35			Y - Started min till but difficult as gives neighbour straw which he then puts back - not sure what is worth more			
36			Y	Y - Fatter tyres		Y - Stopped sugar beet - 12 years
37		Y	Have min-till cultivator but didn't use it this year because of the weather so used plough instead. Have only had it a year.			
38			Y - Mainly min-till, still plough when weather isn't conducive (5 years)			
39		Y			Y – Doesn't flat lift.	
40	Y					
41				Y - Avoid poaching and keeping stock off when wet. Concerned about pans.	Y - Uses a slitter to provide some air - goes down 7 inches.	
42		Y		Y - Try not to make a mess when ground is wet.		
East						
22			Y - as much as possible	Y -Low ground pressure tyres, large tractors and combines are on tracks.	Y - Drills seeds	
23			Y - Non-inversion tillage (4-5 years)	Y - Avoid compaction at all costs.	Y - Heavy set of discs for sub-soiler	
24		Y		Y - Low ground pressure tyres. Sub soils and uses tramlines		
25			Y - Trying to do min till			
26			Y - Min till for 15 years. Only plough before & after sugar beet.		Y - Mole drain, flat lift or subsoil to a depth of 12 inches especially after sugar beet	
27					Y - Sub soil	
28			Y - Trying to do zero tillage		Y - Direct drilling	
29					Y - Direct drilling - 10 years	
31			Y - Non inversion tillage (10 to 5 years)			
32		Y		Y - Low ground pressure tyres	Y - Two thirds of OSR is direct drilled	Y - Stopped sugar beet (running around too late in the season)
33					Y - Direct drilling	

Are you within a CSF area?

Farmer No.	Y/N	How much of an impact?	Benefits?
South West			
30	Doesn't know		
34	Y	Had talks about soil erosion, changing of min-till, salt preparation and cropping.	
35	Y	Have had people round to give advice on soil husbandry. Manure management plan	Have got money to do various things
36	Y	Not really	
37	N		
38	N		
39	Y	Not really but has to remember where buffer strips are.	
40	Y	Not really	
41	Y	Not really - fits in well.	
42	Y	Not really	Has a grant for concreting and tracks.
East			
22	Y	No	
23	Y	New area so have had very little contact	
24	Y	New area so have had very little contact	
25	Y	Not heard anything	
26	N		
27	Y	None	
28	Y	None	
29	N		
31	Y	No difference because already within an NVZ which has had an impact on when fertilisers can be applied	
32	Doesn't know		
33	N		

Are you a part of any AES's? What effect do they have?

Farmer No.	AES	How much of an impact?
South West		
30	OELS	Not really
34	ELS and HLS	Not really
35	HLS	Fertiliser restrictions, grassed out some of the floodplain, but generally good practice and management.
36	ELS, HLS	Not really
37	ELS	Not really
38	ELS	New to the scheme but won't have a big impact
39	ELS and HLS	Not really
40	ELS	Not really
41	ELS	Not really
42	ELS	Not really
East		
22	OELS	Gone for field edge options so doesn't affect what he does - put less productive land into permanent field edge options and that's it.
23	Countryside Stewardship	Grass margins, no fertiliser and herbicide spray margin, wild bird mix in certain areas but done it for 12 years now so make very little difference.
24	Countryside stewardship	Not really - have been doing it a long time
25	HLS and OELS	Form filling and remembering to do stuff at the right time
26	HLS	Changed cropping as now have wild bird seed mixed in
27	None	Not worth it for the size of farm
28	HLS	Got grass margins that they wouldn't otherwise have
29	ELS	Not really
31	HLS and ELS	Areas of bird covers and grass strips around ditches which would never have had before and reduces output area.
32	ELS	Has had to take land out of production near water ways - thinks he would be better off keeping the land in production rather than in ELS, but doesn't want to risk getting fined for putting fertilisers etc into the water.
33	ELS	Not really

Are you within an NVZ?

Farmer No.	Y/N	How much of an impact?	Comments
South West			
30	N		
34	Y	More paperwork rather than anything practical.	
35	Y	Not highly stocked enough for it be an issue	
36	Y/N	Has 15 acres within it so not much of an effect.	
37	N		
38	Y	Moderate	Some issues with regards to timings - closed season might be too long because crops grow early in Spring in SW.
39	N		
40	Y	Moderate	Limits N inputs, limits stocking levels, lots of paper work. Spent a lot on slurry storage.
41	N		
42	N		
East			
22	Y	Complies with rates of compost and organic manures but feels they are sensible.	
23	Y	None	
24	Y	None	
25	Y	None but need to remember to fill in forms	Storing manure on a temporary clamp - only allowed for a year which is a bit of a pain.
26	Y	Very little	Cap on bio solids but that decision is down to water companies and not farmer
27	Y	A nuisance	
28	Y		
29	Y	Very little	Have to consider fertiliser application more so as not to break the rules.
31	Y	Moderate.	Has had an impact on when fertilisers can be applied.
32	Y	Moderate	Limits amount of N, changes the amount of chicken manure and fertiliser that can be put on.
33	N		

What advice do you receive?

Farmer No.	Agronomist	Other	Comments
South West			
30	N		No agronomist - not value for money considering the small area of arable.
34	Y	LEAF	
35	Y	LEAF	
36	Y	NiabTag, FWAG	Is FACTS qualified
37	Y	Soils for Profits	
38	Y	Son is BASIS trained and will be taking over	
39	Y	Natural England - CSF	Once you've worked out crop requirements for one year - it doesn't change much for the next
40	Y	Consultant for slurry	
41	N	CSF, DairyCo discussion group	Doesn't need an agronomist because doesn't grow crops.
42	Y	CSF and DairyCo	
East			
22	N	Independent organic advisor when first started	No agronomist as farmer is BASIS registered (or was)
23	Y		
24	Y		
25	N	Soil Association	
26	Y	Niab Tag,	
27	N	EA mostly	
28	Y	EA soils info	'Think soils' is a bit too basic
29	Y		
31	Y		
32	Y	Member of NiabTag	
33	Y	Albrecht testing	

Do you attend things such as workshops and farm walks?

Farmer No.	Y/N	Are they good?	Comments
South West			
30	Y	Very interesting.	Usually something for everyone
34	Y	Very useful - has taken away info and changed practices.	
35	Y	Useful	
36	Y	Useful	
37	Y	Useful	Focused on compaction, run off
38	Y	Useful but don't go to that many	
39	Y	Good environment to share ideas	CSF - point scoring issue - if you go along to these things, more likely to get help with it.
40	Y	Useful	Depends upon the person who does them
41	Y	0	
42	Y	Good and useful but doesn't feel that they're directed at them (more at problem farms).	
East			
22	Y	Good to talk to others	Topics include; soils, farm biodiversity, diversity of crops.
23	Y		
24	Y	Useful	Cover soil but not necessarily carbon
25	Y	Mostly beneficial	Topics include soil NVz, Agri-schemes and min till. Has given up the day so will pay full attention rather than just skim an email
26	Y	Useful	
27	Y		Finds it hard to attend them with calving and lambing
28	Y	Useful	Not always that interesting
29	N	Find them boring	
31	Y		
32	Y	Useful	Good to hear other's views and opinions
33	Y	Brilliant - good to share ideas	

Are you in any contractual agreements?

Farmer No.	Y/N	Who?	What does it entail?	Comments
South West				
30	Y	Red tractor through Soil Association Farm Assured scheme		
34	Y	Tesco's Nature's Choice & LEAF	Good practice and LEAF Audit (environmental)	
35	N	National Trust have a say though		
36	Y	Tesco's Natures Choice	Conducting an audit.	Assurance has made industry better, but thinks they go a little too far. Why another audit? Doesn't achieve anything, just a hoop to jump through.
37	Y	Freedom Foods - animal welfare standards	Maintaining animal welfare standards.	
38	N			
39	Y	Milk Link via Sainsbury's	Carbon footprints	Not really that valuable. More for Sainsbury's use than farmers'.
40	N			
41	Y	DairyCrest	Doesn't' stipulate anything environmental	
42	Y	Milk Link via Sainsbury's	Carbon footprints	Doesn't include sequestration of grassland
East				
22	Y	Supply feed for organic pigs through Waitrose and Duchy	Have to do stuff for organic certification not necessarily directly for suppliers	
23	N			
24	Y	Camb grain via Sainsbury's	Good practice and are involved in sewage sludge and animal manure application. And restricting the use of pesticides.	
25	N			
26	Y	Camb grain via Sainsbury's	No influence at all	
27	N			
28	N			
29	Y	Camb grain via Sainsbury's	Need good farming practice and work within the rules	
31	Y	Pharmaceutical company	Can't use certain chemicals because of pharmaceuticals, nothing to do with environment or soil.	
32	Y	Camb grain via Sainsbury's	No influence at all	
33	N			

What do you think of the Soil Protection Review?

Farmer No.	Positive	Negative	Improvements?
South west			
30		Very basic	
34		Doesn't do much for them	
35	Find it useful		
36			
37		Waste of time	Has right intention but doesn't go far enough. Needs to address run off and appropriate cropping.
38		Load of rubbish/an insult to farmers	Nothing in its current form could be done to make it a useful tool.
39		Waste of time but can see why it's there.	Not necessary to write down every rut in field. A fine system would work better but wouldn't really want it.
40	Easy to fill out	Form filling exercise only	Not detailed enough to make a difference. Timing of the form is wrong - should be reviewed in Spring - farming doesn't work on a Jan-December calendar year.
41		Waste of time.	Should be written by a farmer.
42		Load of nonsense	
East			
22			
23			
24			
25		Meaningless rubbish	
26			
27			
28			
29		A load of rubbish, insulting	
31			
32			
33		Too simplistic - soil management is far more complicated that what can be put on a piece of paper	

Are there any current themes or priorities?

Farmer No.	Y/N	What?
South West		
30	Y	Switch to resource management and improved efficiency
34	N	
35	N	
36	N	
37	Y	How to make things (slurry) go further.
38	N	
39	Y	Soil compaction, run off, diffuse pollution
40	Y	CSF is being pushed a lot. Slurry management in particular (along with grants etc)
41	N	
42	N	
East		
22	N	
23	N	
24	N	
25	N	
26	Y	OM and not selling straw. Atmospheric sulphur.
27	N	
28	Y	Run off and erosion, nutrients and phosphates in water courses
29	N	
31	Y	Leaching of pesticides and fertilisers
32	N	
33	Y	Soil etc is creeping into main farming media more in past 6 months.

Do you think there needs to be improvements in the advice?

Farmer No.	Y/N	Why yes?	Why no?	What improvements?
South West				
30	Y	Too many projects. Things come and go. Farmers being grant led		More consistency.
34	Y	It will always help		Small group meetings would be the best environment for advice
35	Y	Always room for improvement but there is a lot out there already		
36	N		There is quite a lot already	
37	Y			Should be more on soil biology, carbon and carbon release. More practical workshops
38	Y	Wouldn't hurt		Current advice is theoretical rather than practical. Need advisors who have knowledge and have done research on soil.
39	Y	Better arable advice for livestock farmers with regards to crop requirements - to save money		Day time meetings are good, better than night time meetings. Also having them at the right time (i.e. when it's raining!). Better incentives are needed to get people to engage with events.
40	Y	Need more advice on run off		Workshops are good but they need to be made interesting to get people there.
41	Y	Only if it can help us.		Soil info is focused on arable sector, not so much grassland farming.
42	Y	Only grass so not sure what else needs to be done.		Some advice is too broad, doesn't apply to all regions/soil types/farming systems.
East				
22	Y	Very little advice out there apart from 'Think Soils' book		Found agronomist was not useful after switching to organic. Need advice for organic farmers and not just conversion advice. More long term management advice, 5 years plus.
23	N		Agronomist is well informed and knows where to go for advice.	
24	Y	Most know a lot about it but don't necessarily do much about soil, therefore it's an area ripe for further exploration		Profitability, ease of working, cost saving related to soil. Room for climate change advice to related to carbon.
25	Y	Information is rarely helpful		Too many people, too many points of contacts.
26	Y	A lot of mix messages and confusion.		Shame that ADAS disappeared. Problems with organisations like NIAB Tag with invested interest with sponsors. Defra would be the best place to get info from but current soil info is patronising.
27	Y			Would prefer one to one advice
28	Y	More focus on biological activity of soil and zero tillage.		Have more research similar to that in Australia and America.
29	Y	Wouldn't do any harm		
31	N		There is plenty out there, you just need to pick and choose what suits you	
32	N		There's enough out there already	
33	Y	There should be masses more, but people providing the info need to get up to date first. Behind America and Australia. Soil food Web		Have more research similar to that in Australia and America.

Do you find advice or legislation difficult to comply with?

Farmer No.	Y/N	What?	Other comments
South West			
30	Y	Can't get into some of the schemes because of the size and situation of the farm.	
34	N		Not if you're in the frame of mind that you want to do something.
35	N		If we had more stock, there would probably be problems with CSF and NVZ, no slurry storage.
36	Y	Some impracticalities e.g. weather and timings. Thinks there is some unrealistic advice, some commercially driven advice, not necessarily very good advice, and then some good advice, which might all overlap.	
37	Y	Conflicting. All black and white. All very regimented and you can get penalised on ELS for e.g. letting hedges grow out which is better the wider environment	
38	Y	Manure storage rules don't make sense	
39	N		Have to remember what badge people are wearing when they give you advice.
40	Y	In a year where weather isn't good, get problems with slurry storage and application - need more flexibility. Remembering dates and what we can and can't do.	
41	Y	Different organisations say different things.	
42	Y	Difficult with current weather conditions, and amount of slurry, storage and spreading.	
East			
22	N		Advice on how to manage soils is perfectly sensible
23	N		
24	Y	Structures of different schemes. Thinks it originates from someone trying to write what the rules are for a huge scheme that covers huge areas so it's not always suited for all areas.	
25	Y	Timings are difficult to comply with	
26	Y	Sometimes under cross compliance - weather related and timings	
27	Y	Edges of ditches and fields	
28	Y	The research is behind the times	
29	Y	What is the point of the SPR? Not enough flexibility in the RB209	
31	Y	Lack of flexibility in agri schemes, and clashes with applying fertiliser and weather timings.	
32	Y	N recommendations between NVZ and RB209 and what the crop N max is.	
33	N		Selects where he gets advice from

Appendix VI: Farmer Interview Schedule

1. Can you provide some brief details on your farm?

- *Livestock or arable? Or both? Is arable for livestock feed?*
- *Size of farm? Production area.*
- *Soil type?*

2. How high do you rate your soil within your farm management programme?

- *Is it an important part of your management?*
- *Do you place any specific focus on your soil?*

3. Do you add OM?

- *Where do you source it from?*
- *Why do you add it?*
- *What value or benefit does it have? (Better yields? Reduced fertiliser use? Improved workability? Do you notice the effects?)*

4. Do you have your soil tested?

- *What do you have tested?*
- *Why do you test?*
- *Did you gain anything from it and would you do it again?*
- *Who by?*
- *Is it costly?*

5. Do you consider the OM content of your soil to be important?

- *Does it have a significant influence on your output? Workability?*
- *How do you decide how to manage it?*

6. What advice do you receive?

- *What does it cover?*
- *What do you feel are the current priorities in the advice that you receive?*
- *Is soil ever raised as an issue?*
- *Do you attend workshops/farm walks?*

7. Do you think there needs to be more information/improvements in advice regarding soil and SOM? If so, what?

- *More workshops?*
- *Improved evidence?*

8. Would you consider taking further steps to increase your SOM, such as OM additions, min-till, switching to organic?

- *What would be the drivers/incentives for this?*
- *What would prevent you from taking these further steps?*

9. Do you find that the advice is ever conflicting or difficult to apply with regards to your soil management?

10. Are you in any contractual agreement with supermarkets or your buyers (e.g. horticultural company)? Does it cover soil organic matter?

11. Are you within CSF and/or NVZ regulations? Agri-schemes?

- *If so, what influence does this have on your farm management, in particular, OM additions and soil management?*

13. Is there anything else you would like to add?

REFERENCES

1. AHDB (2015) Monitor Farms, Available at: http://cereals.ahdb.org.uk/monitorfarms.aspx, Accessed: 18th June 2015.

2. Baker, J., Ochsner, T., Venterea, R., Griffis, T. (2007) Tillage and soil carbon sequestration – What do we really know?, Agriculture, Ecosystems and Environment, vol. 118, pp. 1 - 5

3. Bell, M., Worrall, F., Smith, P., Bhogal, A., Black, H., Lilly, A., Barraclough, D., Merrington, G. (2011) UK Land-Use Change and its Impacts on SOC: 1925 – 2007, *Global Biogeochemical Cycles*, vol. 25, GB4015.

4. Bellamy, P. H., Loveland, P. J., Bradley, R. I., Lark, R. M. and Kirk, G. J. D. (2005) Carbon losses from all soils across England and Wales, 1978 – 2003, *Nature,* vol. 437, pp. 245 - 248.

5. Berhe, A. A., Arnold, C., Stacy, E., Lever, R., McCorkle, E. and Araya, S. N. (2014) Soil erosion controls on biogeochemical cycling of carbon and nitrogen, *Nature Education Knowledge*, vol. 8, pp 2.

6. Bhogal, A., Chambers, B. J., Whitmore, A. P. and Powlson, D. S. (2007) The effects of reduced tillage practices and organic material additions on the carbon content of arable soils, *Defra*, Project SP0561.

7. Bhogal, A., Nicholson, F. A., Rollet, A. and Chambers, B. J. (2009) Best Practice for Managing Soil Organic Matter in Agriculture, *Defra*, Project SP08016.

8. Boatman, N., Dwyer, J. and Ingram, J., (2006) OBS 04: The environmental implications of the 2003 CAP reforms in England, Synthesis report from external observatory projects OBS 01, 02, 03, October 2006*, Central Science Laboratory, York and Countryside*, *Community Research Unit, Gloucester University.*

9. Bot, A and Benites, J (2005) The importance of soil organic matter: Key to drought-resistant soil and sustained food production*, FAO Soils Bulletin 80,* Food and Agriculture Organisation of the United Nations, Rome.

10. Bouma, J. and Droogers, P. (2007) Translating soil science into environmental policy: A case study on implementing the EU soil protection on the Netherlands, *Environmental Science and Policy,* vol. 10, pp. 454-463.

11. Buller, H., Wilson, G. and Holl, A. (Eds) (2000), *Agri-Environmental Policy in the European Union*, Ashgate, UK.

12. Burton, I. (1987) Our Common Future: The World Commission on Environment and Development, *Environment: Science and Policy for Sustainable Development*, Vol. 29, pp. 25-29.

13. Burton, R. J. F., Kuczera, C. and Schwarz, G. (2008) Exploring Farmers' Cultural Resistance to Voluntary Agri-environmental Schemes. *Sociologia Ruralis,* vol. 48, pp. 16 - 37.

14. Campbell, C. (1978) *Chapter 5: Soil Organic Carbon, Nitrogen and Fertility*, in Schnitzer, M. Khan, S. (1978) *Soil Organic Matter, Developments in Soil Science 8*,Elsevier Scientific Publishing Company, The Netherlands.

15. Chander, K.. and Brookes, P.C. (1991) Effects of heavy metals from past applications of sewage sludge on microbial biomass and organic matter accumulation in a sandy loam and silt loam UK soil, *Soil Biology and Biochemistry*, vol. 23, pp. 927 – 932.

16. Choudhury, S.G., Srivastava, S., Singh, R., Chauden, S.K., Sharma, D.K., Singh, S.K. and Sarkar, D. (2014) Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice-wheat cropping system under reclaimed sodic soil, *Soil and Tillage Research*., vol. 136, pp. 76 – 83.

17. Cloke, P., Cook, I., Crang, P., Goodwin, M., Painter, J. and Philo, C. (2004) *Practising Human Geography*, Sage, London

18. Coleman, D., Crabtree, B., Froud, J. and O'Carrol, L., (1992) Comparative Effectiveness of Conservation Mechanisms, *Department of Agricultural Economics,* Manchester University, Manchester, UK.

19. Courtney, P., Mills, J., Gaskell, P., and Chaplin, S., (2013) Investigating the incidental benefits of Environmental Stewardship schemes in England, *Land Use Policy*, vol. 31, pp. 26 – 37.

20. Davies, B., and Finney, J.B., (2002) Reduced cultivations for cereals: research, development and advisory needs under changing economic circumstances, *HGCA Research Review No. 48*.

21. Dawson, J.J.C. and Smith, P. (2007) Carbon losses from soil and its consequences for land-use management, *Science of The Total Environment*, vol. 382, pp. 165 – 190.

22. DeBaets, S., Meersmans, J., Vanacker, V., Quine, T.A. and Van Oost, K. (2013) Spatial variability and change in soil organic carbon stocks in response to recovery following land abandonment and erosion in mountainous drylands, *Soil Use and Management*, vol. 29, pp. 65 – 76.

23. Defra (2002) The Strategy for Sustainable Food and Farming: Facing the Future, Publication no. PB7751A.

24. Defra (2004) The First Soil Action Plan for England: 2004 – 2006, Publication no. PB9411.

25. Defra (2006) Change in the area and distribution of set-aside in England in 2005 and its environmental impact, *Defra Agricultural Change and Environmental Observatory*, February 2006.

26. Defra (2007) Stakeholder workshop on the proposed Soil Framework Directive, London, May 2007.

27. Defra (2008) Understanding behaviours in a farming context: Bringing theoretical and applied evidence together from across Defra and highlighting policy relevance and implications for future research. *Defra Agricultural change and Environmental Observatory Discussion Paper*, November 2008

28. Defra (2009a) Protecting our Water, Soil and Air: A Code of Good Agricultural Practice for farmers, growers and land managers, ISBN 9790112432845.

29. Defra (2009b) Safeguarding Our Soils: A Strategy for England, Publication no. PB13297.

30. Defra (2010) Uptake of the Single Payment Scheme by Farmers, Defra Agricultural Change and Environmental Observatory Research Report No. 19, May 2010.

31. Defra (2013a) Farm Practices Survey Autumn 2012 – England, *National Statistics*, 28th March 2013.

32. Defra (2013b) Nitrate Vulnerable Zones, Available at: https://www.gov.uk/nitrate-vulnerable-zones, Last Updated: 18th December 2013, Accessed: 18th December 2013.

33. Defra (2013c) Campaign for the Farmed Environment: Summary of Evidence, *Defra Agricultural Change and Observatory Research*, Report no. 33, February 2013.

34. Defra (2013d) Business Management Practices on Farm 2011/12, England, *National Statistics*, 21st May 2013.

35. Defra (2014a) Agriculture in the English regions 2013 – 2nd estimate, *National Statistics*, Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/387749/agriaccounts-regstatsnotice-17dec14.pdf, Last updates: 17th December 2014, Accessed: 11th April 2015.

36. Defra (2014b) Organic systems and standards in farming, Available at: https://www.gov.uk/organic-systems-and-standards-in-farming, Last Updated: 3rd January 2014, Accessed: 3rd January 2014.

37. Defra and RPA (2005) Cross Compliance Handbook for England, 2006 edition, Publication no. PB11305.

38. Defra and RPA (2009) Single Payment Scheme: Cross Compliance: Guidance for Soil Management (2010 edition), Publication no. PB13315.

39. Dlugokencky, E. and Tans, P. (2014), *NOAA/ESRL,* http://www.esrl.noaa.gov/gmd/ccgg/ trends, Accessed: 19th September 2014

40. Dobbs T. and Pretty J., (2008) Case study of agri-environmental payments: The United Kingdom, *Ecological Economics,* Vol. 65, pp. 765 – 775.

41. Drexhage, J. And Murphy, D. (2010) Sustainable Development: From Brundtland to Rio 2012, Background Paper prepared for the consideration by the High Level Panel on Global Sustainability, September 2010, *United Nations,* New York.

42. Driver, A. (2010) *Complex CAP plans detrimental to farmers – NFU*, Farmers Guardian (Online), 8th October 2010. Available at http://www.farmersguardian.com/home/latest-news/complex-cap-plans-detrimental-to-farmers-%E2%80%93-nfu/34860.article. Last Updated 20th October 2010, Accessed 20th October 2010.

43. Environment Agency (2011) Catchment Sensitive Farming: ECSFDI Phase 1 and 2 Full Evaluation Report, June 2011.

44. Escobar, M.P. and Buller, H. (2014) Projecting Social Science into Defra's Animal Welfare Evidence Base: A review of current research and evidence base on the issue of farmer behaviour: A report to the Department for Environment, Food and Rural Affairs.

45. *Europa (2007) Single Farm Payment Council Regulation.IN Legislation, E. U. (Ed.) No. 1782/2003.*

46. European Commission (2006) *Thematic Strategy for Soil Protection*. Communication (COM(2006) 231).

47. European Commission (2012) The implementation of the Soil Thematic Strategy and ongoing activities, Communication COM(2012) 46 final.

48. European Commission (2013a) The history of the CAP, Available at: http://ec.europa.eu/agriculture/cap-history/index_en.htm, Last Updated: 22nd December 2013, Accessed: 22nd December 2013

49. European Commission (2013b) Overview of CAP Reform 2014 – 2020, Agricultural Policy Perspectives Brief, No.5, December 2013

50. European Commission (2014) Withdrawal of the proposal for a Soil Framework Directive, Available at: http://ec.europa.eu/environment/soil/process_en.htm, Last Updated: 10th June 2014, Accessed: 20th July 2014,

51. FAO (2001) Soil Carbon Sequestration For Improved Land Management, *World Soil Resources Reports*, *Food and Agriculture Organization of the United Nations*, Rome. Available at: ftp://ftp.fao.org/agl/agll/docs/wsrr96e.pdf, Accessed: 12th December 2013.

52. FAO (2003) World Soil Resources Report 101: Biological Management of Soil Ecosystems for Sustainable Agriculture, *Report of the International Technical Workshop*, *Food and Agriculture Organization of the United Nations*, Rome.

53. FAO (2004) A Review of Carbon Sequestration Projects, *Food and Agriculture Organization of the United Nations*, Rome. Available at: http://www.fao.org/fileadmin/templates/nr/images/resources/pdf_documents/misc37e.pdf, Accessed: 5th December 2013.

54. FAO (2011a) The state of the world's land and water resources for food and agriculture (SOLAW) – Managing systems at risk, *Food and Agriculture Organization of the United Nations*, Rome and *Earthscan*, London.

55. FAO (2011b) Soil Carbon Sequestration: SOLAW Background Thematic Report, TR04B*, Food and Agriculture Organization of the United Nations*, Rome. *Available at: http://www.fao.org/fileadmin/templates/solaw/files/thematic_reports/TR_04b_web.pdf*, Accessed: 12th December 2013

56. FAO (2013) Climate-Smart Agriculture Sourcebook*, Available at: http://www.fao.org/docrep/018/i3325e/i3325e.pdf*, Accessed on 12th December 2013.

57. Fazey, I., Bunse, L., Msika, J., Preedy, K., Evely, A., Lambert, E., Hastings, E., Morris, S., Reed, M. (2014) Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research, *Global Environmental Change*, vol. 25, pp.204-220

58. Ferandez, R.O., Ferandez, P.G., GiraldezCervera, J.V. and Perea Torres, F. (2007) Soil properties and crop yields after 21 years of direct drilling trials in southern Spain, *Soil and Tillage Research,* vol. 94, pp. 47 – 54.

59. Flynn, A.J., P. Alvarez, J.R. Brown, M.R. George, C. Kustin, E.A. Laca, J.T. Oldfield, T. Schohr, C.L. Neely, and C.P. Wong (2009) Soil carbon sequestration in U.S. rangelands: Issues paper for protocol development, *Environmental Defence Fund*, New York, NY, USA.

60. Flyvbjerg, B. (2006) Five Misunderstandings About Case-Study Research, *Qualitative Inquiry*, vol. 12, pp. 219-245.

61. Foth, H. (1990) *Fundamentals of Soil Science, 8th Edition*, John Wiley & Sons, USA.

62. Freibauer, A., Rounsevell, M.D.A., Smith, P. and Verhagen, J. (2004) Carbon sequestration in the agricultural soils of Europe, *Geoderma*, vol. 122, pp. 1 – 23.

63. Garforth, C., Angell, B., Archer, J. and Green, K. (2002) Improving access to advice for land managers: a literature review of recent developments in extension and advisory services. *Report to the Department for Environment, Food and Rural Affairs on research project KT0110*,

64. Garforth, C., Angell, B., Archer, J., Green, K. (2003) Fragmentation or creative diversity? Options in the provision of land management advisory services, *Land Use Policy*, vol. 20, pp. 323 – 333

65. Gattinger, A., Muller, A., Haeni, M, Skinner, C., Fliessbach, A., Buchmann, N., Mader, P., Stolze, M., Smith, P., El-HageScialabba, N., Niggli, U., (2012) Enhanced top soil carbon stocks under organic farming, *Proceedings of the National Academy of Sciences*, Vol. 109, pp. 18226 – 18231.

66. George, A. and Bennett, A. (2004) Case Studies and Theory Development in the Social Sciences, MIT Press, Boston.

67. Giobergia, J.P., Martellotto, E. and Lavado, R.S. (2013) Complementary irrigation and direct drilling have little effect on soil carbon content in semiarid Argentina, *Soil and Tillage Research*, vol. 134, pp. 147 – 152.

68. Gorton, M., Douarin, E., Davidova, S. and Latruffe, L. (2008) Attitudes to agricultural policy and farming futures in the context of the 2003 CAP reform: A comparison of farmers in selected established and new Member States. *Journal of Rural Studies,* 24, pp. 322-336.

69. Gosling, P. and Shepherd, M. (2002) *Theory and reality of organic soil fertility - organic matter*. UK Organic Research 2002 Conference. Organic Centre Wales, Institute of Rural Studies, University of Aberystwyth.

70. Guillem, E and Barnes, A. (2013) Farmer perceptions of bird conservation and farming management at a catchment level, *Land Use Policy*, vol. 31, pp. 565 – 575

71. Haines, A., Alleyne, G., Kickbusch, I., Dora, C. (2012) From the Earth Summit to Rio+2: Integration of health and sustainable development, *The Lancet*, vol. 379, pp. 2189 - 2197

72. Harris, D., Horwath, W., van Kessel, C., (2001) Acid fumigation of soils to remove carbonates prior to total organic carbon or carbon-13 isotopic analysis, *Soil Science Society of America Journal,* volume 65, pp. 1853.

73. Haynes, R.J. and Naidu, R. (1998) Influence of lime, fertiliser and manure applications on soil organic matter content and soil physical conditions: a review, *Nutrient Cycling in Agroecosystems*, vol. 51, pp. 123 – 137.

74. HGCA (2015) *Soil Research*, Available at: http://dev.hgca.com/hgca/research/soil-research.aspx, Accessed 18th June 2015.

75. Hickman, J. and Whiney, D. (2006) Soil Conditioners, *North Central Regional Extension Publication 295*, Kansas State University.

76. HMRC (2014) HTM24064 - Agricultural purposes: Set-aside scheme, Available at: http://www.hmrc.gov.uk/manuals/ihtmanual/ihtm24064.htm, Accessed: 3rd January 2014.

77. Hodge, I. and Reader, M. (2010) The introduction of Entry Level Stewardship in England: Extension or dilution in agri-environment policy?, *Land Use Policy,* vol. 27, pp. 270 – 282.

78. Hodgeson, J. (1978) *Soil sampling and soil description*, Oxford University Press, Guildford & Worcester.

79. Holstein, J. and Gubrium, J., (2006) Chapter 8: The active interview in Silverman D., (2006) *Qualitative Research: Theory, Method and Practice 2nd Edition*, Sage Publications Ltd, UK

80. Howley, P., Yadav, L., Hynes, S., O'Donoghue, C. and O'Neill, S., (2014) Contrasting the attitudes of farmers and the general public regarding the 'multifunctional' role of the agricultural sector, *Land Use Policy*, vol. 38, pp. 248 – 256.

81. Hsu, A., Lloyd, A., Emerson, J. (2013) What progress have we made since Rio? Results from the 2012 Environmental Performance Index (EPI) and Pilot Trend EPI, *Environmental Science and Policy*, vol. 33, pp.171 – 185.

82. Ingram J (2010) Technical and social dimensions of farmer learning: an analysis of the emergence of reduced tillage systems in England. *Journal of Sustainable Agriculture*, Volume 34, Issue 2, 183 – 201.

83. Ingram, J. and Fernades, E. C. M. (2001) Managing carbon sequestration in soils: concepts and terminology. *Agriculture, Ecosystems and Environment,* 87, pp. 111 - 117.

84. Ingram, J. and Morris, C. (2007) The knowledge challenge within the transition towards sustainable soil management: An analysis of agricultural advisors in England. *Land Use Policy* 24 (1) pp. 100-117.

85. Ingram, J. S. L. (2008) Are farmers in England equipped to meet the knowledge challenge of sustainable soil management? An analysis of farmer and advisor views .*Journal of Environmental Management,* 86, pp. 214-228.

86. Ingram, J., Fry, P., Mathieu, A. (2010) Revealing different understandings of soil held by scientists and farmers in the context of soil protection and management, *Land Use Policy,* vol. 27, pp. 51 - 60

87. Ingram, J., Mills, J., Frelih-Larsen, A. and Davis, M. (2012) *Uptake of soil management practices and experiences with decisions support tools: Analysis of the consultation with the farming community.* Deliverable 5.1 for EU SmartSoil project.

88. IPCC (1990a) Climate Change 1990, The IPCC Impacts Assessment, Full Report of Working group 2, Edited by Tegard, W.J McG., Sheldon, G.W and DC Griffiths, *The Intergovernmental Panel on Climate Change First Assessment Report, Australian Government Publishing Service*, Camberra, Australia.

89. IPCC (1990b) Climate Change 1990, The IPCC Response Strategies, Full Report of Working Group 3, *The Intergovernmental Panel on Climate Change First Assessment Report, Australian Government Publishing Service*, Camberra, Australia.

90. IPCC (1995) Climate Change 1995, The IPCC Second Assessment, Synthesis Report, *The Intergovernmental Panel on Climate Change Second Assessment Report*

91. IPCC (2001), Climate Change 2001, Impacts, Adaptation and Vulnerability, Synthesis Report of Working Group 2, *The Intergovernmental Panel on Climate Change Third Assessment Report.*

92. IPCC (2007) Climate Change 2007 Synthesis Report, An Assessment of the Intergovernmental Panel on Climate Change, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Edited by Pachauri, R.K and Reisinger, A., Geneva, Switzerland.

93. IPCC (2013) Technical Summary In Climate Change 2013: Mitigation of Climate Change, Contribution of Working Group 3 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

94. Jandl, R., Rodeghiero, M., Martibez, C., Cotrufo, M.F and Bampa, F., Wesemael, B., Harrison, R.B., Guerrini, I.A, Richter, D., Rustad, L., Lorenz, K., Chabbi, A. and Miglietta, F. (2014) Current status, uncertainty and future needs in soil organic carbon monitoring, *Science of The Total Environment*, vol. 428, pp. 376 – 383.

95. Janzen, H. H. (2006) The Soil Carbon Dilemma: Shall we hoard it or use it? *Soil Biology and Biochemistry,* 38, pp. 419 - 424.

96. Jobbaggy, E. G. and Jackson, R. B. (2000) The Vertical Distribution of Soil Organic Carbon and its Relation to Climate and Vegetation. *Ecological Applications,* 10, pp. 423 - 436.

97. Joos, F. and Spahni, R. (2008) Rates of change in natural and anthropogenic radiative forcing over the past 20,000 years, *Proceedings of the National academy of Sciences USA*, vol. 105, pp. 1425–1430.

98. Juntti, M. and Potter, C. (2002) Interpreting and Reinterpreting Agri-Environmental Policy: Communication, Trust and Knowledge in the Implementation Process. *Sociologia Ruralis,* 42, pp. 215 - 232.

99. Kaljonen, M. (2006) Co-construction of agency and environmental management. The case of agri-environmental policy implementation at Finnish farms, *Journal of Rural Studies*, vol. 22, pp. 205 – 216.

100. Kibblewhite, M., Deeks, L. and Clarke, M. (2010) Gap analysis on the future requirements of soil and water management in England. *Royal Agricultural Society for England.*

101. Kitchen, R. and Tate, N. (2013) *Conducting research in human geography*, Routledge, London.

102. Kleber, M. And Johnson, M.G. (2010) Advances in understanding the molecular structure of soil organic matter: implications for interactions in the environment, *Advances in Agronomy*, vol. 106, pp. 77 – 142.

103. Kleijn,D. and Sutherland, W.J., (2003) How effective are Agri-environmental schemes in conserving and promoting biodiversity? *Journal of Applied Ecology*, vol. 40, pp. 947 – 969.

104. Klerkx, L. and Proctor, A. (2013) Beyond fragmentation and disconnect: Networks for knowledge exchange in the English land management advisory system, *Land Use Policy*, vol. 30, pp. 13 – 24.

105. Kolk, A., Levy, D. Pinkse, J. (2008) Corporate Responses in an Emerging Climate Regime: The Institutionalisation and Commensuration of Carbon Disclosure, *European Accounting Review*, vol. 17, pp. 719 – 754.

106. Labarthe, P., Laurent, C. (2013) Privatisation of agricultural extension services in the EU: Towards a lack of adequate knowledge for small-scale farms?, *Food Policy*, vol. 38, pp. 240 – 252.

107. Lal, R. (2004a) Soil carbon sequestration impacts on global climate change and food security, *Science,* 304, pp. 393.

108. Lal, R. (2004b) Soil carbon sequestration to mitigate climate change, *Geoderma,* 123, pp. 1 - 22.

109. Lal, R., Griffin, M., Apt, J., Land, L. and Morgan, M. G. (2004) Managing Soil Carbon, *Science,* 304, pp. 393.

110. Le Quéré C., Peters G. P., Andres R. J., Andrew R. M., Boden T. A., Ciais P., Friedlingstein P., Houghton R. A., Marland G., Moriarty R., Sitch S., Tans P., Arneth A., Arvanitis A., Bakker D. C. E., Bopp L., Canadell J. G., Chini L. P., Doney S. C., Harper A., Harris I., House J. I., Jain A. K., Jones S. D., Kato E., Keeling R. F., Klein Goldewijk K., Körtzinger A., Koven C., Lefèvre N., Maignan F., Omar A., Ono T., Park G.H., Pfeil B., Poulter B., Raupach M. R., Regnier P., Rödenbeck C., Saito S., Schwinger J., Segschneider J., Stocker B. D., Takahashi T., Tilbrook B., van Heuven S., Viovy N., Wanninkhof R., Wiltshire A., and Zaehle S. (2014) Global Carbon Budget 2013, *Earth Systems Science Data*, vol. 6, pp. 235 – 263.

111. Lindsay, J. (2003) *Techniques in Human Geography*, Routledge, London.

112. Lobley, M., and Potter, C. (1998) Environmental Stewardship in UK Agriculture: A Comparison of the Environmentally Sensitive Area Programme and the Countryside Stewardship Scheme in South East England, *Geoforum*, vol. 29, pp. 413 – 432.

113. Lobley, M. and Butler, A. (2010) The impact of CAP reform on farmers' plans for the future: Some evidence from the South West England, *Food Policy,* 35, pp. 341 - 348.

114. MEA (2005) Ecosystems and Human-well Being: Synthesis, USA, Island Press.

115. Majone, G. and Wildavsky, A., (1978) Implementation as Evolution, *Policy Studies Review*, vol. 12, pp. 103 – 117.

116. Manies, K. L., Harden, J. W., Kramer, L. and Parton, W. J. (2001) Carbon dynamics within agriculture and native sites in the loess region of Western Iowa. *Global Change in Biology,* 7, pp. 545 - 555.

117. Marschner, B., Brodowski, S., Dreves, A., Gleixner, G., Gude, A., Grootes, P.M., Hamer, U., Heim, A., Jandl, G., Ji, R., Kaiser, K., Kalbitz, K., Kramer, C., Leinweber, P., Rethemeyer, J., Schäffer, A., Schmidt, M.W.I., Schwark L., and Wiesenberg, G.L.B. (2008) How relevant is recalcitrance for the stabilization of organic matter in soils?, *Journal of Plant Nutrition Soil Science*, vol. 171, pp. 91 – 110.

118. Matthews, J., Bridges, E., Caseldine, C., Luckman, A., Owen, G., Perry, A., Shakesby, R., Walsh, R., Whittaker, R. And Willis, K. (2003) *The Encyclopaedic Dictionary of Environmental Change*, Arnold, London.

119. Miller, M. (2013) Interdisciplinary research and the early career: The effect of interdisciplinary dissertation research on career placement and publication productivity of doctoral graduates in the sciences, *Research Policy*, vol. 42, pp. 1152-1164

120. Mills, J., Gaskell, P., Reed, M., Short, C., Ingram, J., Boatman, N., Jones, N., Conyers, S., Carey, P., Winter, M., and Lobley, M. (2013) Farmer attitudes and evaluation of outcomes to on-farm environmental management. Report to Department for Environment, Food and Rural Affairs (Defra). *CCRI, Gloucester*

121. Meteorological Office (2014) UK Climate, Available at: http://www.metoffice.gov.uk/public/weather/climate, Accessed: 1st September 2014

122. Metzger, N. and Zare, R., (2000) Interdisciplinary Research: From Belief to Reality, *Science*, Vol. 283, pp. 642 – 643.

123. Moran, D., MacLeod, M., Wall, E., Eory, V., McVittie, A., Barnes, A., Rees, R.M., Topp, C.F.E, Pajot, G., Matthews, R., Smith, P. and Moxey, A. (2011) Developing carbon budgets for UK agriculture, land use, land use change and forestry out to 2022, *Climatic Change*, vol. 105, pp. 529 – 553.

124. Morris, C. and Potter, C., (1995) Recruiting the New Conservationists: Farmers' Adoption of Agri-environmental Schemes in the UK, *Journal of rural Studies*, vol. 11, pp. 51 – 63.

125. Morris, C. (2004) Networks of agri-environmental policy implementation: a case study on England's Countryside Stewardship Scheme, *Land Use Policy,* Vol. 21, pp. 177 – 191

126. Munkholm, L.J., Schjonning, P., Rasmussen, K.J. and Tanderup, K. (2003) Spatial and temporal effects of direct drilling on soil structure in the seedling environment, *Soil and Tillage Research*, vol. 71, pp. 163 – 173.

127. National Soil Resources Institute (NSRI), (2013), *The Soils Guide,* Available: www.landis.org.uk, Cranfield University, UK, Accessed 13/08/2013

128. National Soil Resources Institute (NSRI), (2014) *Soilscapes*, Available at: http://www.landis.org.uk/soilscapes/index.cfm, Accessed: 1st September 2014.

129. Natural England (2010a) Entry Level Stewardship, Environmental Stewardship Handbook (3rd Edition - February 2010). ISBN 978-1-84754-185-7.

130. Natural England (2010b) Soils for Profit, *Available at http://www.naturalengland.org.uk/regions/south_west/ourwork/soilsforprofitproject/default.aspx*, Accessed: 28th October 2010.

131. Natural England (2014) Soils For Profit Project, Available at: http://www.naturalengland.org.uk/regions/south_west/ourwork/soilsforprofitproject/default.aspx, Accessed: 2nd January 2014

132. NFU (2013) Catchment Sensitive Farming Grant Update, Available at: http://www.nfuonline.com/science-environment/nvzs-and-water-quality/catchment-sensitive-farming-grant-update/, Accessed: 3rd January 2014

133. NFU (2014) Soil Framework Withdrawn, Available at: http://www.nfuonline.com/news/latest-news/soil-framework-directive-withdrawn/, Accessed: 20th July 2014, Date Updated: 22nd May 2014.

134. Orum, A., Feagin, J. and Sjoberg, G. (1991) The nature of the case study. In Feagin, J., Orum, A. and Sjoberg, G. (Eds) *The case for the case study*, University of North Carolina Press, pp. 1-26.

135. Ostle, N.J., Levy, P.E. Evans, C.D and Smith, P. (2009) UK land use and soil carbon sequestration, *Land Use Policy*, vol. 26, pp. 274 – 283.

136. Oxford Dictionaries (2015a) Definition of Mitigation, Available at: http://www.oxforddictionaries.com/definition/english/mitigation, Date Accessed: 17th June 2015.

137. Oxford Dictionaries (2015b) Definition of Case Study, Available at: http://www.oxforddictionaries.com/definition/english/case-study, Date Accessed: 28th April 2015

138. Palm, C., Blanco-Canquil, H., DeClerck, F., Gatere, L. and Grace, P. (2014) Conservation agriculture and ecosystem services: An overview, *Agriculture, Ecosystem and Environment,* vol. 187, pp. 87 – 105.

139. Palmer, M., Stockdale, E., Shiel, R. and Gowning, J. (2006) Improved knowledge transfer for better soil management. Report to the ARF.

140. Parry, H., Ramwell, C, Bishop, J., Cuthbertson, A, Boatman, N., Gaskel, P., Dwyer, J., Mills, J., and Ingram, J., (2006) OBS 03: Quantitative approaches to assessment of farm level changes and implications for the environment, Agricultural Change and Environmental Observatory Programme, Final report October 2006, *Central Science Laboratory, York and Countryside and Community Research Unit, University of Gloucester.*

141. Paul, H., Ernsting, A., Semino, S., Gura, S. and Lorch, A. (2009) *Agriculture and climate change: Real problems and false solutions, Executive summary of the report*. Conference of the Parties, COP15 of the United Nations Framework Convention on Climate Change. Copenhagen. December 2009.

142. Paustian, K., Six, J., Elliott, ET., Hunt, H.W (2000) Management options of reducing CO_2 emissions from agricultural soils, *Biochemistry,* vol. 48, pp. 147 – 163.

143. Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. And Wagner, F. (2003) Good Practice Guidance for Land Use, Land-Use Change and Forestry (Annex A –

Glossary), *Institute for the Global Environmental Strategies for The intergovernmental Panel on Climate Change.*

144. Persson, J., and Kirchmann, H., (1994) Carbon and nitrogen in arable soils as affected by supply of N fertilisers and organic manures, *Agriculture, Ecosystems and Environment*, vol. 51, pp. 249 – 255.

145. Ponce-Hernandez, R (2004), *Assessing Carbon stocks and assessing win-win scenarios of Carbon sequestration*, Rome, Available at: http://www.fao.org/fileadmin/templates/nr/images/resources/pdf_documents/carbonstocks.pdf, Accessed: 10th December 2013.

146. Powlson, D., Bhogal, A., Chambers, B., Coleman, K., Macdonald, A., Goulding, K., and Whitmore, A., (2012), The potential to increase soil carbon stocks through reduced tillage or organic material additions in England and Wales: A case study, *Agriculture, Ecosystems and Environment*, vol. 146, pp. 23-33.

147. Pretty (2008) Agriculture sustainability: concepts, principles and evidence, *Philosophical Transactions of the Royal Society B,* 363, pp. 447 - 465.

148. Qingjie, W., Hao, C., Hongwen, L., Wenying, L., Xiaoyan, W., Mchugh, A. D., Jin, H. and Huanwen, G. (2009) Controlled traffic farming with no tillage for improved fallow water storage and crop yield on the Chinese Loess Plateau. *Soil Tillage and Research,* 104, pp. 192 - 197.

149. Quine, T. A. and Zhang, Y. (2002) An investigation of spatial variation in soil erosion, soil properties and crop production within an agricultural field in Devon, UK. *Journal of Soil and Water Conservation,* 57, pp. 55 - 65.

150. Read, N (1987) Agricultural Advisers and Independent Consultants in England and Wales-The End of Symbiosis? *Agriculture Administration and Extension,* vol. 25, pp. 189 – 197

151. Robson, C. (1993) *Real World Research*, Blackwell, Oxford.

152. Rowell, D.L (1994) *Soil Science: Methods and Applications,* Longman Scientific & Technical, Singapore

153. Rural Payments Agency (RPA) (2014) Cross Compliance, Available at: http://rpa.defra.gov.uk/crosscompliance, Accessed 5th January 2014.

154. SAC and AEA Technology, (2011) Evaluation of Environmental Impacts of 2003 CAP Reforms and the Likely Implications of the CAP 'Health Check' Regulations in England, Executive Summary, *SAC Rural Policy Centre,* July 2011.

155. Schimel, D.S., J. I. House, K. A. Hibbard, P. Bousquet, P. Ciais, P. Peylin, B. H. Braswell, M. J. Apps, D. Baker, A. Bondeau, J. Canadell, G. Churkina, W. Cramer, A. S. Denning, C. B. Field, P. Friedlingstein, C. Goodale, M. Heimann, R. A. Houghton, J. M. Melillo, B. Moore, III, D. Murdiyarso, I. Noble, S. W. Pacala, I. C. Prentice, M. R. Raupach, P. J. Rayner, R. J. Scholes, W. L. Steffen, and C. Wirth (2001) Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems, *Nature*, vol. 414, pp. 169 – 172.

156. Schmidt M.W. I., Torn M.S., Abiven S., Dittmar T., Guggenberger G., Janssens I.A., Kleber M., Kogel-Knabner I., Lehmann J., Manning D.A. C., Nannipieri P., Rasse D.P., Weiner S. and Trumbore S.E. (2011) Persistence of soil organic matter as an ecosystem properly, *Nature,* vol. 478, pp49 - 56

157. Smith, P. (2008) Land use change and soil organic carbon dynamics, *Nutrient Cycling in Agroecosystems*, vol. 81, pp. 169-178.

158. Smith, P. (2012) Soils and climate change, Current Opinion in Environmental Sustainability, vol. 4, pp. 539 – 544.

159. Smith, P. (2013) Delivering food security without increasing pressures on land, *Global Food Security*, vol. 2, pp. 18-23.

160. Smith, P., Chaoman, S. J., Scott, W. A., Black, H. I. J., Wattenbach, M., Milnes, R., Campbell, C. D., Lilly, A., Ostle, N., Levys, P. E., Lumsdon, D. G., Millard, P., Towers, W., Zaehle, S. and Smith, J. U. (2007) Climate change cannot be entirely responsible for soil carbon loss observed in England and Wales 1978 - 2003. *Global Change Biology,* 13, pp. 2605 - 2609.

161. Smith, P., Fang, C.M, Dawson, J.J.C. and Moncrieff, J.B (2008a) Impact of global warming on soil organic carbon, *Advances in Agronomy*, vol. 97, pp. 1 – 43.

162. Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Watternbach, M. and Smith, J. (2008b) Greenhouse gas mitigation in agriculture, *Philosophical Transaction of The Royal Society B,* vol. 363, pp. 789 – 813.

163. Smith, P. and Gregory, P. (2013) Climate Change and sustainable food production*. Proceedings of the Nutrition Society*, vol. 72, pp. 21-28.

164. Sneddon, C., Howarth, R., Norgaard, R. (2006) Sustainable Development in a Post-Brundtland World, *Ecological Economics*, vol. 57, pp. 253 – 268.

165. Soil Association, (2009) *Soil Carbon and Organic Farming: Full Review,* Soil Association, November 2009.

166. Steele, T. and Stier, J. (2000), The Impact of Interdisciplinary Research in the Environmental Sciences: A Forestry Case Study, *Journal of the American Society for Information Science*, vol. 51, pp. 476 - 484

167. Stoate, C., Boatman, N.D., Borralho, R.J., Rio Carvalho, C., de Snoo, G.R. and Eden, P. (2001) Ecological impacts of arable intensification in Europe, *Journal of Environmental Management*, vol. 63, pp. 337-365.

168. Stocker, T.F., D. Qin, G.-K. Plattner, L.V. Alexander, S.K. Allen, N.L. Bindoff, F.-M. Bréon, J.A. Church, U. Cubasch, S. Emori, P. Forster, P. Friedlingstein, N. Gillett, J.M. Gregory, D.L. Hartmann, E. Jansen, B. Kirtman, R. Knutti, K. Krishna Kumar, P. Lemke, J. Marotzke, V. Masson-Delmotte, G.A. Meehl, I.I. Mokhov, S. Piao, V. Ramaswamy, D. Randall, M. Rhein, M. Rojas, C. Sabine, D. Shindell, L.D. Talley, D.G. Vaughan and S.-P. Xie, (2013) Technical Summary In Climate Change 2013: The Physical Science Basis, *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

169. Tan, B., Fan, J., He, Y., Luo, S. and Peng, X. (2014) Possible effect of soil organic carbon on its own turnover: A negative feedback, *Soil Biology and Biochemistry,* vol. 69, pp. 313 – 319.

170. Tollefson, J. And Gilber, N. (2012) Earth Summit: Rio Report Card, *Nature,* vol. 486, pp. 20 – 23.

171. Tscharntke, T., Clough, Y., Wanger, T., Jackson, L., Motzke, I., Perfecto, I., Vandermeer, J. and Whitbread, A. (2012) Global food security, biodiversity conservation and the future of agricultural intensification, *Biological Conservation*, vol. 151, pp. 53-59.

172. Trombore, S. E. and Czimczik, C. I. (2008) An uncertain future for soil carbon. *Science,* 321, pp. 1455 - 1456.

173. UN (1987) Our Common Future, Report of the World Commission on Environment and Development, United Nations.

174. UN (1992a) United Nations Conference on Environment and Development (UNCED), *Rio de Janeiro, 3-14 June 1992,* Available at: http://www.un.org/geninfo/bp/enviro.html, Accessed: 23rd December 2013

175. UN (1992b) , Agenda 21, United Nations Conference on Environment & Development, Rio de Janerio, Brazil, 3 to 14 June 1992.

176. UN (1994) Elaboration of an International Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or desertification, Particularly in Africa, General Assembly.

177. UN (1998) Kyoto Protocol to the United Nations Framework Convention on Climate Change, Available at: http://unfccc.int/resource/docs/convkp/kpeng.pdf, Accessed: 16th December 2013.

178. UN (2013) World population projected to reach 9.6 billion by 2050 with most growth in developing regions, especially Arica, *UN Press Release*, 13th June 2013.

179. UNEP (2013) Rio Declaration on Environment and Development, *Available at: http://www.unep.org/Documents.Multilingual/Default.asp?documentid=78&articleid=1163,* Accessed: 20th December 2013

180. UNFCCC (2006), United Nations Framework Convention on Climate Change: Handbook, Technographic Design and Print Ltd, UK

181. UNFCCC (2013a) First steps to a safer future: Introducing The United Nations Framework Convention on Climate Change, Available at: http://unfccc.int/essential_background/convention/items/6036.php, Accessed: 20th December 2013.

182. UNFCCC (2013b) Kyoto Protocol. Available at: http://unfccc.int/kyoto_protocol/items/2830.php, Accessed: 20th December 2013.

183. Unilever (2010) Encouraging Biodiversity at Colworth Estate. *Available at http://www.unilever.co.uk/sustainability/casestudies/environment/ukencouragingbiodiversityatcolworthestate.aspx*, Accessed: 5th November 2010.

184. Yang, T., Percvial, R. (2009) The Emergence of Global Environmental Law, *Ecology Law Quarterly*, vol. 36, pp. 615 – 664.

185. Van Moort, J.C, De Vrieg, D., (1970) Rapid carbon determination by dry combustion in soil science and chemistry, *Geoderma*, volume 4, pp. 109-118

186. Van Oost, K., Govers, G., Quine, T. A. and Heckrath, G. (2004) Comment on 'Managing Soil Carbon', *Science,* 305, pp. 1567b.

187. Van Oost, K., Govers, G., De Alba, S. and Quine, T. A. (2006) Tillage erosion: a review of controlling factors and implications for soil quality. *Progress in Physical Geography,* 30, pp. 443 - 466.

188. Van Oost, K., Quine, T. A., Govers, G., De Gryze, S., Six, J., Harden, J. W., Ritchie, J. C., Mccartney, G. W., Heckrath, G., Kosmus, C., Givaldez, J. V., Silva, M. D. and Merckx, R. (2007) The impact of agricultural soil erosion in the global carbon cycle. *Science,* 318, pp. 626 - 629.

189. Vermeulen, G. D. and Mosquere, J. (2009) Soil, crop and emission responses to seasonal-controlled traffic in organic vegetable farming on loam soil. *Soil Tillage and Research,* 102, pp. 126 – 134.

190. Walford, N., (2002) Agricultural adjustment: adoption of and adaption to policy reform measures by large-scale commercial farmers, *Land Use Policy,* Vol. 19, pp. 243 – 257.

191. Walter, G., Wander, M. and Bollero, G., (1997) A farmer-centred approach to developing information for soil resource management: The Illinois Soil Quality Initiative, *American Journal of Alternative Agriculture*, vol. 12, pp. 64 – 72.

192. Wang, Y., Tu C., Cheng, L., Li, C., Gentry, L., Hoyt, G., Zhang, X. And Hu, S. (2011) Long-term impact of farming practices on soil organic carbon and nitrogen pools and microbial biomass and activity, *Soil and Tillage Research*, vol. 117, pp. 8-16.

193. Westbury, D. B., Park, J. R., Mauchline, A. L., Crane, R. T. and Mortimer, S. R. (2011) Assessing the environmental performance of English arable and livestock holdings using data from the Farm Accountancy Data Network (FADN). *Journal of Environmental Management,* 92, pp. 902-909.

194. Wilson, G.A., (1996) Farmer Environmental Attitudes and ESA Participation, *Geoforum,* vol. 27, pp. 115 – 131.

195. Wilson, G. A. and Hart, K. (2000) Financial imperative or conservation concern? EU farmers' motivations for participation in voluntary agri-environmental schemes, *Environment and Planning A,* 32, pp. 2161 - 2185.

196. Zaccai, E. (2012) Over two decades in pursuit of sustainable development: Influence, transformations, limits, *Environmental Development*, vol. 1, pp. 79 - 90

197. Zhao, Y., Wang, P., Li, J., Chen, Y., Ying, X., and Liu, S., (2009) The effects of two organic manures on soil properties and crop yields on a temperate calcareous soil under a wheat-maize cropping system, *European Journal of Agronomy*, vol. 31, pp. 36 – 42.