CRANFIELD UNIVERSITY

LAURA JANE HATHAWAY-JENKINS

THE EFFECT OF ORGANIC FARMING ON SOIL PHYSICAL PROPERTIES, INFILTRATION AND WORKABILITY

SCHOOL OF APPLIED SCIENCE

EngD
Academic Year: 2011

Supervisors: Prof RJ Godwin, Dr R Sakrabani, Prof A Whitmore
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This thesis is submitted in fulfilment of the requirements for the degree of EngD.

Abstract

Organically managed land has increased to 4 % of the total area of agricultural land in the UK. Changing land management can impact upon the rural environment (soils, hydrology and biodiversity) and rural community (socio-economics and culture). This thesis aims to compare the effects of organic farming practices on soil physical, chemical and hydrological properties in relation to conventional farming systems. The research combines data from three different scales: field measurements, plot measurements and catchment modelling.

At the field scale: 16 pairs of farms (organic and conventional between 50 and 3000 m apart) located in England, over a range of soil textures: clayey, silty, medium and coarse were investigated. There were also two different land uses (grass and winter wheat). Data was obtained on soil properties including: shear strength, Atterberg limits, field capacity, aggregate stability, HOST values, infiltration rates and Soil Organic Carbon (SOC). The analysis of the data shows that, whilst it is possible to detect the effects of both soil texture and land use (grassland / arable) on a number of the soil properties; there is no evidence that organic farming improves soil properties or physical condition - equally there is no detrimental effect. This is in agreement with the results of a number of other European studies. There was evidence to show that infiltration rates are greater on organically managed grassland than conventional grassland; which agrees with the HOST analysis where fewer fields were degraded under organic management. Fewer traces of pesticides and herbicides were in the soil water from the organic fields compared with the conventionally managed fields; none were at a level which would contribute to agricultural pollution.

At the plot scale: a two year arable trial on three pairs of neighbouring farms (organic and conventional between 350 – 1500 m apart) located in the UK, over a range of soil textures: clay, clay loam and sandy silt loam were investigated. Different tillage regimes including: reduced tillage and conventional plough based systems were implemented in the plots. Data were obtained on soil chemical, physical and hydrological properties. Tillage regimes (reduced or traditionally ploughed) make a difference to soil quality; this varies with soil texture and management. There is an improvement for: SOC, maximum water holding capacity, plastic limits and shear strength under reduced tillage; whereas, yield and infiltration rates are higher under ploughing. Overall, organic management can have a benefit for a number of soil physical and chemical properties in arable fields. However, this varies with soil texture and any resulting effects are not always in the same direction. For example, SOC is higher in organically managed land in clay loam soil, lower in the sandy silt loam soil and no significant difference for the clay soil. Organic management improves soil quality for maximum water holding capacity, aggregate stability, shear strength and infiltration rate. However, there is no significant difference due to organic management in bulk density, field capacity, plastic limit, total porosity, pH, total C:N ratio or workability. Infiltration rates are higher or equal to conventional arable land and this could be related to the significant improvement in maximum water holding capacity for organically managed soils. This has implications for flood prevention; as organically managed land has an increased capacity to store water.

The different scales were combined using the measured infiltration data at the field and plot scale in the USDA SCS runoff model. This enabled catchment scale modelling of totally grassland, totally arable, organic and conventional landscapes for three climatic zones: Midlands (dry), South (intermediate) and South West (wet) in the UK. The USDA SCS model provides useful catchment scale comparisons, where if all the grassland is managed organically runoff is substantially reduced by 60 – 70 % and in turn reduces the effective flood return period from the 1 in 10 year to 1 in 1.5 years for dry climatic conditions. Moving from conventional (60 % arable / 25 % grass / 15 % fallow) to organic management (45 % arable / 40 % grass / 15 % fallow) reduces the effective flood in the wet climatic region from the 1 in 10 year return period to the less severe 1 in 5 year. Similarly, for the intermediate and dry climatic regions the effective flood reduces from the 1 in 10 year return period to the less severe 1 in 3 year. If all farms within a catchment manage the grass fields with organic or less intensive conventional management there could be a reduction of runoff. This could have an economic benefit through substantially reducing flood damage costs to residential properties (by 33 %, 47 % and 100 % for dry, intermediate and wet respectively) and prevent loss of productive agricultural land.

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List of Abbreviations

ANOVA: Analysis of variance
BFI: Base flow index
BS: British standard
C: Carbonates
C: Clay
C: N: Carbon to nitrogen ratio
CAP: Common agricultural policy
CEC: Cation exchange capacity
CL: Clay loam
CO_2: Carbon dioxide
Con: Conventional
CRASH: Catchment resources and soil hydrology model
D: Dicaroboximides
DDE: dichlorodiphenyldichloroethylene
Defra: Department for environment food and rural affairs
DOC: Biodynamic, bio-organic and conventional trials in Switzerland
dt50: Half life
EA: Environment agency
ELS: Entry level scheme
EU: European Union
FC (pF2): Field capacity
FEH: Flood estimation handbook
FYM: Farmyard manure
G: Grass
GHG: Greenhouse gas
GM: Genetically modified
GUS: Groundwater ubiquity score
HELS: Higher entry level scheme
HOST: Hydrology of soil type
IR: Infiltration rate
K: Potassium
L: Loam
LOI: Loss on ignition
LSD: Least significant difference
LSU: Livestock unit
LS: Silty clay loam
M: Maize
MT: Minimum tillage
N: Nitrogen
N_{max}: maximum nitrogen limit
NOEC: No observed effect concentration
NSRI: National Soil Research Institute
NVZ: Nitrate vulnerable zone

OC: Organochlorine
OELS: Organic entry level scheme
ON: Organonitrogen
OP: Organosphorus
ORC: Organic research centre
Org: Organic
OSR: Oilseed rape
P: Phosphorus
PL (LPL): Plastic limit
RELU: Rural economy and land use
REML: Restricted maximum likelihood
RT: Reduced tillage
SAP: Soil action plan
SB: Spring barley
SCS-CN: Soil conservation service – curve number model
SOC: Soil organic carbon
SOM: Soil organic matter
SP: Synthetic pyrethoids
SPR: Standard percentage runoff
SPS: Single payment scheme
SW: Spring wheat
SWAT: Soil and water assessment tool
SC: Sandy clay
SCL: Sandy clay loam
SYZL (SSL): Sandy silt loam
USDA: United States Department of Agriculture
WB: Winter barley
WCG: White clover and grass mix
WFD: Water framework directive
WHC: Water holding capacity
WO: Winter oats
WW: Winter wheat
ZL: Silt loam
ZC: Silty clay
ZCL: Silty clay loam
ρ_b: Bulk density

Glossary of Terms

Aggregate stability: Soil aggregates are groups of soil particles that bind to each other. The space between the aggregates provides pore space for retention and exchange of air and water. Aggregate stability is a measure of the ability of a soil aggregate to resist disruption and breaking down when a water force is applied. This is the percentage of aggregates which are retained on the sieves after wet sieving. Higher percentage values mean that the soil is more stable, it is dependent upon the amount of soil organic matter (SOM) and the percentage clay present in the aggregate.

Arable: a land classification unit which is cultivated and used to produce a non-grass crop.

Atterberg Limits: are a basic measure of the rheological properties of a soil. It depends on the water content of the soil which is affected by the amount of soil organic matter (SOM) present. It defines several different states namely plastic and liquid limits where the consistency and behaviour of a soil is different and hence so are its engineering properties. Plasticity indicates how easily a soil can be deformed without cracking in response to an applied stress and is an indicator of the likely mechanical behaviour and workability of soils.

Cropping rotation: the successive planting of different crops on the same land to improve soil fertility and help control insects and diseases.

Conventional: is generally a more intensive farm management system with high inputs of non-organic fertilisers, pesticides and generally higher yield output. It does not refer to a specific type of tillage regime.

Field Capacity (FC): the amount of soil moisture or water content held in soil after excess water has drained away and the rate of downward movement has materially decreased, which usually takes place within 2–3 days after a rain or irrigation in previous soils of uniform structure and texture.

Flood Return Period: is also known as a recurrence interval and is an estimate of the interval of time between flood events of a certain intensity or size (FHRC, 2010). Changing land management can alter the size of a flood event and so an equivalent flood return period can be calculated.

Grassland: is land that has been in grass ley or permanent pasture with a either grass or a mixture of clover which is used for grazing of cattle and sheep.

HOST: is the Hydrology of Soil Type and classifies the main soil types in the UK into 29 classes (Boorman *et al.*, 1995). These 29 classes based upon soil physical properties which are correlated with catchment scale hydrological variables the dominant pathways of water movement through the soil and substrate.

Infiltration: is the process by which water on the ground surface enters the soil. The rate at which this occurs is measured in mm hr^{-1}. The rate decreases as the soil becomes saturated and if the amount of precipitation exceeds the infiltration rate runoff can occur.

Leaching: is the process by which soluble matter such as nutrients and pesticides are dissolved in groundwater and then transported through the soil.

Liquid Limit (LL): is the water content where a soil changes from plastic to liquid behaviour.

Minimum tillage: is a tillage method aimed at generally shallower simpler operations that reduce time and energy and may also conserve both soil and water by leaving more of the crop residue or stubble on the surface rather than burying it by using a mouldboard plough. Frequently, the weeds are controlled by herbicides.

Non inversion tillage: is a method of minimum tillage which involves reducing cultivation depth and avoiding the use of the plough which does not turn the soil. The technique enables cheaper and quicker establishment and is predominantly used for winter cereals.

Non organic: see conventional.

Organic: is a more integrated environmentally and economically sustainable agricultural production system with less reliance on external inputs such as chemical fertilisers and with strict controls and legislations about the production of organic food (Lampkin, 1999).

Penetration resistance: is a measure of the resistance of any soil to the entry of any device or biological matter. It varies depending on soil physical properties such as the particle size distribution, water content, resistance to compression and shear strength (Campbell and O'Sullivan, 1991).

Permanent wilting point (PWP): is defined as the soil moisture content at which during a drying phase a plant wilts and can no longer recover its turgidity when placed in a saturated atmosphere for 12 hours.

Plastic Index (PI): is a measure of the plasticity of a soil. The plasticity index is the size of the range of water contents where the soil exhibits plastic properties. The PI is the difference between the liquid limit and the plastic limit (PI = LL-PL). Soils with a high PI tend to be clay, those with a lower PI tend to be silt, and those with a PI approaching 0 are sandy soils with little or no silt or clay.

Plastic Limit (PL): is the water content where soil starts to exhibit plastic behaviour.

RELU: stands for Rural Economy and Land Use, a programme which was set up following the outbreak of foot and mouth disease in 2005. It aims to provide funding for projects to investigate changing rural land use and the impacts for the rural economy.

Runoff: is the water from rain, snowmelt or irrigation that flows over the land surface and is not absorbed into the ground, instead it flows into streams or other surface waters and can contribute to flash flooding.

Shear strength: is the maximum strength of soil at which point significant plastic deformation occurs due to an applied stress. The shear strength of a soil depends on a number of factors such as the moisture content, percentage clay, percentage sand, soil bulk density and amount of soil organic matter.

Soil management: is defined as all of the operations, practices and treatments which are employed to protect the soil in terms of structure, carbon content and to enhance its performance in terms of fertility and other environmental benefits such as habitat provision and flood prevention.

Soil Organic Matter: is defined as any plant and animal material added to the soil which is not fully decomposed.

Soil Structure: The shape of soil units (peds) that occur naturally in a soil horizon. Some possible soil structures are granular, blocky, prismatic, columnar, or platy. Soils can also be structure less such as consolidated mass (massive) or as individual particles (single-grained).

Soil Workability: is a measure of the optimum water content at which agricultural tillage produces the greatest proportion of small aggregates. If the soil is tilled when it is wetter large clods can be produced and soil structural damaged can occur. However, if the soil is drier then tillage requires excessive energy and can also produce large clods (Rounsevell and Jones, 1993; Dexter and Bird, 2001).

Statistical Analysis: both ANOVA (analysis of variance) and REML (restricted maximum likelihood) analysis provide a method of analysing the significance of findings. The data is presented in data of means with significant differences ($p < 0.05$) shown by different letters. For example:

	Organic Arable	Organic Grass	Con Arable	Con Grass
Mean	**39.01**[a]	**63.34**[b]	**36.71**[a]	**62.08**[b]

There are no significant differences between grass (organic and conventional) or arable (organic and conventional) systems. However, both arable systems are significantly different from grass systems.

Traditional tillage: is the cultivation of the land using a mouldboard plough based system, where the mouldboard plough is followed by tines, discs, presses to form a tilth before seeds are sown.

Water holding capacity: is the ability of the soil to retain or store water, it is dependent upon soil texture, structure and the amount of soil organic matter and is the difference between field capacity (FC) and permanent wilting point (PWP).

1 Introduction

Farmers and land owners (both organic and conventional managers) are encountering new challenges in the face of changing climatic conditions and the recent economic downturn. There is a need to maintain and increase crop yield and production. This is especially important as there is a growing global population predicted to reach 8 billion by 2020 (Nygaard, 2010). It should also be stressed that there is a need for these challenges to be managed sustainably, improving soil health for better production for future generations.

This section highlights the differences between conventional and organic farming. Conventional farming (non organic) is a more input intensive system compared to organic farming with high inputs such as fertilisers, pesticides and high outputs in terms of yield (Byrne, 1997). However, when considering the tillage regime to be adopted, it should be noted that minimum tillage (generally non-inversion with fewer passes) can be less intensive especially in terms of labour requirements. On the other hand, organic farming aims to create an integrated environmentally and economically sustainable agricultural production system (Lampkin, 1999). There is generally a reduced reliance on external inputs, such as chemical fertilisers, and improved soil management techniques with strict controls and legislations controlling the production of organic food within the UK (Lampkin, 1999; Royal Commission on Environmental Pollution, 1996).

The period of conversion to an organic system varies depending on cropping history but most farms will first need to go through a two year period when the land is managed organically, but the crops and livestock cannot be marketed as organic. This is not always economically viable as crop yields are often reduced. Although financial support is available during conversion there is no guarantee of long-term improved income (Lampkin, 1999). The key to long-term success in organic farming is soil management; as a combination of reduced inputs and improved soil management, should lead to profitability. Even with small decreases in yield the organic price premium should compensate. There is a need to establish a comprehensive code of good soil management practices to guarantee profitability both in the long term and during the transition to organic farming (Defra, 2007).

1.1 Background to the research

Since the First Soil Action Plan for England 2004-2006 (SAP), the importance of soil in the agenda for sustainable development has increased. Defra (2004) defines soil as a ‘fundamental and irreplaceable natural resource’ promoting the need for good soil management. There are many different uses of soil; however, the majority of land in the UK (over 80%) is used for agriculture or forestry. This area needs to be targeted in terms of sustainable soil management.

Costanza *et al.* (1997) determined the seventeen ecosystem services and functions and attempted to place an economic value upon each. Seven of these are specifically associated with soil:

- disturbance regulation
- water regulation
- water supply
- erosion control and sediment retention
- soil formation
- nutrient cycling
- waste treatment

Disturbance regulation is becoming increasingly important as the effects of habitat change due to climate change are felt especially in terms of extreme flooding or droughts (depending upon location). Soil needs to be managed in a sustainable manner, especially on agricultural land, to ensure that these services are able to continue to function.

Prior to the Common Agricultural Policy (CAP) reform, soil management was neglected due to economic pressures and subsidies, which did not encourage sustainability and good management practices. This is beginning to change following the implementation of Cross Compliance conditions to the Single Payment Scheme

(SPS) in January 2005. Cross Compliance provides a baseline standard for agriculture and contributes to environmental protection, including soil erosion prevention and protection of soil organic matter (SOM) and structure (Defra, 2006a).

Defra in 2005 launched agri-environment schemes (environmental stewardship schemes), which build upon the base of Good Agricultural and Environmental Conditions through Cross Compliance. These include Entry Level Scheme (ELS), Organic Entry Level Scheme (OELS) and Higher Entry Level Scheme (HELS). The schemes encourage good environmental conditions beyond the SPS and farmers receive additional payments between £30-60 per hectare per year. These include OELS accounts for land in conversion (£175 per hectare per year) and only land that is farmed in accordance with the specified standards established by council regulation 2092/91 (regulated by private companies in the UK e.g. Soil Association) can enter this scheme.

Diffuse pollution has been a common problem for the farming industry for years leading to problems of eutrophication and blue baby syndrome (Merrington *et al*., 2002). The above schemes which were outlined also try to prevent this and align the UK with the Water Framework Directive (WFD). The EU WFD (2000/60/EC) states that the UK must protect, enhance and maintain all surface, coastal and groundwater bodies in order to achieve good chemical and ecological status by 2015. Therefore, nitrate vulnerable zones (NVZ) and catchment sensitive farming initiatives were set up to try and alleviate the effects of diffuse pollution relating to agriculture. This integrated catchment management of the air, water and soil also has potential benefits on water resources and flood risk mitigation (Environment Agency (EA), 2007).

In the UK, the occurrence of flooding, especially summer floods has greatly increased over the last few years (Environment Agency (EA), 2008). There are a number of factors which contribute to this: firstly changing climatic behaviours with different rainfall patterns altering both duration and intensity of rainstorms and secondly increasing loss of soil medium as a buffer against excess runoff (Godwin and Dresser, 2003). In urban areas surface sealing of the soil with tarmac and concrete has led to increased runoff being experienced and in rural areas poor soil management leading to compacted soil and low infiltration of rainwater. These lead to a 'peaky' flood hydrograph which if attenuated would reduce the extreme flood events experienced in the summer of 2007 in the UK.

One possible method of reducing runoff is through improved soil management and sustainable farming methods. Recently, the public's awareness of environmental issues and sustainable agriculture has increased through various government initiatives, such as Local Agenda 21. Many issues have been brought into the public spotlight through the media, for example, the sustainability of the world's food production, Genetically Modified (GM) and organic farming. The increased knowledge of the public has led to improved consumer choices and pressure to change unsustainable practices of soil management, highlighting the importance of market and consumer power. However, it is important to note that individual farmers are more driven by the costs of production such as fertiliser, labour and fossil fuels. To survive, farming businesses must balance being able to respond to consumer demand and production costs; this is not only reflected in price but also the safety and quality of the produce. There is a constant need to adapt to changing circumstances and become more efficient.

The UK government is trying to modify and monitor management to ensure environmental sustainability in agricultural practices via legislation and advisory papers (such as Code for Good Agricultural Protection of Soils). Hence, Defra (2007) produced several papers such as an action plan to develop organic sustainable farming and a paper on sustainable farming and food strategy. The Rural White Paper (Defra, 2007) recognised the key role of agriculture in rural England as a producer of food and an employer, in addition to the management activity that creates much of the countryside environment.

Much literature (Defra, 2006b) has been produced on the subject of diversification especially relating to farmers' understanding of the Common Agricultural Policy (CAP) reform. Diversification is advised by Nix (2010) as a method of supplementing income of the farm by:

- reducing the area farmed by selling land

- converting to organic agriculture
- using redundant buildings for alternative purposes
- and adding value to produce through direct selling to the consumer

This is fundamentally changing how land is farmed as more farmers are converting to organic systems as shown in Table 1.1 – an added benefit is higher payments from OELS (£60 per ha per year, Defra, 2006a).

Table 1.1: Total amount of certified organic land in England and as a percentage of agricultural land in the UK (Nix, 2010).

Year	Fully Organic (ha)	In conversion (ha)	Organic land as % of total agricultural land
2008	238, 255	53, 223	3.1
2009	258, 744	89, 037	3.7
2010	283, 949	90, 860	4.0

1.2 Research aims and objectives

Soil surface management in both arable and grassland farming can have a very significant effect upon soil structure and tilth, infiltration and runoff and energy use for tillage. Whilst the short-term effects of different soil management systems are well documented, the medium-term effects of alternative residue management and reduced tillage versus traditional plough have not been quantified. These data are important for improvements in soil workability, which in turn could influence farming practices and the costs of farming operations as well as improving infiltration rates [which may reduce flood risk downstream (Godwin and Dresser, 2003)].

1.2.1 Aim

The aim of this research is to investigate the effects of organic farming practices on soil properties, hydrology and workability at different scales in comparison to conventional farming practices.

1.2.2 Objectives

The specific objectives of the research are:

1. To compare the effects of organic and conventional management on soil physical, chemical and hydrological properties in both grass and arable fields
2. To determine the effects of soil management and tillage regime interactions with organic and conventional farming systems in terms of soil physical, chemical, hydraulic properties and soil workability
3. To estimate the potential economic benefits related to organic management practices from a reduction in runoff
4. To provide suggestions of best management practices

1.3 Managing the research

1.3.1 Project methodology

The project critically reviews existing available knowledge on agricultural systems and soil management. There is currently little information on the impact of land status (organic or conventional) on infiltration rates and the relationship between this and flood risk. This research aims to fill the knowledge gap for medium-term data and provide more information on the impacts of organic agriculture on soil properties and potential flood risk alleviation.

Several experimental investigations combine to achieve this aim; these experiments are both field-scale and plot-scale. They involve paired fields under both organic and conventional farming systems based upon: soil texture, previous land use and current crop rotation (see Appendix A for further details). The results provide sound scientific background to support the modelling aspect of the project which offers relevant information to policy makers linking the commercial and management aspects of this research.

The work comprises four phases that are shown in Figure 1.1. This four-phased approach to the research enabled suitable data to be collected in order to model a catchment suitable for predicting the effect of soil surface management on flood potential in organic and conventional farms. Phase one collected baseline data; whereas phases two and three provided data for validating the model. The model was implemented and validated in phase four.

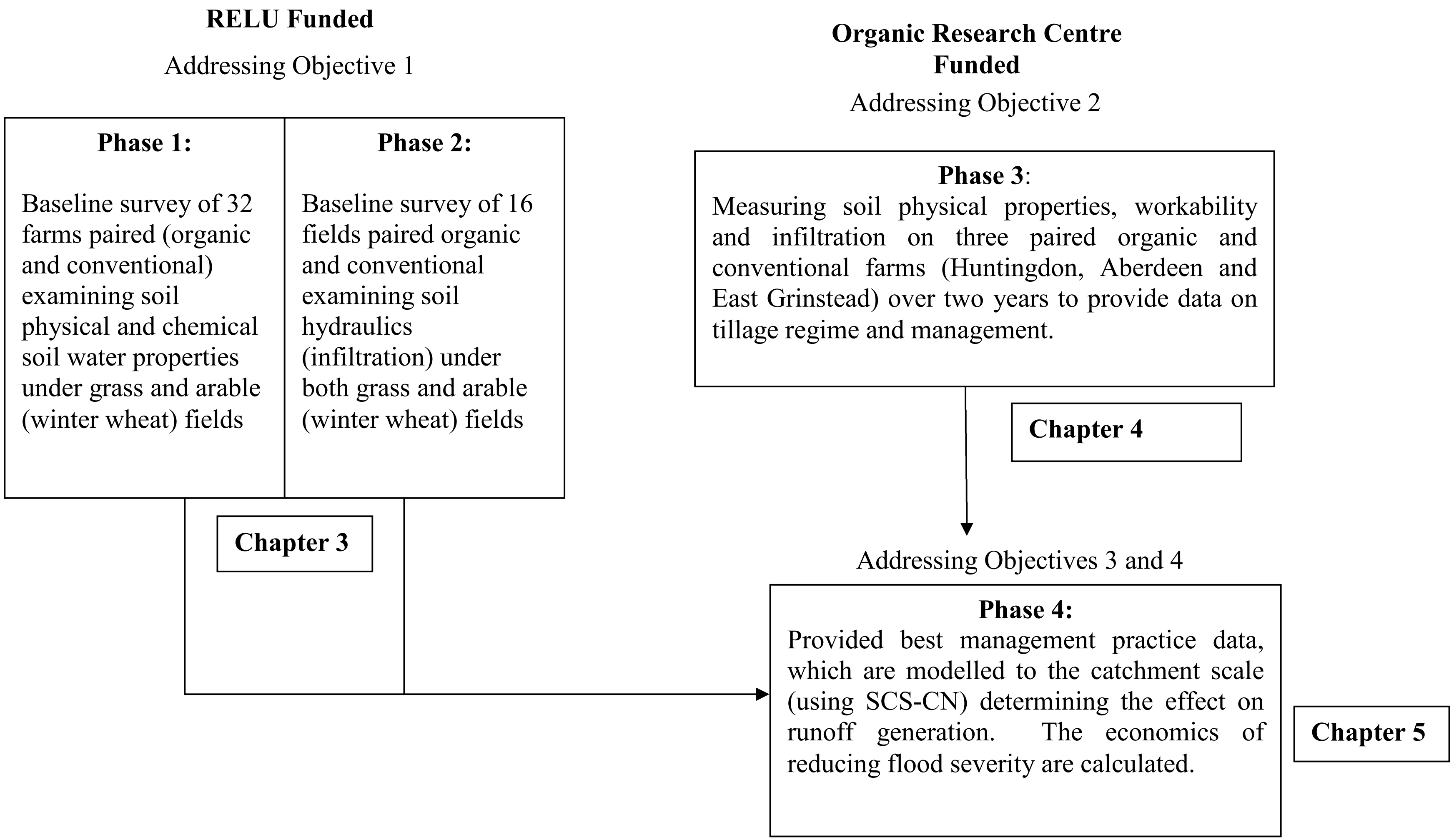


Figure 1.1: Overview of the different phases of research showing how this helps to fulfil each objective.

The project has been jointly funded by both Rural Economy and Land Use (RELU) programme and the Organic Research Centre (ORC). RELU is a government funded research body which uses interdisciplinary research to help inform future policies and management practice for the countryside and rural economy. This research formed part of a larger project investigating the scale effects of organic farming and this will be discussed further in Chapter 3. The ORC is a registered charity, which aims to develop and support sustainable land-use, agriculture and food systems; this research formed part of their investigations into soil health in organic farms.

1.3.2 Thesis structure

Chapter 1 provides an introduction to the research and background information, which links into the subsequent chapters. Chapter 2 focuses on reviewing the current literature on organic agriculture and comparative studies between organic and conventional practice, to help identify scientific and knowledge gaps within the literature. Chapter 3 details the first and second phases of the research and displays the results and principal findings from this research. Chapter 4 features the third phase of the research highlighting the methodology, results and discussion. Chapter 5 introduces the modelling aspects of the data in relation to runoff and flooding. Chapter 6 integrates the findings from Chapters 3, 4 and 5 to provide suggestions for best soil management. Chapter 7 reports the main conclusions of the research and ideas for future work.

2 Literature Review

2.1 Introduction

This section introduces the main findings from the literature review: firstly looking at the concept of organic farming and then considers both physical and chemical soil properties in this context. Subsequently, soil hydraulics and the implications for flood control are examined. Finally, it highlights alternative soil management practices and current policy relating to soil management. This section also aims to identify the current gaps in knowledge and hence provide justification for this research.

2.2 Organic Farming

It is essential to understand the differences in the agricultural system that exist between organic and conventional farming. The principles and regulations behind organic farming, in relation to the farming system but also specifically to soil management are highlighted. Then there follows a critical review of the current comparative research studies between organic and conventional farms.

A systems perspective is essential to understanding sustainability which is central to organic farming. The agricultural system is envisioned in its broadest sense, from the individual farm encompassing all aspects from soil to management, to the local ecosystem, on local and catchment scales (Hess *et al*., 2000). Sustainable agriculture is difficult to define, as the concept is holistic including production, environmental, economic and social factors. Therefore, organic principles will be highlighted in reference to Philipps (2003) who states that 'organic farming aims to achieve sustainability through the duplication of the natural biological cycles present in soils.' The organic farming methods aim to manage the soil so as to sustain and build soil fertility. This is achieved by recycling nutrients, maintaining soil structural stability and soil biological activity to achieve crop and livestock health; thus reducing the need for artificial inputs.

Philipps (2003) highlights two key areas where different principles of farming are applied between organic and conventional agriculture:

1. **Rotation Design** – in organic agriculture this needs to be adequate to provide a break between crops to avoid specific pests and diseases. It also needs to ensure that soil is not laid bare for prolonged period especially over winter. Organic farmers grow crops with different root structures (see Figure 2.1) to help improve soil structure; hence there is rarely continuous cropping on a field.

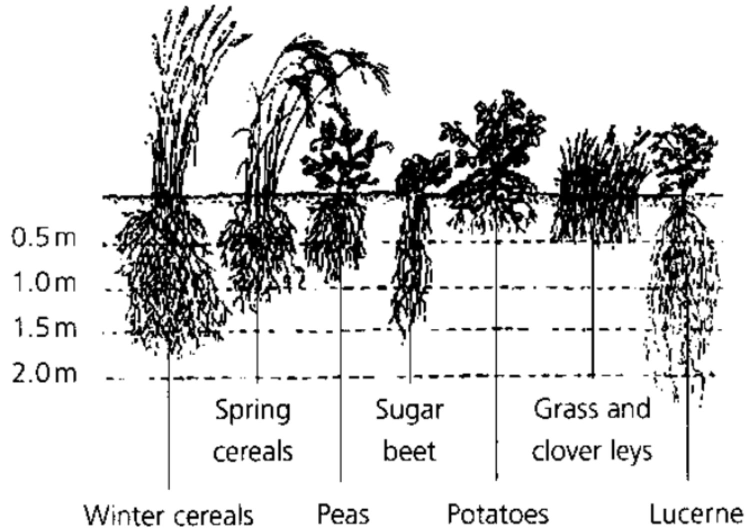


Figure 2.1: Rooting patterns of different crops, indicating the importance of crop rotations in organic farming for maintaining good soil structure (Adapted from Philipps, 2003).

2. **Fertilisation Strategy** – organic farms have strict guidelines to follow regarding the substances that can be allowed to fertilise the land. There are strict guidelines to follow about the length of time compost is required to have been matured especially if it is from a non-organic source (see Table 2.1).

Table 2.1: Required treatment of manures from non organic resources when being applied to organic land (Adapted from Philipps, 2003 and Defra, 2002).

Source of Manure	Treatment
Straw and farmyard manure (FYM)	Stacked for six months or composted for three months
Non-poultry manures from straw based pig units	Stacked for twelve months or composted for three months
Slurry	Aerated
Compost	Stacked for six months or composted for three months (restricted use of mushroom compost, worm compost and green waste if from non organic source)

According to Pulleman *et al.*, 2003, ‘soil plays a crucial role in defining sustainable management.’ This is because soil structure and organic matter are important for both soil workability and availability of water and nutrients for plants. Hence, the Soil Association’s (2010) definition of organic farming is highly relevant as it stresses management of a healthy soil by developing and protecting an optimum soil structure, biological activity and fertility.

In the UK, 68 % of the agricultural land is designated as Nitrate Vulnerable Zone (NVZ) (Defra, 2010). Any organic farms in these areas still need to comply with the rules and regulations involving amount, type and timing of applications of nutrients, (namely Nitrogen (N)) to prevent leaching. Generally, organic farms have to apply the lower amount 170 kg ha^{-1} N averaged over the cropped area; but this does differ according to land use, for example, 250 kg ha^{-1} N is allowed over grassed areas. There are also N_{max} limits which are based upon crop type grown and must be adhered to. There are closed periods where organic manures cannot be applied; usually from 1st August to 1st November for arable land (Shepherd *et al.*, 2003). This helps to meet requirements of the Water Framework Directive (WFD), which aims by 2015 to obtain good ecological status of all waterways in the UK.

In recent years, there has been a shift away from conventional agricultural methods towards organic techniques. The amount of fully converted land is 743 516 hectares and 4.6% of farms in the UK are registered as fully organic (Soil Association, 2010). This is higher than the amount estimated in Nix (2010) but the amount of land converting to organic status has decreased by 6.6 % since 2008 suggesting a reduction in the rate of conversion. Organic farming remains central in many debates, especially as the sales of organic produce have dramatically increased and now command a market value of £1.85 billion in the UK (Soil Association, 2010).

2.2.1 Comparative Studies

Several studies have been based on comparisons between organic and conventional farming methods, in terms of their implications for soil properties, microbiology and nutrient analysis (Marinari *et al.*, 2006; Pulleman *et al.*, 2003; Parfitt *et al.*, 2005; Wells *et al.*, 2000, Armstrong Brown *et al.*, 2000). Pulleman *et al.* (2003) compared conventional and organic arable farming on soil structure and organic matter dynamics. They concluded that although organic methods were favourable the farmer needs to be careful not to destroy the soil structure so that the benefits from increased biochemical activities are not lost.

Table 2.2: This table shows four broad soil characteristics and whether organic farming provided a benefit (+/ ++), no change (0) or a negative affect (- / - -) when compared with conventional farming methods (Adapted from Stolze *et al.*, 2000). The numericals show the number of studies relating to each soil property.

Soil Properties	++	+	0	-	--
Soil Organic Matter		5	2		
Soil Physical Structure			4		
Soil Erodibility	1	1	2	1	
Flood Prevention			3		
Soil Total	1	6	11	1	

Stolze *et al.* (2000) emphasizes the problem of inconsistent data between comparisons of organic and conventional fields on soil properties. Aggregate stability was found to be higher in organic management (Maidl *et al.*, 1988 and García *et al.*, 1994); however a number of European studies found no difference between conventional and organic (Diez *et al.*, 1991; Gehlen, 1987; König *et al.*, 1989; Petersen *et al.*, 1997). Long-term (greater than five years) trials have found that there is no significant difference in soil physical properties, bulk density and soil stability (Alföldi *et al.*, 1996; Rothamsted Research, 2005) between organically and conventionally managed soil. A positive effect from organic farming cannot be confirmed (only for topsoil – Maidl *et al.*, 1988), although, Shepherd *et al.*, (2002) suggested that organic farming produces a better soil structure, whilst comparing 90 fields organic versus conventional, and discovered that soil bulk density was negatively correlated with organic matter content of the soil. Stolze *et al.* (2000) reviewed comparative research between organic and conventional farming methods for a range of soil physical, chemical and biological properties. Table 2.2 reports their major findings; showing that the same property can be beneficial or have no difference depending upon the study. This highlights the difficulty in performing comparative studies between two different farming systems across a range of soil types with the majority of studies showing no major effects, some show a positive benefit and one a negative effect.

Soil Organic Matter (SOM) plays a central role in the maintenance of soil fertility and helps to limit physical damage. Some comparisons shows that organically managed soils have a higher total soil carbon content compared to conventionally managed soils (Armstrong Brown *et al.*, 1993; Labrador *et al*., 1994; Petersen *et al*., 1997; Pomares *et al*., 1994). However, in some cases no significant differences were observed (Amman, 1989; König *et al.*, 1989). This could be due to organic farming practices temporarily inducing a higher decomposition of soil organic carbon or could be linked to an increase in harrowing (mechanical weed removal) (Thomsen and Sørensen, 2006). Long-term investigations support the theory that organic soil management conserves more SOM. However, minimum tillage can also be seen as playing an important role in maintaining organic matter (Stolze *et al.*, 2000).

The DOC (Bio**d**ynamic, Bio-**o**rganic, **c**onventional) trial (Switzerland) compares bio-dynamic, organic and conventional system since 1978 in a long-term trial. The major differences in treatment are related to fertiliser regime and pesticide regime. Only the conventional system has inorganic fertiliser and the other two systems receive organic amendments; which typically contain 45-69 % of the nutrients (N, P, and K). The differences between the treatments after 17 years of the experiment are small in terms of soil properties, but there is increased microbial activity within organic and biodynamic systems. The results also indicate that the mean yields were 20 % lower for organic and bio-dynamic compared to conventional systems (Mäder *et al.*, 1996). Reganold *et al.* (1993) compared 16 paired biodynamic and conventional farms in New Zealand for a range of soil properties. They found that biodynamic soils had higher biological and physical quality, significantly greater organic matter content and microbial activity, better soil structure and lower bulk density. Earthworms were much more numerous on the biodynamic vegetable field than on the conventional vegetable field.

Defra funded a research project focusing on biodiversity into the benefits of organic agriculture compared to non organic farming practices for field, farm and landscape complexity (Norton *et al.*, 2009). This study concluded that organic farming was important for maintaining landscape and local complexity which was beneficial for biodiversity.

Armstrong-Brown *et al.* (2000) tested 30 paired organic and conventional farms across a range of soil types and management regimes. The farms ranged from grassland to horticultural/arable and purely arable. Pasture farms showed no significant differences in terms of soil physical (aggregate stability, bulk density, soil water retention) and chemical (SOC, pH, total N) properties between organic and conventional farms. The management factors deemed most important for differentiating between conventional and organic management included frequent farmyard manure applications to land and the inclusion of grass leys in arable rotations.

Due to the reduced reliance on manufactured fertilisers in organic agriculture, larger amounts of organic inputs (such as manure or compost) are needed to maintain nutrient supply. It was determined in a recent study by Bhogal *et al.* (2009) that repeated and large amounts (up to 65 t ha^{-1} organic carbon) of SOC were required to induce a measurable change in soil physical properties. However, many benefits arise from increased organic additions to the soil (a practice common in organic agriculture) such as improvements in soil quality, fertility and water holding capacity which in the longer term increase yield and hence improve farm economics. Although, there could be negative impacts relating to loss of nutrients both to the atmosphere and to water supplies (Bhogal *et al.*, 2009).

The positive aspects are provision of real data but, statistical analysis and hence generalisations can be problematic as all farms are unique (Lampkin, 1995). However, there are many different factors involved other than just organic or conventional practices; and there is a demand for this type of comparative data so results continue to be produced (Østergaard, 1996). van Diepeningen *et al.* (2006) suggested that soil texture had a much stronger effect on the soil physical characteristics than the management type.

2.3 Soil physical properties

Soils need examining in terms of chemical, biological and physical aspects, which are linked in complex interactions. Soil properties vary in terms of geographical location, parent material, climate, biota, land-use and management (Brady, 1990). This section reviews the current research into soil physical properties: soil structure, compaction, workability, aggregate stability, penetration resistance and shear strength.

Soil properties are highly significant to plant growth, the type of land-use and the management required for the best return from the land (Cresser *et al.*, 1994). Dexter (2004) produced an index of soil quality based on the idea that of physical properties are deemed more influential than chemical and biological properties. It incorporates observations on soil compaction, the amount of SOC and plant root growth. Overall, this index is useful as a better understanding of the interactions between physical, chemical and biological properties can provide a more helpful determination of soil quality and sustainability.

There have been many studies into different soil physical properties: structure (Håkansson and Lipiec, 2000; Papadopoulos *et al.*, 2006; Shepherd, 2002; Gerhardt, 1997), texture, aggregate stability (Eynard *et al.*, 2005; Pinheiro *et al.*, 2004; Hermawan and Cameron, 1993; Sparling *et al.*, 1992; Bronick *et al.*, 2005), bulk density and plasticity (Soane *et al.*, 1972; Archer, 1975) in relation to different land use, management and soil type. The following research papers reveal the links between various soil properties such as soil structure and compaction linked to the turnover rate of Soil Organic Matter (SOM) and its decline (Jensen *et al.*, 1996). Shepherd (2002) determined that SOM levels and management are the primary factors, which affect soil structure on both organic and conventional farms. Other studies illustrate the importance of soil organic matter and its positive effect on aggregate stability and shear strength in different cropping systems (Haynes and Swift, 1990; Tisdall and Oades, 1982; Chaney and Swift, 1984; Ekwue, 1990).

2.3.1 Soil Structure and Compaction

Soil structure is the three dimensional arrangement of mineral particles (sand, silt, clay) and pores within the soil (Dexter, 1988). Good soil structure enables crop development and growth through balancing water/oxygen supply to root systems, providing mechanical anchorage, forming seedbeds and buffering inputs of rainwater by infiltration and evaporation (see Figure 2.2). The management methods associated with organic farming induce the formation of an ameliorated soil structure, which is porous, better developed and has increased organic matter (Gerhardt, 1997).

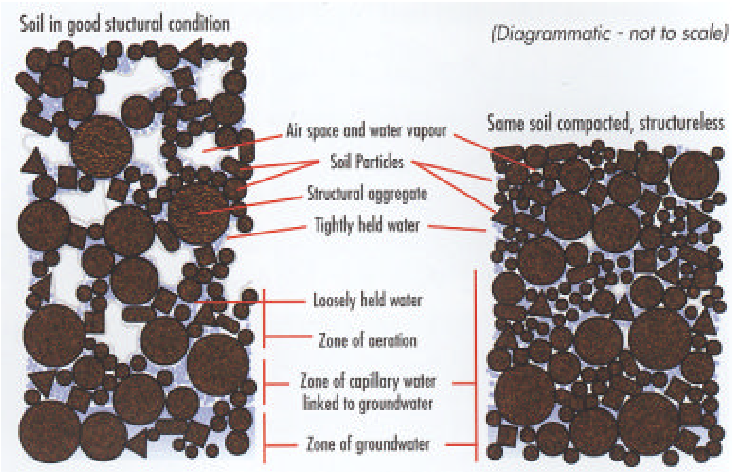


Figure 2.2: Compaction effects on soil structural conditions. Diagram a) shows good soil structure whereas diagram b) shows the effect of compaction on pore spaces (NSRI, 2001).

Soil structure is very important and is linked to soil porosity; the academic literature (summarised in Warkentin, 2001) has focused upon two key dimensions thought to be linked to good soil structure. These are SOM contents and external pressures on soil. SOM contents will be discussed further later in this literature review section. Warkentin (2001) outlined external pressures such as tillage, having a major impact on soil structure. Compaction of the soil, decreased porosity as well as habitat biodiversity but, post tillage nutrient recycling rates increased because of better aeration of the soil and improved microbial action during tillage operations. Gardner and Clancy (1996) found general trends for improved structure on organic farms but differences in individual parameters were rarely statistically significant.

Papadopoulos *et al.* (2006) investigated the effects of crop rotation on soil structure within a stockless organic arable system through analysis of macroporosity and pore size distribution. Significant differences between treatments were found in overall macroporosity percentage (11.7 %) with red clover (*Trifolium pratense*) having the highest. However, the benefits to soil structure and porosity from clover were initially large and significant but they were not long lasting (decreasing to 1.6 % after four years). This highlights the importance of including clover in the crop rotation not only for fertility building but also for the benefits to structure, macroporosity and infiltration.

Ball *et al*. (1997) provided soil physical properties data (bulk density, shear strength, cone resistance, macroporosity, relative diffusivity, air permeability and water infiltration) on the impact of arable cropping (yields) through tillage and compaction of soil structure. Ball *et al.* (1997) determined that the best method for reducing soil structural degradation and improving yields was zero-traffic but if the soil was compacted recovery took three years. Soil physical structural research now focuses upon the modelling of soil architecture which provides microenvironments that differ in physical, chemical and biological properties (Ranjard and Richaume, 2001; Young *et al*., 2001).

Raper (2005) provides an overview of the impacts of soil compaction in terms of reducing infiltration and erosion. The main findings will now be briefly outlined. Soil compaction and rut formation negatively impacts rainfall infiltration (reducing on clay soils by 18- 21 %) and rooting depth; hence can potentially cause increased soil erosion and runoff. Soil compaction effects can last for three years and may not be reduced immediately by tillage. Soil compaction is a function of soil type (Craul, 1994; Gaultney *et al*., 1982), management of the land (for example tillage regime), soil moisture content (reduced soil strength and compaction is more likely to occur if topsoil is close to field capacity), increased vehicle loadings and repeated loadings.

Compaction by vehicle traffic causes an increase in the sealing or capping of soils, which reduces infiltration. There is a reduction in water holding capacity of near the surface horizon, which decreases the amount of moisture available for plant growth. Gaultney *et al.* (1982) found that water stood for longer on compacted plots and that runoff rates were higher on soil that had been trafficked. Poor soil structure and compaction can contribute to impeded soil drainage and increase the amount of runoff or surface ponding of water on the land (NSRI, 2001). Raper (2005) suggests several methods to help reduce the effects of compaction in agricultural soils – smaller axle load, less tractive element and soil contact stress, increased soil drying and conservation tillage. Mueller *et al.* (2009) highlighted the benefit of reducing contact with the soil through controlled traffic and including perennials in the rotation for improving soil structure. Compaction is a problem that is present in both organic and conventional farming systems, which may contribute to flooding downstream in catchments (Environment Agency, 2007). The contribution of land management and preventative measures employed to alleviate these problems need to be quantified and related to the flood hydrograph to aid flood mitigation measures.

2.3.2 Soil Workability

A key function of an arable soil is its workability; creation of seedbeds suitable for seed germination and crop growth. The condition of land for field operations can be classified in terms of trafficability and workability. Trafficability is defined as when the soil can provide traction and withstand traffic without damage; whereas workability is defined as when the soil is suitable for cultivation and soil engaging operations (Earl, 1997). Currently, in the UK there are two main types of tillage system: inversion (including traditional plough-based systems) and non-inversion (including minimum tillage systems). Both systems have advantages and disadvantages; ploughing helps to ease weed problems, which can be prevalent in organic agriculture due to reduction in pesticide use, but it can cause soil compaction and erosion, which lower the workability of the soil. Minimum tillage especially at shallow depths can permit faster land preparation allowing more successful crop establishment before the soil becomes too wet for seedbed preparation (Morris *et al*., 2010a). However, there are still weed issues that can be controlled in organic agriculture by mechanical weeding or spraying in conventional agriculture. The major reasons for changing tillage systems are cost pressures associated with cultivation, such as increasing fuel and labour costs, and timeliness of operations (relating to the work days available). Therefore, as the climate changes and with different land management systems (organic and conventional), the type of cultivation whether minimum tillage or traditional ploughing should be considered. If the number of work days are reduced it may become a more viable option to use a minimum tillage system, which normally requires less work days compared to a traditional plough-based systems.

Watts and Dexter (1998) measured the tensile strength of soil aggregates and estimated soil friability for a range of differently managed soils. This showed that under arable land the amount of SOC and friability reduced compared to permanent pasture. Mueller *et al.* (2003) found the maximum soil water content for optimum tillage for cohesive soils to be 90% of the water content at the field capacity moisture content or for non-cohesive soils this is equal to 70% of the water content at the tension of -5kPa. This enables relatively quick measurements of workability in the field to be made. Rounsevell (1993) reviews the different types of model used to determine the workability of different soil types. He highlights the main components as soil properties (field capacity, plastic limit) and climatic data (rainfall and evapotranspiration). These models are empirical and there are limits to their usage especially in the short-term, for example predicting work-days within a week is not possible. However, they are useful for comparing the effects of climatic change (Cooper *et al.*, 1997) on work-day as well as changing management regime.

Studies have shown the importance of soil moisture content and plasticity in terms of workability (Mueller *et al.*, 2003; Baver *et al.*, 1972). These revealed that the soil plasticity and dry bulk density could be dependent on the type of SOM. Soil plasticity has also been linked to clay content and different soil management but ultimately whether the plastic limit increases or decreases with organic matter is related to texture (Archer, 1975).

Plasticity indicates how easily a soil can be deformed without cracking in response to an applied stress and is an indicator of the likely mechanical behaviour and workability of soils. Atterberg limits are important as these are linked to soil texture but can be affected by amounts of SOM (Campbell, 1991). The amount of SOM does not affect the plasticity index; however, it creates a strong bond with water raising the position for the plastic and liquid limits (Brady, 1990). Baver *et al*. (1972) suggested that SOM would cause a shift in the plasticity index extending the friability zone to fairly high moisture contents.

2.3.3 Aggregate stability

Aggregate stability is an indication of soil strength related to soil structure and amount of SOM present. It impacts on aeration, water and nutrient supply, thus affecting plant growth (Tisdall and Oades, 1982). Changes due to management and different land-uses can cause a response in aggregate stability shown before changes in SOM are observed (Haynes and Swift, 1990).

Kemper and Koch (1966) tested the relationship between SOM and aggregate stability. They determined that lower levels of SOM increased the variability of arable soils. Tisdall and Oades (1982) draw some conclusions from their study. Firstly, that above a certain amount of SOM (which varies depending on soil type) no additional stabilising effect can be felt. Secondly, particle arrangement is more important in some soils than the absolute amount of SOM present.

Haynes and Swift (1990) revealed that air-drying could improve aggregate stability where there is high SOM and porosity as it is able to retain more water. Likewise, this method decreases aggregate stability where there is less SOM; and may mask the effect of treatment. Haynes *et al.* (1991) found a difference between two different land-uses for aggregate stability. However, research by Hathaway-Jenkins (2006) did not correspond with this trend in aggregate stability. This emphasises that soil textural similarity (clay content) can have a larger impact on aggregate stability than the amount of SOM present.

The SOM content is important for structural development and aggregate stability (Shepherd *et al.*, 2002; Tisdall and Oades, 1982) which is related to the type of SOC, as Sparling *et al.* (1992) outlined the difference between microbial C and total SOC. Only part of SOC is responsible for stability of soils and organic materials are not the major binding agent. A fine network of polysaccharides, roots and hyphae, not measured in SOC, hold the aggregates together - these are affected by management practices (Tisdall and Oades, 1982). SOC is protected from microbial decomposition when occluded within stable aggregates, which are able to withstand wind and water erosion. The more unstable aggregates break up due to tillage erosion and hence accelerate the decomposition of SOC previously enclosed within the aggregates (De Gryze *et al.*, 2007). Macro aggregation is dominated by landscape-scale processes such as water and tillage erosion rather than the local variables such as variations in organic matter or texture (De Gryze *et al.*, 2007). SOM plays an important role in soil structure and aggregate stability is highest under grassland, decreasing rapidly under arable cultivation (Loveland and Webb, 2003).

2.3.4 Shear strength and penetration resistance

Shear strength is conveyed through cohesive forces between particles and frictional resistance met by particles that are forced to slide over each other (Marshall and Holmes, 1988). The strength of soil affects its behaviour: load bearing, tillage, compaction and root penetration. Soil strength can be affected by the amount of SOM and moisture; SOM increases whereas moisture decreases the strength of the soil (Smith and Mullins, 1991).

Penetration resistance is a measure of the soil resistance to the entry of any device or biological matter. It varies depending upon soil physical properties such as particle size distribution, water content, resistance to compression and shear strength (Campbell and O'Sullivan, 1991). The limiting resistance for root growth in untilled soils are 4.9 MPa and tilled soils are 3.6 MPa (Ehlers *et al.*, 1983).

The penetration resistance of a soil is controlled more by soil strength rather than bulk density. Ekwue and Stone (1995) reported that bulk density, penetration resistance and shear strength of soils increased with incremental increases in moisture content to a point. SOM also plays a part in this relationship. At low moisture content and high SOM penetration resistance is reduced; yet, at high moisture contents and high SOM penetration and soil strength is increased. However, after peak values (dependent on soil texture) are achieved further moisture increases caused decreases in these soil properties. Improving a soil's resistance to compaction can be achieved by increasing soil strength through reducing soil moisture. Allen and Musick (1997) found that relatively moist soils (above 60% field capacity) during heavy traffic operations greatly increased compaction and decreased infiltration even for a relatively lightweight tractor.

2.3.5 Summary

Overall, this section has highlighted importance of soil physical properties and their interactions; the knowledge gaps are identified and will now be further explained. There were few UK-based studies on the relative benefits of organic or conventional systems for soil quality. Hence there is a need to look at the effects of organic farming shown in European countries and determine whether the same benefits can be found in the UK. These benefits in soil quality have been shown to relate soil physical quality and compaction to the amount of water infiltration. This is shown as an area that requires more research to investigate the impacts of changing land management on soil structure in the UK and the impacts on water infiltration.

2.4 Soil chemical properties

Soils are key determinants of land-use and are highly important in terms of fertility and crop growth. A fertile soil is 'capable of producing a desired crop with favourable yield and quality characteristics' (Cresser *et al.*, 1994). Soil chemical properties will be discussed in the following section. These are highly important as differences in the level of soil organic matter can influence the soil physical properties which in turn will influence the availability and leaching potential for the major nutrients required by crops (nitrogen, potassium, phosphorus).

2.4.1 Soil Organic Matter (SOM)

Soil Organic Matter (SOM) is a key requirement in sustainable agriculture. SOM is a set of fractions ranging from light macro-organic, biomass carbon, mineralisable carbon, carbohydrates and enzymes. SOM increases linearly with input levels (such as green manures) but this is very dependent on climate, soil type and most importantly soil management (Parton *et al.*, 1996). In terms of soil management, additions of SOM from crop residues or organic amendments increase the concentration of free low density macro-organic matter by 10-40% and this in turn affects the properties of soil (Carter *et al.*, 1998; Kay, 1998).

SOM is both a source and a sink for plant nutrients and provides energy substrate for soil organisms. It helps to stabilise macro and micro aggregates to promote infiltration of air (Tisdall, 1996). It promotes water retention and influences the fate of pesticides (Gregovich *et al.*, 1994; 1997). It also influences soil physical processes through mycorrhizal fungi such as compactability (Soane, 1990), friability (Watts and Dexter, 1998) and soil erodibility (Feller and Beare, 1997).

There is a need, highlighted by Carter (2000) to monitor changes over time, test the methods of estimation, protect soil functions that are provided by SOM and prevent irreversible declines. Loveland *et al.* (2000) recognise that the use of monitoring SOM over short periods is not helpful as changes are very small. Analytical methods measure Soil Organic Carbon (SOC) content, which is related to SOM by multiplying by a factor of 1.72. Changes in SOC are generally slow to occur and difficult to measure against the large background of carbon content in arable soils in the UK (Chambers *et al.*, 2007). Returning organic materials to the soil is important for maintaining the existing SOC levels and completing natural nutrient and carbon cycles.

Loveland *et al.* (2000) also highlight that the critical SOM values are soil specific range of factors based on the most limiting soil function/ process. The amount of clay present will influence the SOM due to the protective adhesive nature of the clay particles (Webb *et al.*, 2003). Therefore, it is important to be careful when comparing SOM levels due to crop derived carbon and erosion related to topography. Greenland *et al.* (1975) used dichromate oxidation to determine SOM levels of soils and determined that soils with less than 2% SOC were unstable whereas 2-2.5% SOC were moderately stable and greater than 2.5% is stable. These data are unsubstantiated but, based on reviewing findings at the time, Loveland *et al.* (2000) concluded that soil structure is likely to become unstable if SOM contents fell below 3.4 % or 2 % SOC.

Soil disturbance by tillage is believed to be the primary cause of the historical loss of SOC (Baker *et al.*, 2007). Some soil scientists have been investigating the effect of conservation tillage and organic land management to determine if this leads to substantial SOC sequestration. However, Baker *et al.* (2007) highlight that there is a lack of long-term data that would support this conclusion and hence, whilst there are benefits in terms of soil structure and porosity, carbon sequestration should not be a motive for changing tillage regime.

Körschens and Müller (1996) studied the effects of N fertiliser and FYM on the crop yield, SOC and total N level. They found a positive correlation between management practice (organic or conventional), crop yield, amount of SOC and total N. They also found that the SOM additions were ineffective in sandy soil compared to the loam. This is due to compaction and the need for better land management. Raupp (1995) supports this finding with results from a long-term plot experiment demonstrating SOM differences between agricultural systems due to organic matter inputs. After *circa* 10 years of treatments SOM increases in the following order: conventional (0.79% C) < organic (0.92% C) < biodynamic (1.02% C). The importance of actual organic matter inputs to the soil in influencing SOM contents is illustrated by Amman (1989) who found no differences in SOM content between organic and conventional. Armstrong-Brown (2000) showed that in general arable soils contain less SOM than grassland soils but the texture of the soil is more important, especially the amount of clay and silt.

2.4.2 Nitrogen

Several nutrients are required for plants to grow, these are classified as primary (nitrogen, phosphorous, potassium), secondary (calcium, magnesium, sulphur) and micro nutrients (Miller and Gardiner, 2001). These nutrients are all required in different quantities depending upon the crop; however any deficiencies can reduce yield (Archer, 1988). Deficiencies in the primary nutrients can be the major limiting factors to growth and are also the nutrients responsible for most agricultural pollution.

Deficiencies in N are the major reason for poor crop production especially in organic farming systems. Conventional farming systems use inorganic substitutes and sometimes a combination of FYM to help boost levels of N; these are carefully matched with the requirements of the crop and applied during the appropriate stage in the growing cycle as determined by RB209 (Defra, 2010). Total N can be seen more as a reflection of fertiliser regime in arable fields. It affects the bulk density (ρ_b) due to fungal growth, hyphae, which aid structural development (Tisdall, 1996).

In organic farming systems, N is provided by the use of legumes in the crop rotations to help fix N from the atmosphere, residue management (recycled into the soil) and addition of compost or animal wastes (see Figure 2.3). This can be difficult to manage as these methods are highly dependent upon biological activities to ensure that N is available in the correct format for crop uptake. Therefore, there is a higher potential for N to be available when not required by the crop and hence a greater risk of leaching (Philipps, 2003).

Bremer (1975) found that 95 % of the total nitrogen found within soils occurs in the unavailable organic form. The remaining amount of total nitrogen is in the inorganic form which if not taken up by crops is at risk of leaching (Cooke, 1982). Defra (2004) suggest that in England up to 70% of the nitrate leaching into water courses originates from agricultural land.

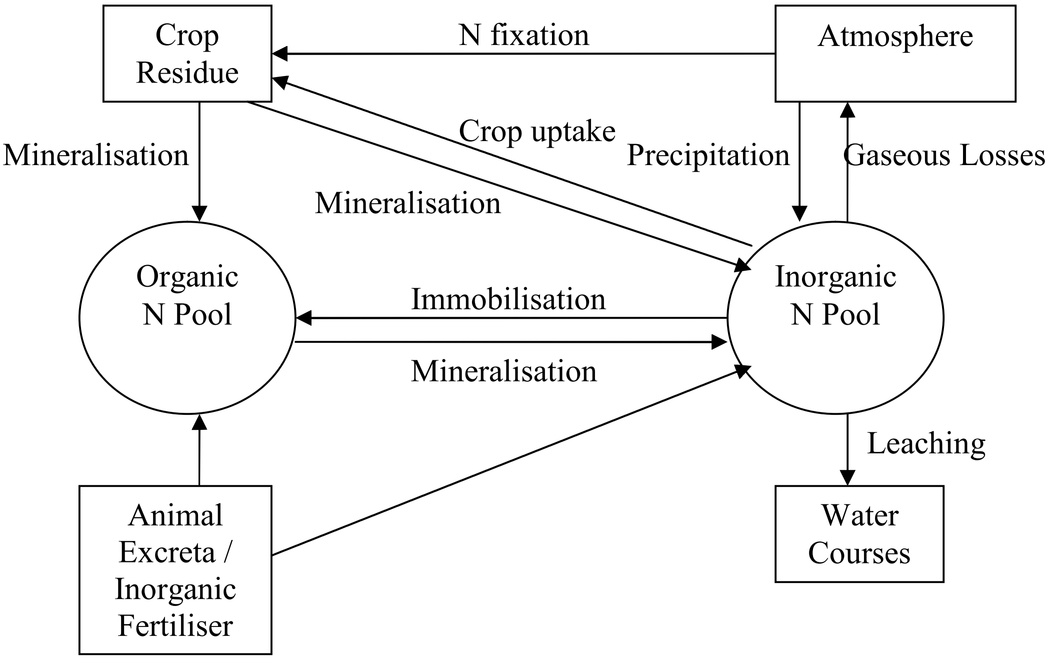


Figure 2.3: Simplified soil nitrogen cycle for organic and conventional farms. Mineralisation comprises of several processes aminisation, ammonification and nitrification which is performed by micro-organisms (Adapted from Phillips, 2003).

Nitrogen cycle is closely linked to the Carbon (C) cycle and in soils they are inseparable (O'Sullivan *et al*., 2001). The C: N ratio is very important as it helps to determine the ease that N containing compounds can mineralise and indicates whether the soil is mineralising or immobilising C or N (Ashman and Puri, 2002). C:N stocks in soil are not affected by tillage and crop rotation in arable soils (Nicolardot *et al.*, 2007). Shepherd (1999) showed that the method of incorporation of residues had no effect on leaching potential and that mineralisation is greater when the land is cultivated. The ploughing of grassland can have a great impact upon the SOC contents and available N as it releases the stored carbon which reduces the efficiency of N usage (O'Sullivan *et al*., 2001).

Low and Armitage (1970) examined the effect of soil use and management on leaching in England; the largest amount of nitrate leaching occurred in fallow land (greater than 100 kg N ha yr^{-1}) followed by white clover (less than 25 kg N ha yr^{-1}). This has serious implications for the management of organic land as crop rotations including ley and clover are essential in an organic system.

2.4.3 Phosphorus

The amount of phosphorus (P) in the available pool is very small and, to become available for crop uptake, it is released from readily mineralisable organic matter or unstable compounds (see Figure 2.4 Philipps, 2003). Mycorrhizal fungi play an important role in ensuring availability of P for in crop roots. P needs to be maintained for long term fertility and in organic systems this is achieved through the use of manures, composts and residue management.

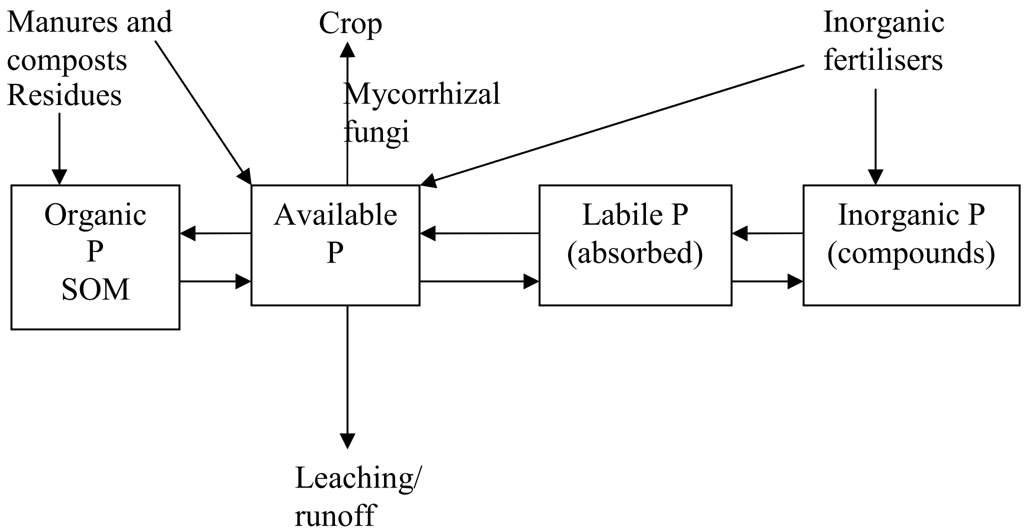


Figure 2.4: Simplified diagram of the soil P cycle (Adapted from Philipps, 2003 and Troeh and Thompson, 1993). P changes form from organic to available through mineralisation and the reverse by immobilisation.

Mineralisation and immobilisation of P is affected by pH, soil moisture and temperature. The availability of P is greatest when the pH is between 6.5 and 7; at lower and higher pH, P precipitates or adsorption increases and hence is unavailable (Ashman and Puri, 2002).

If the level of P within the soil is high, above 70 mg l^{-1} extractable P (Smith *et al.*, 1998) then there is a high risk of P erosion (particulates) and runoff (dissolved P); which can contribute to eutrophication of watercourses. Shepherd and Withers (2001) stress that P – inputs should be lowered to help prevent eutrophication.

2.4.4 Potassium

Potassium (K) availability is less dependent upon the biological activities compared to N and P. K is often needed in large supplies as plants assimilate more potassium than is required ('luxury consumption'); therefore K can often be in short supply even though it is fairly mobile (Ashman and Puri, 2002). The texture of the soil greatly affects the likelihood of leaching, for example a sandy soil is more likely to leach K (Philipps, 2003). In organic systems, composts and manure applications are used to return K to the land; however it can be difficult to control K fixation and monitor the reserves of K within the soil (Andrist-Rangel *et al.*, 2007). Gosling and Shepherd (2005) found that extractable K was significantly lower in organically managed farms; it is argued this is because organic systems are mining the reserves of K which built during conventional management. Hence, the build up of or removal of nutrients (nutrient budgets) are particularly important to monitor in organic systems to aid long term fertility of the soil and prevent erosion and leaching.

2.4.5 Nutrient Budgets

A soil surface nutrient budget can be calculated for a farm using information about the field management and measurements of the soil, crops and manure. Berry *et al.* (2003) studied nine organic farms and determined nutrient budgets for each of them. Nutrient budgets for seven of the farm rotations showed an N surplus and six a P surplus and three a K surplus; only rotations with large amounts of manure added or imported feed showed a K surplus or a balanced K budget. These indicate that there is no reason why organic farms should be inherently unsustainable in relation to N (see Table 2.3).

Table 2.3: Summary of two European countries for N, P, K balances (kg ha^{-1}) in organic and conventional farms (Adapted from Stolze *et al.*, 2000).

Country	N balance Organic	N balance Conventional	P balance Organic	P balance Conventional	K balance Organic	K balance Conventional
Sweden	-15	+44	-12	+37	-4	+39
Germany	+42	+118	-4	+13	-27	+31

The formulation of nutrient budgets has major implications for understanding nutrient availability and cycling (Shepherd, 1999; Withers *et al*., 2001; Powlson, 1993; Smith and Chambers, 1993). These studies highlight the potential nutrient savings which can arise from using organic amendments, as in organic farms there is a reduced reliance on inorganic fertilisers. Inorganic fertilisers are increasingly more expensive due to rises in fuel prices and hence production costs. The use of FYM (farmyard manure) and organic manure have been studied for its effects on soil fertility and leaching in both organic and conventional management systems (Wong *et al.*, 1999; ADAS, 2002). FYM was found to have positive effects for soil fertility due to increasing SOC contents.

It is important to note the differences in the fraction of the organic amendments. The nutrients are mainly in the organic fraction and hence are not readily available to the crop for uptake until mineralisation has occurred. This is aided by the soil microbial community, which is larger where there are higher levels of organic matter (substrate). Crop rotations are the key to organic farming systems both in managing nutrients, pests and soil fertility as well as increasing the amount of SOM present (Stockdale *et al.*, 2002). The general conclusion that can be drawn from the literature is that nutrient surpluses are smaller for organic than conventional farms, when comparing the same farm types.

2.4.6 Summary

Overall, this section has outlined the principles underlying soil chemical properties and the research that has already occurred. The areas that are important for research include dynamics of SOM or SOC; this is increasingly being conveyed into the agenda for addressing climate change. A potential change in land use or management can reduce or enhance the amount of SOM and affect major nutrient cycles. Whether SOC can be sequestered on organically managed agricultural land and through reducing tillage in the UK has not been investigated. Whilst nutrient cycling and SOC dynamics are not the main focus of this research, it is vital to understand the impact on sustainability of the farming system. This research compares organic and conventional farming systems in terms of SOC and will investigate whether SOC is able to be sequestered on organic farms.

2.5 Soil hydraulic properties

Soil surface conditions play a major role in determining the rates of water infiltration and evaporation from the soil (Lampurlanés and Cantero-Martínez, 2006). Tillage is the most effective method to alter pore space combined with residue cover and surface roughness. Therefore, this section will firstly discuss porosity and infiltration before considering the effects of tillage on hydraulic conductivity.

2.5.1 Porosity

Porosity is determined by the arrangement of the solid particles; if soils are compacted the porosity is low (Brady, 1990). Where there are larger SOM contents, the porosity is generally large. Soil pore characteristics are dependent upon soil texture but are affected by seasonal management (short-term) and probably provide the basis for later significant changes also in mechanical tilth characteristics (Schjønning *et al*., 2007). As soil structure develops and improves, soil becomes increasingly porous, pore spaces form between peds and soil becomes less dense so bulk density decreases; experimental work by Antille (2006) into low tyre inflation pressures reduced compaction of soils and confirmed this relationship. The porosity of a soil is important in terms of water retention (to alleviate flooding) but also to provide enough water for crops to maintain yield (see Figure 2.5 for moisture release curve). Soil water flow at the soil surface is mainly regulated by macropores even though it is a very small fraction of total soil porosity (Moret and Arrué, 2007).

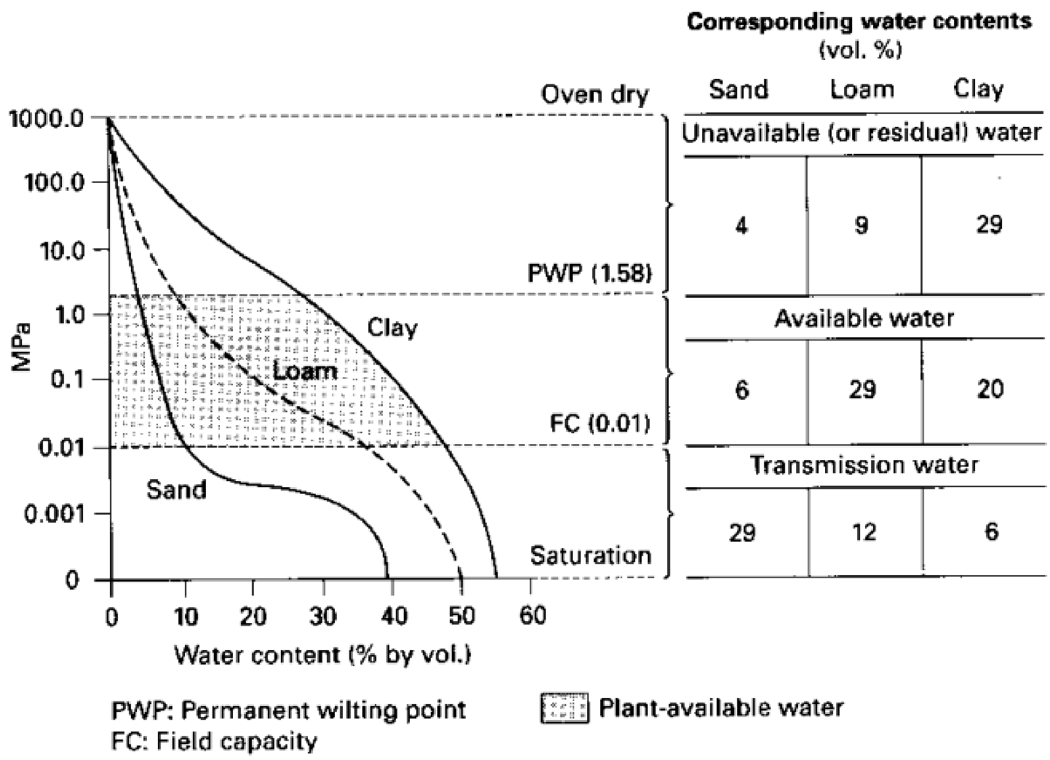


Figure 2.5: Soil Moisture release curve showing how water is held by different soil textures (Source Ashman and Puri, 2002).

Field Capacity is defined as the point after saturation when all the gravitational water has drained (Miller and Gardiner, 2001). Figure 2.5 shows field capacity as 0.01 MPa (10 kPa) but in this research the UK standard 5 kPa was used (Hall *et al.*, 1977). It is important as this determines the length of time when a field is able to be worked. Godwin and Dresser (2003) suggest that a method of flood prevention would be to ensure that during a peak rainfall month soil is not near to field capacity so as to increase water storage capacity. This could be achieved through adequate field drainage and prevention of soil compaction through the use of zero-traffic or low inflation tyre pressures (Antille, 2006).

2.5.2 Infiltration Rates

Infiltration is the entry of water into the soil via the soil surface; it is similar to hydraulic conductivity which is a measure of the downward movement of water through the soil profile (Godwin and Dresser, 2003). Any surface water that cannot infiltrate into the soil may runoff the land into rivers and streams through quick flow processes. Therefore, improving infiltration rates is essential to reduce runoff and flooding downstream in a catchment.

Infiltration is affected by the type and amount of vegetation and surface cover, soil texture and structural condition and moisture content of the soil (Godwin and Dresser, 2003). Surface land management can modify these variables influencing the amount of surface storage, infiltration rate and capacity of the soil to retain water. If porosity is large (greater than 30%) and pores are continuous, then the soil water storage capacity and the potential for deep infiltration also large. This can be enhanced through the use of a residue cover which promotes infiltration and prevents evaporation as it provides soil aggregation and structural stability (Lampurlanés and Cantero-Martínez, 2006).

The tillage regime can drastically alter the infiltration of soil depending upon the soil structural conditions and the level of SOC present. Franzluebbers (2002) identified that a uniformly stratified SOC through the profile helps reduce bulk density (by 12 %) and increase water retention (by 37 %). He also determined that tillage in the short term increased soil porosity; however, tillage dispersed the soil structure and mixed surface SOC which is a critical feature controlling water infiltration, storage and transmission in soils. Ball *et al.* (1997) reviewed several studies and concluded that under various soils and climatic conditions no tillage regime can lead to a decrease in structural porosity in the upper part of the soil. Comparisons with conventional tillage regimes show that no tillage regime can result in greater (Ball *et al.*, 1997), or smaller (Lampurlanés and Cantero-Martínez, 2006) infiltration rates. Schnug *et al* (2006) investigated infiltration rates on organic and conventional farms in Germany and found that improving soil porosity helped increase infiltration and could contribute towards mitigating flood peaks.

Over the past 30 years, agricultural land use has been changing from rotational grassland and arable farming to intensive arable only stockless systems. This has contributed to degradation and compaction to soils; which can reduce the amount of infiltration and increase the speed of runoff. At the local scale this is seen through 'muddy floods' which damage roads and properties (Boardman *et al.*, 2003). Monitoring studies have been carried out at the plot/ field scale in terms of the impacts on surface runoff and drainage flows (Burt and Slattery, 1996; Davies *et al.*, 1973; Melvin and Morgan, 2001). Mainly these were carried out in lowlands covering a range of land uses and management practices (cultivation and runoff mitigation measures).

However, the extent to which farming practices affect flooding at the catchment scale during a rainfall event is unclear (O'Connell *et al.*, 2007).

Table 2.4: Effects of soil degradation on SPR HOST classification (Adapted from Holman *et al*., 2002 in Godwin and Dresser, 2003).

HOST Class	SPR (%)	Degraded HOST Class	Degraded SPR (%)
1	2	3	12
2	2	3	12
3	12	7	21
4	2	3	12
5	12	7	21
6	34	18	47
7	21	10	35
8	30	18	47
9	25	No Change	25
10	35	No Change	35
11	2	No Change	2
12	60	N/A	N/A
13	2	3	12
14	40	15	48
15	48	N/A	N/A
16	22	21	47
17	29	19	45
18	47	26	59
19	45	22	60
20	47	23	60
21	47	26	59
22	60	27	60
23	60	No Change	60
24	40	26	59
25	50	29	60
26	59	10	N/A
27	60	18	N/A
28	60	N/A	N/A
29	60	N/A	N/A

2.5.3 HOST

Hydrology of soil type (HOST) is the classification of the main soil types in the UK into 29 classes (Boorman *et al.*, 1995). These 29 classes are based upon soil physical properties that are correlated with catchment scale hydrological variables and the dominant pathways of water movement through the soil and substrate (base flow index, BFI and standard percentage runoff, SPR). BFI is the long-term average proportion of flow that comes from stored sources and SPR is the percentage runoff derived from event data, adjusted to standard rainfall and catchment moisture conditions (Boorman *et* *al.*, 1995). This model allows the level of degradation of soil to be input and hence modifies the HOST class (see Table 2.4). A physically degraded soil, for example compacted, can lead to a significant change in the amount of runoff for most of the HOST classes (Godwin and Dresser, 2003). These data are useful in flood estimation and predicting the individual flood events and durations.

2.5.4 Flood Risk

According to the Environment Agency (EA) (2008) 5 million people live in areas which are at risk of flooding. In addition to this 1.3 million hectares of the most productive agricultural land in England and Wales are in the flood plain. Increasingly the effects of extreme rainfall are being felt as widespread serious flooding occurred in England and Wales in June and July 2007.

The EA (2008) believe that the flooding was caused by drains, river channels and flood defences being overwhelmed by the extreme flows of water. This could be linked to building on flood plain land as well as the intensification of agriculture. Both of these would have the effect of capping the soil surface and preventing the water from being absorbed or percolating through the soil. This would mean that there is more water running overland – a quick flow process which is causing the peaky hydrograph (Figure 2.6) and this makes flood risk areas difficult to predict.

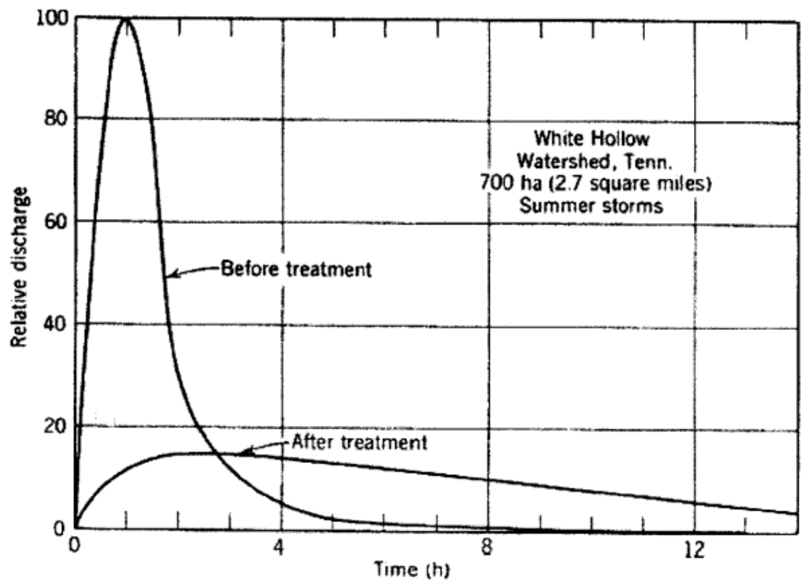


Figure 2.6: Effect of land management on flood hydrograph. The 'before' treatment indicates the 'peaky' flood hydrograph and the 'after' treatment shows the attenuated flow and mitigated flood risk (Source Godwin and Dresser, 2003).

During autumn of 2000, England and Wales experienced severe flooding. Holman *et al.* (2003) hypothesise that due to the wet weather in both spring and autumn there was increased potential for soil structural damage or degradation. In the five catchments that were studied all fields of different land uses (arable or grassland) should signs of damaged topsoil structure and linked to the Soil Conservation Service (SCS) curve numbers revealed the enhanced runoff values (see Figure 2.7). This highlights the need for an holistic catchment-wide approach to managing the interactions between agricultural land use and hydrology to help alleviate flood risk downstream.

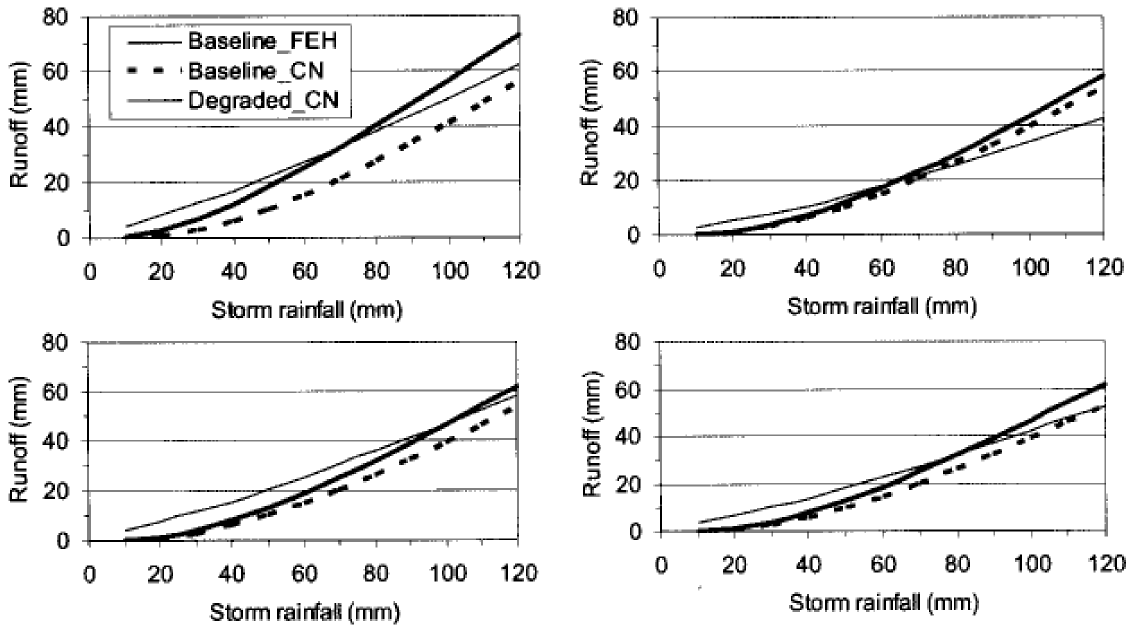


Figure 2.7: Potential increase in runoff caused by soil structural degradation for a range of rainfall events on four different catchments in the UK (Source Holman *et al.*, 2002). Flood Estimation Handbook (FEH) and Soil Conservation Service Curve Number (CN) show two different modelling of runoff with a degraded option on CN.

2.5.5 Summary

This section has outlined soil hydraulic properties (porosity and infiltration) and the research that has already occurred in relation to SOC levels, soil structure and tillage regimes. The HOST classifications are also described and current flooding problems in the UK. It also provides a brief discussion on two techniques for hydrological agricultural catchment modelling. However, there are no specific studies comparing organic and conventional farming systems in the UK. Overall, there is a need to establish a solid research base with field trials investigating the effects of organic farming in terms of water storage (Defra, 2004).

2.6 Soil Management Practices

The method of soil management adopted can have implications for infiltration and water retention capacity of soils as well as affecting nutrient cycles and decomposition of SOM. Changing soil management methods either through tillage regime or residue management can improve infiltration and reduce capping and improve available pore space by reducing compaction (Godwin and Dresser, 2003). This section looks at the impacts of different tillage schemes on soil properties.

2.6.1 Tillage regimes

Three main tillage regimes will be considered: conventional tillage, reduced cultivations (minimum / reduced tillage) and direct drilling (no tillage). Raper (2005) outlines the typical numbers of passes for a conventional tillage scheme as: initial primary tillage, secondary tillage, additional secondary tillage, planting and repeated spraying or cultivation operations during the growing season, harvest. During these operations up to 70 % of the field is trafficked which has implications for soil compaction. Peigné *et al.* (2007) define minimum tillage as a range of tillage practices that are mainly non-inversion. There is a reduction in typical number of passes which are: planting, spraying if necessary, harvesting and cover crop establishment (Raper, 2005). Another aspect of tillage regime is controlled traffic; this involves crop zones and traffic zones that are permanently separated (Chamen, 2010). The traffic lanes are compacted and hence are able to withstand further traffic without more deformation (Raper, 2005).

There are potential advantages of reduced tillage in preserving soil quality, fertility and preventing degradation and compaction. However, not all soil or agricultural systems (for example) organic are suitable for direct drilling or reduced cultivations. Organic systems can suffer from greater problems relating to weeds and restricted availability of N (Peigné *et al.*, 2007).

Reduced tillage and no tillage can help to improve soil structure and stability which increases soil moisture content, lowers compaction and increases SOM (Holland, 2004). This can be attributed to the reduced use of heavy machinery which promotes aggregate formation, maintains porosity and increases water infiltration. There is also potential for less energy to be consumed due to lower fuel requirements, fewer pesticides and fertiliser uses; therefore directly reducing the amount of fossil fuels consumed (see Table 2.5).

Table 2.5: Energy inputs for three tillage systems highlighting economic efficiency (Adapted from Davies *et al.*, 2001).

Tillage System	Energy Requirement (MJ ha^{-1})
Direct drilling (zero cultivation)	35-80
Reduced cultivations (tines and discs)	100-230
Traditional cultivation (mouldboard)	200-360

Conventional tillage can cause the break down and decomposition of protected SOM especially after a number of years with no tillage (Nicolardot *et al*., 2007). This break down of SOM can lead to increased compaction and reduce water holding capacity of a soil (Raper, 2005). Deep tillage helps to mix the SOM over a greater depth, which can increase the immobilisation and fixation of N in subsoil. This can reduce the SOC level in the soil, which in Nicolardot *et al*. (2007) was determined to be 285 g m^{-2} higher under no-tillage than conventional tillage. This work was based in Germany measuring three different tillage systems: mouldboard plough, two layer plough and loosening over three years. They determined that aggregate stability was greater under loosening only treatment.

The level of SOM in the soil needs to be carefully monitored especially on organic farms. Reduced tillage needs to be approached carefully on organic farms and include perennial mulches, mechanical control of cover crops, controlled traffic and rotational tillage (Peigné *et al.*, 2007). Bescansa *et al.* (2006) found that conservation tillage has a greater impact on soil water properties (increasing water retention by 13 %). There was no difference due to crop residue management and crop yield improved slightly depending on conservation tillage system. It is important to investigate the effects of tillage regime for different agricultural systems (organic and conventional).

2.6.2 Residue Management

The physical and chemical properties of soil determine the suitability for sustaining crop growth, they are dependent upon SOM. The equilibrium level of SOM depends on the balance between input through crop residues and output through decomposition, erosion and leaching (Mulumba and Lal, 2008). Crop residue management has been shown to significantly affect the decomposition of SOM (Coppens *et al.*, 2007).

2.6.3 Removal or Incorporation

Several long-term trials have been established to determine the effects of residue removal or incorporation on crop yields (Christian *et al.*, 1999) and soil properties (Mulumba and Lal, 2008; Coppens *et al.*, 2007; Malhi *et al.*, 2006). For crop yields (winter wheat) over the nine year study period; straw incorporation caused a one-third reduction in yield, due to problems establishing a good seedbed, compared to direct drilling where the straw was removed (Christian *et al.*, 1999).

Mulumba and Lal (2008) found that incorporation of residues significantly increased available water capacity by 18–35%, total porosity by 35–46% and soil moisture retention at low suctions from 29 to 70%. Malhi *et al.* (2006) found that straw management had no effect on total organic C and N in the 0–15 cm soil. When straw was removed there were a lower proportion of fine aggregates compared to incorporation. Coppens *et al*. (2007) indicate that antecedent moisture conditions can affect the decomposition of mulched (incorporated) residues. The findings of these trials have implications for erosion rate and water retention in relation to flood prevention which can be beneficial due to improved soil physical properties (Malhi *et al*., 2006).

2.6.4 Amendments

According to Lohr and Park (2007) soil improvement is a long-term process where years are required to achieve optimum organic efficiency as inputs are relevant to both annual cropping and long-term farm productivity. The Broadbalk experiment established in 1843, at Rothamsted, found that organic manures and crop residues should be recycled and used more effectively to increase SOM, supply nutrients and improve soil structure (Carter *et al.*, 2000).

Lohr and Park (2007) investigated efficiency of compost usage within farming systems in both organic and conventional. They determined that there are five common types of amendments:

- Animal manure compost
- Green waste compost
- Finished compost
- Mineral soil amendments
- Biological soil fertilisers.

Lohr and Park (2007) through their research into compost and energy efficiency emphasise a need to understand the economic factors related to organic farming systems. It is difficult for organic farms to find legally acceptable soil inputs and often these have to travel over long distances. Due to the cost associated with compost and mineral amendments; organic farms are increasingly becoming self-sufficient in terms of using their own farmyard manure or green wastes on arable land. However, there is a major problem associated with the use of organic manures in the farming system; this is that large amounts of nitrogen can be lost from the crop and soil system through leaching (Johnston, 1991). This can be mitigated through better analysis and management of the nutrients available within the amendments.

Increasingly, the use of FYM (farmyard manure) and organic manure has been studied for its affects on soil fertility and leaching in both organic and conventional management systems (Wong *et al.*, 1999 and ADAS, 2002). Bulluck *et al.* (2002) investigated the effects of organic and synthetic amendments on three organic and conventional farms on soil physical, chemical and biological properties. They found that organic fertility amendments, enhanced beneficial soil micro-organisms, increased soil organic matter, total carbon, and cation exchange capacity (CEC), and lowered bulk density thus improving soil quality.

Schjønning *et al.* (2007) determined that after 5-6 years of management there is a shift to biotic rather than abiotic bonding and binding mechanism for the cropping systems. The study found that the dynamics of soil structural stabilisation are affected rather quickly when changing management practice; and more tortuous networks of soil pores were found for the enhanced cropping system compared to a system with no compost.

2.6.5 Energy Budgets

On a global scale, agriculture is responsible for about 5 % of the total energy used (Stout, 1990). The amount of fossil fuels used is closely related to the release of CO_2 from a particular agricultural system (Deike *et al.*, 2008). Hansen *et al.* (2001) reviewed many studies in terms of total energy use and efficiency. They discovered that organic farms had higher energy use efficiency and a smaller energy output (lower yields) at the farm scale (see Table 2.6). Pesticide application in conventional farming systems can significantly reduce yield losses caused by weeds and therefore will increase the net energy output changing the input: output ratio (Deike *et al.*, 2008).

Table 2.6: Comparison of farm energy consumption (GJ ha yr^{-1}) in organic and conventional systems in two European locations (Adapted from Stolze *et al.*, 2000).

Location	Organic	Conventional	Percentage of Conventional
UK - livestock	3.3	9.3	64.0
Germany - livestock	17.3	19.4	33.5

Low energy input production schemes are not well accepted by farmers who are interested in the economic benefits rather than energy productivity. Kaltsas *et al.* (2007) determined that there was no difference between organic and conventional farming (in olive groves) for fossil fuel consumption and total energy inputs. In conventional systems there is less weeding; however in organic systems there is no fertiliser application.

2.7 Soil Policy Development

This section gives an overview of current policies and frameworks regarding agriculture, sustainability and soils. There are several UK laws that relate to the protection of soil; but these are mainly relating to urban soils and preventing pollution of soils (Town and Country Planning Act 1990; Environmental Protection Act 1990; Waste Management Licensing Regulations 1994; Sludge (use in agriculture) Regulations 1989; Environment Act 1995, section 57). An EC Regulation 2078/92 promotes organic farming due to its positive effects on the environment (Stolze *et al.*, 2000) and this was introduced into the UK through the Rural White Paper. This outlined the Government's aims for the future in regard to sustainable agriculture; it is currently being up dated.

In 1999, the Government made a commitment to ensure that soil protection received equal priority with air and water as it launched a strategy for sustainable development. In 2004, Defra introduced the First Soil Action Plan for England and Wales 2004-2006 which outlined a programme to provide a clear sustainable vision for the protection of soil. This emphasises a requirement to train soil managers to meet their short-term needs as well as the needs of future generations. It intends to provide appropriate legislation and a political framework that will protect soil as an irreplaceable natural resource and encourage proper management through a better understanding of soils and the processes which occur within them (Defra, 2004). Hence, there is a need for more information on the current state of soil and the physical, chemical and biological processes, which operate within them, allowing meaningful conclusions to be drawn. The Environment Agency's (2004) soil protection code highlights the importance of soil studies on all farming systems. These include studies into the maintenance of organic matter content to keep soil in good condition and the microbial response of soils to organic management.

In 2007, the Environment Agency introduced a new soil strategy 2006-2011 which highlights the following seven cross cutting themes:

1. Climate Change – relating to carbon storage and losses, flood risk management
2. Sustainability – both in the urban and rural environment
3. Integrated catchment management – linking air, water and soil.
4. Tackling agricultural impacts (diffuse pollution)
5. Protecting soil in the built environment
6. Understanding soil biodiversity
7. Improving the knowledge base

These key themes provide areas of research into the effects of soil management on the wider environment.

The EU legislation has imposed several directives that mention soils such as the Habitats directive, Nitrates and Environmental liability directives and more recently the Water Framework and Groundwater directive. Research has determined seven key threats to soils: climate change, compaction, contamination, erosion, loss of biodiversity, loss of organic matter and sealing (Defra, 2009). The EU commission published the findings of this research in 'Thematic Strategy for Soil Protection' (Van Camp *et al*., 2004). Recently there has been a drive to introduce a Soil Framework directive; a proposal was considered by the European Parliament and following the first reading 501 votes to 160 rejected the proposal for a full redraft of the original proposals. This means that a Soil Framework Directive is still a possibility and hence research into the status of soil and its management is still required to influence the need for this directive.

2.8 Modelling catchment scales

Godwin and Dresser (2003) outline two main methods of modelling the effects of soil management on peak runoff rates in small agricultural catchments. These include the Soil Conservation Service (SCS) method and the rational method. The SCS method is detailed in Schwab *et al*. (1996); it uses input variables such as land use and soil and water conservation practices to predict runoff based on runoff curve N numbers (which range from 1 to 100). The rational method which is illustrated in Hudson (1995) uses runoff coefficient values (C) which vary with the intensity of rain and the degree of saturation of the watershed. There are difficulties in determining the time to concentration (longest time for water to travel by overland flow from anywhere in the catchment). The values of C can be unreliable for small catchments as the values can be too high.

Runoff estimation is one of the principal methods used in the UK for estimating the magnitude of the flood for a given frequency of occurrence (Godwin and Dresser, 2003). Both of the runoff modelling techniques above indicates the potential impact of land management on runoff generation. However, these techniques are limited by difficulty in changing input parameters for example alternative cropping and soil management.

Maréchal and Holman (2005) proposed a Catchment Resources and Soil Hydrology (CRASH) model. This was developed by transforming rainfall into simulated river discharge using pre-existing national datasets of soil, land use and weather combined with soil properties and land use. CRASH has been calibrated and validated for three catchments in England with contrasting soil characteristics and meteorological conditions. However, there is a need to test the CRASH model over a wider range of catchments to enable further validation. Further discussion and details of the models can be found in Chapter 5 where the effect of organic farming and runoff is modelled.

2.9 Conclusions

This chapter has reviewed current research into the physical, chemical and hydraulic properties of soil. Major themes are the degradation of soil through compaction, SOM loss and the implications of soil surface management for flood prevention agricultural catchments. It has provided an overview of organic farming and recent conclusions from comparative studies with conventional farming over a range of soil properties; as well has highlighting the difficulty in comparing farming systems. A summary of soil management practices that could impact soil structural quality, which in turn would affect water holding capacity of soils and flooding is also provided. Although comparisons between different tillage regimes (no-tillage and conventional tillage) have been widespread in both short-term and long-term experiments and over a number of different soil textures (Green *et al*., 2003), no reference to specific research linking this to organic farming especially on short-term effects could be found. Therefore, a gap in scientific knowledge has been identified especially regarding the impact of different tillage regimes within organic farming on soil physical properties, workability and infiltration rates.

Defra (2004) identifies a need for a solid research base built upon scientific field trials into the effects of flood alleviation through soil management practices in organic farms. There is also a need to determine the effect of land management (organic or conventional) on runoff generation. This research is aiming to contribute knowledge in this area.

3 Field Scale Studies of Organic Farming and Land Use

3.1 Introduction

This chapter addresses objective 1, outlined in Chapter 1; this was to compare soil physical and chemical properties on organic and conventional farms at the field scale. The results for the soils and water component to the **Rural Economy and Land Use (RELU)** Scale project are presented. Firstly, the background and the need for research to be undertaken into alternative agricultural systems, specifically relating to soil and water properties comparing organic and non organic practices is highlighted. The overall aim of the **RELU** Scale project is described before identifying a gap in research with a focus on comparative research between organic and conventional agricultural systems. Then the outline methodology is shown especially its relation to the aim and deliverables for this component of the work. Finally, the results are discussed and some conclusions drawn.

3.2 Background to the RELU Scale Project

RELU aims to research the challenges and changes that affect rural areas in the UK. This is achieved through several different projects, using interdisciplinary research to help inform future policies and management practice for the countryside and rural economies.

The aim of the **RELU** Scale project is to provide interdisciplinary research into the effects of alternative agriculture at different landscape scales. This research is needed to help understand the complexity of alternative farming systems and their impacts upon rural landscape quality. Defra recently financed a research project focusing on biodiversity and the benefits of organic agriculture compared to conventional farming practices for field, farm and landscape complexity (Norton *et al.*, 2009). This study concluded that organic farming was important for maintaining landscape and local complexity which was beneficial for biodiversity.

The **RELU** scale project was driven by the increasing need for sustainable agriculture, with a growing global population and a higher demand for food, it has to be produced in a manner that does not damage the environment or limit further production. Organic farming has been highlighted as one type of sustainable farming. The amount of land in the UK that is being organically managed is 4 % of the total agricultural land (Nix, 2010). Further research is needed into the effects of conversion of 'conventional' (intensive arable and livestock production) to alternative land management such as organic farming. Current research has shown that changes in land management can impact upon the rural environment (hydrology and biodiversity) and rural community (socio-economics and culture). Intensive agriculture was blamed for many of the environmental problems that are now being felt, such as a reduction in farm biodiversity, loss of farm land and increasing runoff, soil erosion, flood risk, and diffuse pollution pathways.

3.3 Aims and Objectives

The overall aims for the **RELU** Scale project are; firstly to determine the factors that influence the spatial concentration of organic farms at a variety of scales and secondly, to discover the corresponding scale-dependent effects of different farm concentrations on the ecological, hydrological, socio-economic and cultural impacts of those farms.

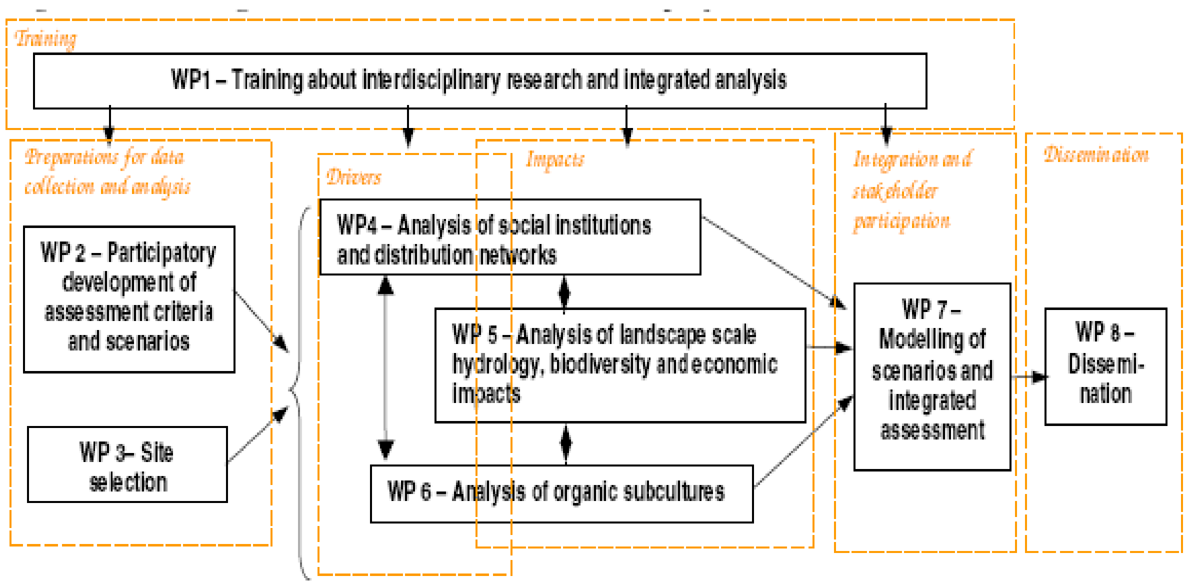


Figure 3.1: Methodological framework and structure to the RELU Scale project (RELU, 2006).

These impacts have been investigated using matched pairs of organic and conventional farms. The work was conducted in the different packages shown in Figure 3.1 to help encompass all of the disciplines with the common aim. Social surveys provide information on farm economic flows and value added, on-farm resources use, marketing choices and supply chain coordination, cross-farm social interactions, and farm family cultural attitudes. Scientific studies into bird, invertebrate and plant biodiversity; soil physical properties and the ease of soil working, water infiltration rates which affect run off, soil erosion and nutrient transfer to downstream surface waters are also performed. Through the combination of quantitative and qualitative empirical methods for data collection, modelling will be performed involving social and natural scientists as well as stakeholders inputs. This will enable the derivation of land management recommendations from both the social and the physical scientific points of view.

The objectives of this component were to compare organically and conventionally managed soils in terms of:

i. Soil physical properties including: soil texture, soil strength, soil structure, aggregate stability, Atterberg limits and soil organic matter
ii. Soil hydrological properties including: field capacity moisture content, hydrological class (HOST) and infiltration rates
iii. Soil water quality (nutrients and pesticides).

3.4 Gap Analysis

In Chapter 2, discrepancies between results of different research projects comparing organic and conventional practices underline the limited value of these studies. It can be seen that, at the present time, there is no consensus whether the two different farming systems, organic and conventional, have positive or negative effects on soil properties. There are many different factors involved other than just organic or conventional practices such as different tillage regimes. There is a demand for this type of comparative data so results continue to be produced (Østergaard, 1996). van Diepeningen *et al.* (2006) suggested that soil texture had a much stronger effect on the soil physical characteristics than the management type. It is generally thought that soil management rather than organic or conventional farming systems has the larger effect on soil properties, especially chemical and biological which are governed by physical properties.

The **RELU** Scale project had an overall hypothesis that organic farming has an effect at different scales. However, in the soil and water study 'scale' was not an issue, hence; it was decided to evaluate the null hypothesis 'that organic farming does not influence soil properties or physical condition'. This was based upon the review and ideas by Stolze *et al.* (2000), Armstrong Brown *et al.* (2000) and Pulleman *et al.* (2003). The alternative hypothesis would be that organic farming has an effect upon soil properties or physical condition. These hypotheses will be evaluated through the results of the research and the statistical analysis of the data to determine whether the null hypothesis can be rejected.

3.5 Outline Methodology for Work Package Five

The objective of *work package five* was to collect a data set which would enable comparisons between organic and conventional farming practises to be drawn. Differences were anticipated due to different crop rotations, appropriate cultivation, cover crops which can help to reduce runoff and erosion, flood risk and pollutant pathways (Godwin and Dresser, 2003). This was achieved through the collection of soil and water quality data at 16 pairs of farms (organic and conventional), and on two land uses (winter wheat and grass).

The following measurements were taken:

- Soil texture, organic carbon, field capacity, Atterberg limits (soil plasticity range which influences soil workability) and aggregate stability by laboratory methods from field samples collected at field capacity moisture content (three replicates in laboratory)
- Soil structure and soil hydrological class (HOST) from field reconnaissance
- *In situ* soil strength by in field measurement (30 replicates per site)
- *In situ* infiltration rates (four pairs of sites – ten replicates per site)
- Soil water quality by field sampling and laboratory analysis to determine organic and inorganic constituents including nutrients and organic constituents in pesticides, herbicides, fungicides.

There are some similarities in the method used for site selection to those published by Norton *et al.* (2009); which covered a wider range of fields (89 paired fields in total) and factors including: habitat surveys, land manager questionnaires and large-scale landscape datasets. However, no direct analyses of soil properties were undertaken in their study.

3.6 Methodology

3.6.1 Field Site Selection

Sixteen field sites on mixed (i.e. arable and grass rotations) farms were chosen using a 10km x 10km moving window using geographical distance and soil types. This helped to find the best matching organic and conventional fields in eight 'clusters' of sites. These were: 1) an organic dominated landscape with greater than 10% organic farming and a minimum of two organic farms (hot spot) and 2) a conventional dominated landscape less than 2 % organic farming with a maximum of two organic farms (cold spot) as shown in Figure 3.2. These were equally split into two main regions with eight in the "midlands" and eight in the "south" of England. Within each site; fields were identified with three arable (predominately winter wheat) and three grass (grass / clover composition) fields. The organic farm database which was obtained from Defra was overlaid with environmental factors such as climate, topography, land use, soil type and hydrological data.

At each site, three fields were chosen which met the requirements of the multidisciplinary team. The closest matching pairs of organic and conventional fields were determined through in-field soil sampling based upon the NSRI soil database (Landis). The farms were neighbours however; appropriate fields were not always on the adjacent boundary. The distance between the fields is given in Table 3.1. This shows spatial differences ranging from 25 m to 3 km; where 50 % of the sampling sites are less than 300 m apart. The time period in which the land has been managed organically (not including time in conversion) ranged between 1 and 58 years. All the grassland was grazed and the age of grassland for 68 % of the sites was greater than 10 years. Table 3.1 shows the previous land use of the arable land, where there was some grass and clover leys which in organically managed land are used for fertility building. The age of different grass leys for the grass fields is also shown.

Figure 3.2: This map shows the 8 clusters of organic ■ (hot) or conventional □ (cold) dominated landscapes which were selected for sampling and their location within the UK. The numbers relate to site numbers (Courtesy of RELU Scale, 2007).

Table 3.1: Details of the sixteen paired sites including the spatial distance between organic and conventional fields and land use history for arable (three previous crops) and grass sites.

Site	Management	Distance between fields (m)	Managed Organically (years)	Previous crop (Arable)	Length of time in ley (Grass)
2H	Org	3000	22	RCG	10
	Con	3000		WW	30
2C	Org	200	6	RCG	20
	Con	200		SG	10
6H	Org	300	11	RCG	100
	Con	300		WW	70
6C	Org	100	6	WO	20
	Con	100		WW	50
9H	Org	50	11	WCG	11
	Con	50		OSR	10
9C	Org	2000	1	WW	10
	Con	2000		WW	15
20H	Org	25	3	C	5
	Con	25		WO	5
20C	Org	100	3	WCG	15
	Con	100		OSR	4
12H	Org	3000	4	WW	50
	Con	3000		WB	20
12C	Org	1000	2	WW	7
	Con	1000		SW	9
16H	Org	1000	7	OSR	25
	Con	1000		WW	10
16C	Org	2500	12	OSR	2
	Con	2500		WCG	2
21H	Org	500	4	G	4
	Con	500		SB	8
21C	Org	100	6	M	50
	Con	100		RCG	40
23H	Org	50	58	WW	30
	Con	50		WCG	30
23C	Org	2000	5	M	10
	Con	2000		M	12

Key: RCG – red clover and grass mix, WW – winter wheat, G – grass, WO – winter oats, WCG – white clover and grass mix, WB – winter barley, SW – spring wheat, OSR – oilseed rape, SB – spring barley, M - maize

The selection of the sites posed a number of challenges due to the multi-disciplinary nature of the **RELU** Scale project, as the sites ideally needed to meet the requirements of ecologists, economists, cultural geographers and soil scientists. Details of the site selection process are given in Gabriel *et al.* (2009) but often the needs were not complementary. Hence, the priority to have neighbouring fields required by soil scientists, to minimise the variation in soil texture, were compromised by the other disciplines which needed spatial separation between organic and conventional fields to reduce the migration of fauna and flora. Overall the objective of having a wide range of soil textures was met.

Site selection was complex and soil maps were relied upon for providing soil series data. However, whilst the soil maps provided an important framework for designing and choosing field locations; they should not be over relied on. This is due to the spatial variability which means that the major soil type may not be present at the field or sub-field scale (Dane and Topp, 2002). This meant that at some of the clusters the soil textures were not similar and hence could not be easily compared. Table 3.2 a and b show the variability of the selected soil types in terms of map based soil series, the manual topsoil texture and the infield classification of soil series. These show significant variation between the classification based on the soil map and the actual infield classification. There was also considerable variation of soil type within a given cluster; with only cluster 20 having a uniform "silty" soil. As a result to partially solve this problem the soils were reclassified (Palmer, 2007) into the four main '**RELU**' soil classes shown. Further details of this are found in Chapter 3.6.4.

The cropping cycle varied considerably between the organic and conventional pairs, with some arable fields having just been reverted from a grassland ley. There were also problems with grassland sites, as there were some fields which were ancient parkland compared to others which were first year ley. There was no control over the type of tillage regime or the farm management practises. This emphasises the complexity in comparing farming systems as found by Stolze *et al*. (2000).

Table 3.2a: Soil texture and series for each of the farms measured showing the RELU cluster in the south region.

UK Location	Cluster ID	Management	Landuse	Soil Series based on soil map	Measured Topsoil Texture	Infield classification of Soil Series	RELU Soil Class
	2H	Organic	Arable	343h, 342a	Clay Loam	Upton / Dullingham	Medium
	2H	Conventional	Arable	343h, 342a	Silty Clay Loam	Upton/ Panton	Silty
	2H	Organic	Grass	343h, 342a	Clay	Upton	Clayey
	2H	Conventional	Grass	343h, 342a	Silty Clay Loam	Icknield/ Dullingham	Silty
S	2C	Organic	Arable	343i	Silty Clay Loam	Panhole	Silty
	2C	Conventional	Arable	343i, 343h	Silty Clay	Panhole / Andover	Clayey
O	2C	Organic	Grass	343i	Silty Clay Loam	Panholes / Millington	Silty
	2C	Conventional	Grass	343i, 343h	Silty Clay Loam	Panholes / Millington	Silty
U	6H	Organic	Arable	343ab, 411a	Clay	Haselor / Elmton	Clayey
	6H	Conventional	Arable	343ab, 411a	Sandy Loam	Oxpasture	Coarse
T	6H	Organic	Grass	343ab, 411a	Clay	Oxpasture	Clayey
	6H	Conventional	Grass	343ab, 411a	Sandy Silt Loam	Elmton	Coarse
H	6C	Organic	Arable	343ab, 411a	Silty Clay Loam	Denchworth	Silty
	6C	Conventional	Arable	343ab, 411a	Sandy Clay	Badsey / Denchworth	Clayey
	6C	Organic	Grass	343ab, 411a	Silty Clay Loam	Evesham	Silty
R	6C	Conventional	Grass	343ab, 411a	Clay	Evesham	Clayey
	9H	Organic	Arable	712b	Clay	Denchworth	Clayey
E	9H	Conventional	Arable	712b	Clay Loam	Denchworth	Medium
	9H	Organic	Grass	712b	Clay	Denchworth	Clayey
G	9H	Conventional	Grass	712b	Clay	Denchworth	Clayey
	9C	Organic	Arable	712b, 512e, 342b	Silty Clay Loam	Wantage	Silty
I	9C	Conventional	Arable	342b, 511d	Silty Clay Loam	Wantage	Silty
	9C	Organic	Grass	712b, 512e, 342b	Silty Clay	Foggathorpe	Clayey
O	9C	Conventional	Grass	342b, 511d	Clay	Block	Clayey
	20H	Organic	Arable	343h, 343i, 342a	Silty Clay Loam	Panholes / Andover / Millington	Silty
N	20H	Conventional	Arable	343h, 342a	Silty Clay Loam	Panholes / Millington	Silty
	20H	Organic	Grass	343h, 343i, 342a	Silty Clay Loam	Panholes/ Andover/Millington	Silty
	20H	Conventional	Grass	343h, 342a	Silty Clay Loam	Panholes	Silty
	20C	Organic	Arable	343h	Silty Clay Loam	Panholes / Andover / Millington	Silty
	20C	Conventional	Arable	343h	Silty Clay Loam	Panholes / Andover	Silty
	20C	Organic	Grass	343h	Silty Clay Loam	Panholes / Millington	Silty
	20C	Conventional	Grass	343h	Silty Clay Loam	Andover/ Sonning	Silty

Table 3.2 b: Soil texture and series for each of the farms measured showing the RELU cluster in the midlands region.

UK Location	Cluster ID	Management	Land use	Soil series based on soil map	Measured Topsoil Texture	In Field classification of soil series	RELU Soil Class
	12H	Organic	Arable	572f, 541b	Clay Loam	Whimple / Worcester / Enborne	Medium
	12H	Conventional	Arable	572f	Silty Clay	Whimple	Clayey
M	12H	Organic	Grass	572f, 541b	Silty Clay Loam	Brockhurst	Silty
	12H	Conventional	Grass	572f	Silty Clay Loam	Brockhurst	Silty
I	12C	Organic	Arable	572f, 541b	Silty Clay Loam	Whimple / Worcester	Silty
	12C	Conventional	Arable	572f	Clay Loam	Brockhurst	Medium
D	12C	Organic	Grass	572f, 541b	Silty Clay	Whimple / Bromsgrove	Clayey
	12C	Conventional	Grass	572f	Clay Loam	Whimple / Wigton Moor / Worcester	Medium
L	16H	Organic	Arable	511c, 711f	Sandy Clay Loam	Winchester	Medium
	16H	Conventional	Arable	511e, 711f	Clay Loam	Eyeworth	Medium
A	16H	Organic	Grass	511c, 711f	Sandy Clay	Blewbury / Wickham	Clayey
	16H	Conventional	Grass	511e, 711f	Sandy Loam	Soham / Cannamore	Coarse
N	16C	Organic	Arable	511c	Silty Clay Loam	Panholes	Silty
	16C	Conventional	Grass	511c	Silty Clay Loam	Panholes	Silty
D	16C	Organic	Grass	511c	Clay	Panholes / Andover / Millington	Clayey
	16C	Conventional	Arable	511c	Silty Clay Loam	Panholes	Silty
S	21H	Organic	Arable	711m, 431	Sandy Loam	Salwick / Whimple / Worcester	Coarse
	21H	Conventional	Arable	711m, 431	Clay Loam	Whimple	Medium
	21H	Organic	Grass	711m, 431	Sandy Loam	Whimple	Coarse
R	21H	Conventional	Grass	711m, 431	Clay Loam	Brockhurst	Medium
	21C	Organic	Arable	572m, 572f	Sandy Silt Loam	Clifton	Coarse
E	21C	Conventional	Arable	572c, 572f	Clay Loam	Whimple	Medium
	21C	Organic	Grass	572m, 572f	Clay Loam	Whimple / Compton	Medium
G	21C	Conventional	Grass	572c, 572f	Clay Loam	Whimple / Salop	Medium
	23H	Organic	Arable	551a, 711b	Sandy Loam	Bridgnorth	Coarse
I	23H	Conventional	Arable	711b, 514d, 572c	Sandy Silt Loam	Eardiston	Coarse
	23H	Organic	Grass	551a, 711b	Sandy Loam	Bridgnorth	Coarse
O	23H	Conventional	Grass	711b, 514d, 572c	Sandy Clay Loam	Eardiston	Medium
	23C	Organic	Arable	541b, 572f	Clay Loam	Salop	Medium
N	23C	Conventional	Arable	711n, 541b, 541r	Sandy Loam	Wick	Coarse
	23C	Organic	Grass	541b, 572f	Clay	Fladbury	Clayey
	23C	Conventional	Grass	711n, 541b, 541r	Sandy Loam	Bromsgrove	Coarse

3.6.2 Field Methodology

A pilot study was performed during July 2006; based upon four paired arable fields (organic and conventional) in southern England (Hathaway-Jenkins, 2006). The soils were sampled for a range of soil physical properties (including total C:N ratio, SOM, penetration resistance, shear strength, aggregate stability, bulk density and Atterberg limits). This methodology was adapted for the full **RELU** sites. The 'going stick' was used in the pilot study to measure shear strength and penetration resistance (similar to a penetrometer) simultaneously for the top 100 – 200 mm *in situ*. Due to problems with both very loose and very dense soils the ‘going stick’ (see Figure 3.3) was replaced in the main study with the shear vane.

Figure 3.3: Going Stick with data logger and showing failure of soil (photograph in soil bin at Cranfield University, Silsoe courtesy of Godwin, 2006).

The variability of the soil texture in the fields sampled meant that bulk density readings were not measured in the main study as this would not have allowed useful interpretation. However, the same methods were followed for the other soil physical properties measured.

Soil sampling and within field assessment was carried out in March and April 2007, when fields were at or near to field capacity moisture content. This provided an equivalent soil moisture content for all the sites and also because soil structural condition is most clearly assessed at this time (Palmer, 2007). The seasonal effects of variations in soil moisture content were therefore minimised. Sampling occurred after the main dressing of fertiliser on the conventional land. At each site a soil assessment was conducted and samples were collected to measure a suite of physical and agro-chemical parameters. To obtain a representative sample of soil, a ‘W’ shaped path sampling strategy was observed, avoiding untypical areas, taking 10 samples; which were bulked. Samples were obtained from 0 - 200 mm depth. One or more small pits were excavated at each site to determine the soil structure and physical conditions of the soil. Although a number of techniques exist to make *in situ* measurements of torsional and penetration shear resistance, which are used as a measure of surface soil shear strength, the shear vane (Franti *et al*., 1985) provided a relatively simple and quick method of estimating the shear strength of the surface of soils (0 – 200 mm) *in situ* based on a grid sampling technique, using 30 samples to cover the field.

For the study of infiltration rates, a subset of fields was selected that covered a range of soils with more uniform textures for all the treatments. The initial baseline survey of the soils revealed a high variability of soil types even within each cluster. Therefore, from the soil series data and the detailed soil textural analysis four clusters were chosen to be sampled. At each of the clusters one grass field and one arable field were sampled for both organic and conventional treatments (see Figure 3.4). The clusters were also chosen because they cover a range of soil types: clay, clay loam, silty clay loam and sandy loam.

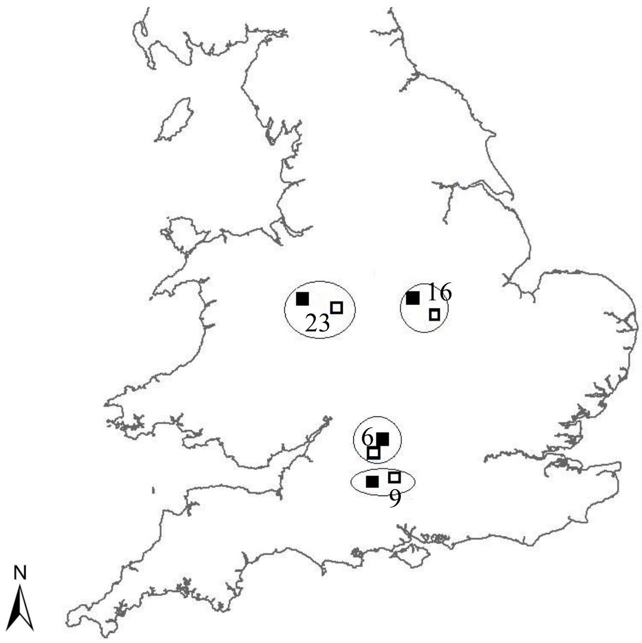


Figure 3.4: Map of the sites showing the clusters in organic ■ (hot) or conventional □ (cold) organic or conventional dominated landscapes which will be used during infiltration measurements (Courtesy of RELU Scale, 2007).

Fieldwork was performed during May and June 2008. At each site, infiltration (saturated hydraulic conductivity) was measured using the Decagon mini disk infiltrometer (see Figure 3.5). This method was chosen in preference to the double ring infiltrometer as it requires less water (which was not always readily available at the fields). Both methods are very time consuming and have a similar accuracy level as they need constant attention to record measurements and ensure that the apparatus is functioning correctly. The rings of the double ring infiltrometer are heavy to move and require a flat undisturbed surface (McKenzie *et al.*, 2002). The advantage of the tension infiltrometer is that it can provide both saturated and unsaturated hydraulic conductivity measurements, as well as steady state infiltration rates. Ten replicates were made in each field along a 'w' shape avoiding atypical areas (Bodhinayake *et al.*, 2004). Each replicate was sampled for 30 minutes at 20 mm tension and the infiltration rate was calculated using the method developed by Zhang (1997) and the van Genuchten parameters (Carsel and Parrish, 1988).

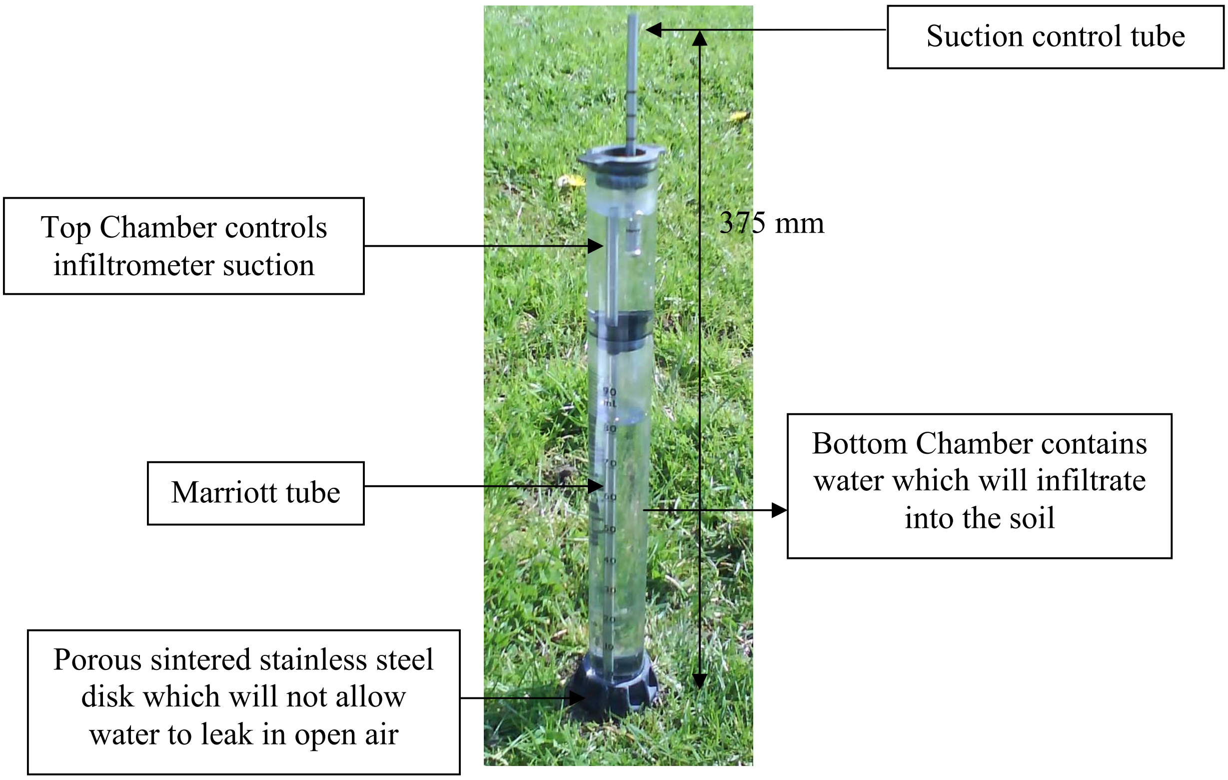


Figure 3.5: Photograph of the Decagon Mini Disk Infiltrometer (courtesy Hathaway-Jenkins, 2008).

3.6.3 Laboratory Methodology

The soil samples were air dried, ground and sieved (Allen, 1989). A 2 mm diameter mesh sieve was used for SOC and texture; a 425 µm mesh sieve was used for Atterberg limits and a combination of 5 mm and 3.35 mm mesh sieves were used for aggregate stability. Soil texture was determined using the pipette method which separates the soil into three fractions: sand, silt and clay and by plotting these values onto a soil textural triangle the texture can be determined (BS 7755). SOC was established by dichromate digestion (BS 1377-3). Aggregate stability was determined through the wet sieving method described by Haynes and Swift (1990). Gravimetric moisture content was measured through oven drying at 105 ^{o}C until a constant weight was achieved. Atterberg limits were determined; firstly the plastic limit (BS 1377-2) and a drop cone penetrometer technique (BS 1377-2) to determine the liquid limit. The arithmetic difference of these two gravimetric moisture contents allows the determination of the plasticity index (Keen and Coutts, 1928).

The pipette method was used to determine soil texture in preference to the hydrometer and hand texturing, as it is the most accurate direct sampling procedure. The main errors are associated with sampling and weighing, however, according to Gee and Or (2002) these are confined to +/- 1%.

Aggregate Stability is measured by wet or dry sieving. It was decided that wet sieving would be the most appropriate method for analysis - care was taken to ensure the water content was uniform in each soil as this can affect cohesion of the soil. The only disadvantage was the time limitation so rapid re-wetting of the samples occurred. However, this may have caused slaking or dispersion of the larger aggregates (Dane and Topp, 2002).

The drop-cone penetration method was determined as the most appropriate method to assess plasticity, as it is more repeatable than the Casagrande method, however it is still prone to both mechanical and operator variability (McBride, 2002).

Soil water sub-samples were analysed for a suite of common pesticides (carbonates, dicarboximides, organochlorine, organophosphorous, organonitrogen, synthetic pyrethoids and triazoles) and nutrients (total inorganic nitrogen, total phosphorus, total potassium). Soil water nutrient values were analysed through centrifuging the sample and the use of flame photometer. Soil water pesticides were extracted and quantified by High Performance Liquid Chromotography (HPLC-UV).

3.6.4 Statistical Methodology

Statistical analysis was performed using Statistica (8.0). First, any data that showed deviation from normality was transformed (Box-Cox). Then the 23 variables that characterised the sites were reduced using (1) correlation analysis to reduce the number of correlated variables and (2) factorial analysis with varimax rotation. This revealed that % clay and % silt had the largest loading in the factor which explained the greatest variation in the data. Thus the rest of the analyses grouped the data by soil texture as well as land use and management. Four groups of soil texture were formed because of the large variation due to spatial differences between the sites, allowing comparisons to be drawn. The soil textural groups were: clayey (defined as > 35 % clay) silty (defined as > 50 % silt), coarse (defined as > 50 % sand and < 18 % clay) and medium (defined as between 18 and 35 % clay).

The null hypothesis, for the soil and water study, was 'organic farming does not influence soil properties or physical condition' as found in some of the studies reviewed by Stolze *et al*. (2000) and van Diepengen *et al.* (2006). With the alternative hypothesis that organic farming has an effect upon soil properties and physical condition; as shown in Bhogal *et al.* (2009) where increasing OM levels improved soil properties. This section will also determine whether the research data is sufficient to reject the null hypothesis.

The differences in soil quality between organic and conventional land management were tested using ANOVA, under the assumption that the measured variables (SOC, shear strength, field capacity, aggregate stability, Atterberg limits, nutrients and pesticides) were normally distributed and outliers were identified and removed from the dataset. Statistical analysis was performed on the data using both the 'hot' and 'cold' spots within each cluster as replicates because the actual intensity of organic farming was not relevant to this component of the work. A general linear model (factorial analysis) was used to determine whether there was significant differences in soil properties between the two treatments organic and conventional); between two land uses (arable and grass) and between four soil texture classes.

However, due to the unbalanced 'experimental design' where there were different numbers of fields for the land use, treatment and soil textures were not present for every treatment. Table 3.3 highlights the difficulty in analysing the data statistically using ANOVA as it shows that whilst the design of the experiment for number of organic and conventional fields for both land uses was balanced, when based upon an examination of soil texture this was not the case. The ANOVA model used was a nested design with land use (fixed effect) nested within treatment (fixed effect) and with soil texture as a random effect. The ANOVA was calculated using both Least Squares (Statistica 9.0) and Restricted Maximum Likelihood (REML) Genstat (10.1). These results were further interpreted in using Fisher LSD as this is one of the least conservative *post hoc* tests (Winer *et al.*, 1991). REML provides a method of fitting the general linear model to the data allowing for the degrees of freedom that are used up in estimating the fixed effects. Therefore, REML accounts for the variance of the data without being affected by the fixed effects and it is also less sensitive to outliers (Crawley, 2007). The REML analysis compared the treatments, land use and soil texture whilst allowing for an unbalanced design and permits unbiased conclusions to be drawn.

Table 3.3: Sample Sizes for each treatment and land use divided by soil texture.

		Land use and Treatment				
		Organic Arable	**Organic Grass**	**Conventional Arable**	**Conventional Grass**	**Total**
Soil Textural Class	Clayey	2	8	3	3	16
	Silty	7	5	5	6	23
	Medium	4	1	5	4	14
	Coarse	3	2	3	3	11
	Total	16	16	16	16	64

3.6.5 Limitations and Evaluation of the data

As previously highlighted, there were limitations with the data collected. This then restricts the output of the research where the results may be unable to fully determine the effect of organic and conventional farming practices for two main reasons. Firstly due to enforced spatial separation of the fields within a cluster, leading to the inherent variability of soils referred to earlier. This did pose problems in terms of comparisons and conclusions which could be drawn as not all treatments (organic or conventional) were present in every soil texture. This led to difficulties in analysing the data statistically as the experiment was unbalanced. Secondly there was a wide range of agricultural practices occurring in terms of length of time the farm had been organic, tillage regimes and crop cycles which could not be classified as typically organic or conventional over which the author had no control. Therefore, this study is only able to provide a best attempt under the limitations imposed by a multidisciplinary project of a snapshot of the current situation of agricultural systems both organic and conventional in the UK. It should, however, provide a platform or benchmark for future research into farming systems research and draw conclusions on the relative effects of organic farming practices in relation to conventional practices.

3.7 Results and Discussion

This section reports the results of both the pilot and main study for each of the soil properties measured.

3.7.1 Pilot Study

In the summer 2006, four pairs of arable fields (organic and conventional) in southern England were sampled for a range of soil physical properties including: penetration resistance, shear strength, plasticity, bulk density, aggregate stability and field capacity, SOM and C:N ratio. These paired fields were selected to be very closely located to each other, to minimise the variability of soil textures (in all of the four cases they were adjacent fields).

The results of the pilot study given in Table 3.4 show that there were significant differences between organically and conventionally managed soils in total C:N ratio, penetration resistance and shear strength. However, where there were differences they were not always consistent and that these varied with soil texture (Hathaway-Jenkins, 2006). Overall, there was no specific trend which could be applied for organic or conventional treatments according to texture or land use. The only exception was that there was a consistently higher C:N ratio for all soil types in organic land management. The penetration resistance was lower (except in sandy clay loam) and the shear strength was higher for the organic soils in two soil types (clay loam and silty clay loam).

SOM was not significantly different between organically and conventionally managed land however there was a trend present that SOM was higher in organic land (with the exception of clay loam). The Loss on Ignition (LOI) method gave consistently higher values for SOM and is not considered as accurate as dichromate oxidation (Walkley and Black, 1934) due to the burning of calcareous material, so this was excluded from the main study. It was concluded in the context of the pilot study that the effect of soil texture and other land management practices, such as grassland or arable, are very important to understand when comparing the two different farming systems.

Table 3.4: Summary of the main results for each soil physical property and texture indicating differences between the treatments of the pilot study (Hathaway-Jenkins, 2006).

Property	Clay	Clay Loam	Sandy Clay Loam	Silty Clay Loam	Overall Mean
SOM – LOI	NS	↑	↑	↓	NS
SOM –Oxidation*	↑	↓	↑	↑	-
C: N Ratio	↑	↑	↑	↑	↑
Bulk Density (ρ_b)	↑	NS	NS	NS	NS
Field Capacity	NS	NS	NS	↓	NS
Plastic Index*	NS	↑	↓	↑	-
Aggregate Stability	NS	NS	NS	NS	NS
Penetration Resistance	NS	↓	↑	↓	↓
Shear Strength (τ)	NS	↑	↓	↑	↑

*** No statistics were calculated for these physical properties. NS = no significant difference. Arrows indicate whether organic treatment is higher (↑) or lower (↓) than non-organic. (LOI- loss on ignition)**

3.7.2 Soil Properties

3.7.2.1 Soil Texture

The soil texture values from each site were plotted onto a soil textural triangle, Figure 3.6, and is summarised in Table 3.5. They show that despite best efforts to ensure otherwise not all land management (organic or conventional) or all land uses are present in each soil textural class. Table 3.4 provides the year that the fields were first managed organically; showing a range from as little as one year to fifty years. This highlights some of the complexity of interpreting data from these variable sites but was driven by the need to have locations that suited the collective requirements of a multidisciplinary project. Also shown are the mean total rainfall figures using data from Smith and Trafford (1976). They range from a low of 605 mm yr^{-1} to a high of 807 mm yr^{-1} with an overall mean of 752 mm yr^{-1} and a standard deviation of 54 mm yr^{-1}. This indicates that the sites had relatively similar mean total annual rainfall.

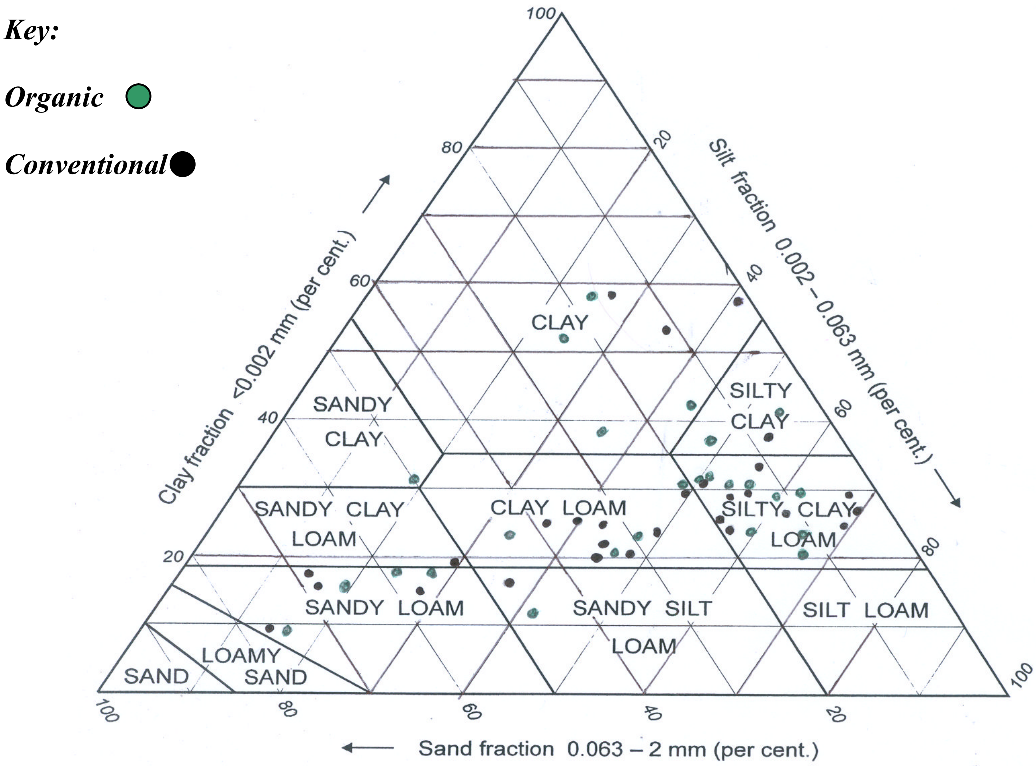


Figure 3.6: Soil textural triangle adapted from Hodgson (1976) showing organic and conventional fields in terms of their soil texture regardless of arable or grassland land use.

Table 3.5: Soil texture and series for each of the farms measured (†Topsoil texture based on the UK soil textural triangle and soil series data from Soil Survey of England and Wales, * Adapted from Smith and Trafford, 1976).

Grouping	Topsoil Texture	Soil Series†	Organic/ Con	Land Use	Years of conversion to organic management	Mean Total Annual Rainfall (mm)*
Clayey	C	Evesham	Organic	Grass	2001	775
	C	Denchworth	Both	Grass / Arable	1996 -2001	775
	C	Haselor	Organic	Arable	1996	775
	ZC	Blewbury	Organic	Grass	2000	605
	ZC	Winchester	Organic	Arable	2000	605
	ZC	Wimple	Both	Grass / Arable	1997-2005	714
	ZC	Foggathorpe	Organic	Grass	1998	775
	SC	Block	Con	Grass	n/a	775
Silty	ZCL	Upton	Both	Grass / Arable	1985	798
	ZCL	Panhole	Both	Grass / Arable	2001-2004	798
	ZCL	Oxpasture	Both	Grass/ Arable	1996	775
	ZCL	Andover	Con	Grass	n/a	807
	ZCL	Wantage	Both	Arable	2007	775
Medium	CL	Brockhurst	Both	Grass / Arable	2000 -2005	714
	SCL	Elmton	Con	Grass	n/a	775
	ZL	Badsey	Con	Arable	n/a	775
	ZL	Soham	Con	Grass	n/a	714
Coarse	SZL	Salop	Organic	Grass/ Arable	2002	763
	L	Eardiston	Con	Arable	n/a	763
	L	Wick	Con	Arable	n/a	763
	L	Broomsgrove	Con	Grass	n/a	763
	LS	Bridgnorth	Organic	Grass/ Arable	1949	763
					Mean (S.D.)	752 (+/- 54)

All groups of research data were explored using multi-variate exploratory analysis; a threshold level of 6% total variance was used to reduce the number of original variables, any variable which explains less variance than this was excluded. The Eigen value is the variance which is extracted by the factor (and the sum of all the Eigen values is equal to the number of variables); so the larger the number the greater explanation of variation in the data is achieved. This analysis provided six factors which could account for over 70% of the variation within the data (Table 3.6). The major factor causing variation was the percentage clay and silt in the soil. The other factors which result from the analysis are coincidental; it is, however, a surprise that SOC does not explain a high percentage of variance. This analysis shows that soil texture (percentage clay and silt) should be included as fixed effects when fitting the generalised model. Hence, further analyses were then performed on the data after grouping by soil texture as described below.

Table 3.6: The factors which can account for the majority of the variance in the data.

Factor	Highest Weighted Variable	Total Variance (%)	Eigenvalue
Factor 1	**Clay and Silt**	**21.4**	**3.6**
Factor 2	BFI and SPR	17.3	2.9
Factor 3	Organonitrogen and triazoles	11.1	1.9
Factor 4	Plastic and Liquid Limit	8.9	1.5
Factor 5	Soil shear strength	7.2	1.2
Factor 6	Organochlorine	6.3	1.1
Total	**-**	**72.3**	**12.3**

The soil textures of the sites were plotted onto soil textural triangles (see Figure 3.7) showing a representative spread of soil textures. There were many different soil texture classes and following on from the factor analysis (where the majority of the variance could be attributed to texture) they were grouped to allow more detailed analysis. Therefore; four principle textural groups were determined (Palmer, 2007): **clayey**, defined as >35% clay; **coarse** defined as >50% sand and <18% clay; **medium** defined as between 18 and 35% clay; and **silty** defined as >50% silt to allow meaningful statistical analysis to be performed. This soil classification was formed, as the study looked at the effects of land management (organic and conventional) and uses (arable and grass) on topsoil. Therefore, it was concluded from the factor analysis that clay and silt content are the most important factor. This led to the formation of the three textural groups: clayey, coarse and medium. The silty classification was formed because of their high silt content and the need for very careful soil management (Palmer, 2007).

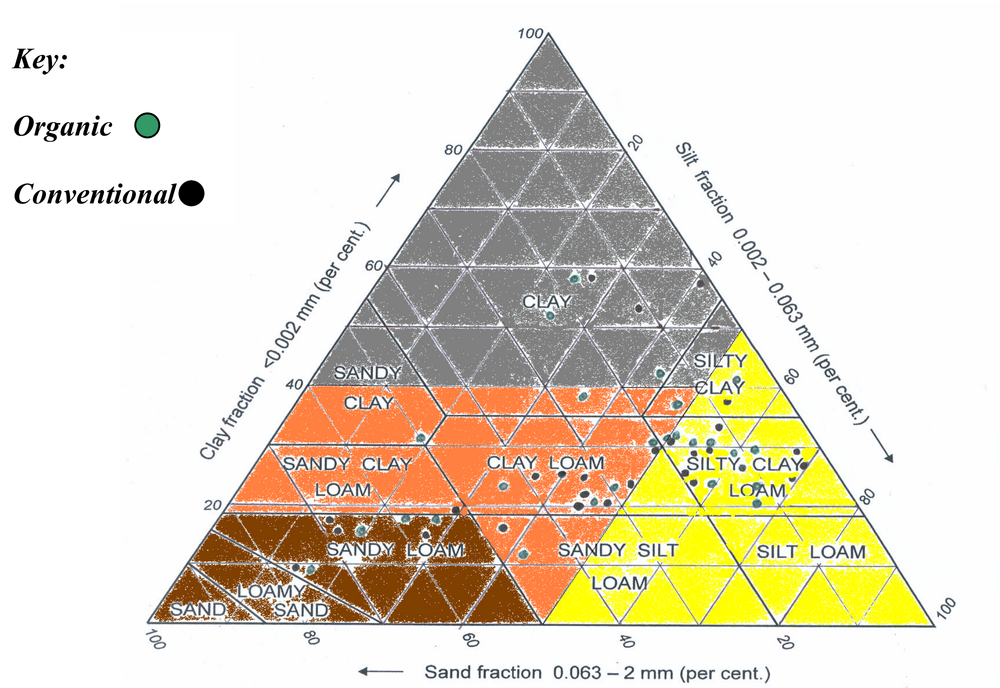


Figure 3.7: Soil textural triangle adapted from Hodgson (1976) showing: 1) organic and conventional fields in terms of their soil texture regardless of arable or grassland land use and 2) the broad classification of soil textures used in subsequent analysis Brown = coarse, pink = medium, grey = clay, yellow = silty.

3.7.2.2 Soil Organic Carbon (SOC)

The amount of SOC can be influenced by land management both past and present (Plaster, 1985). It can help improve soil structure; lower bulk density and increase porosity hence increase water infiltration (Sparling *et al*., 1992; Evangelou, 1998). The results given in Figure 3.8 show that there was no overall significant difference in SOM contents between organic and conventional treatments for each of the four soil textural classes. This aligns with the results presented by Gosling and Shepherd (2002). This can be explained by SOC additions and grass / arable rotations which would improve residual root biomass. Bhogal *et al.* (2009) suggest that to have a significant effect on SOC at least 65 t $ha^{-1}yr^{-1}$ of fresh organic matter needs to be applied whereas currently organic farmers add 40 t $ha^{-1}yr^{-1}$ on average (Trump, 2010). However, the results of the ANOVA given in Table 3.7 show that there were significant differences related to land use, where grass had a significantly higher level of SOC compared to arable ($p<0.05$). The REML analysis (shown Appendix B) shows that this is particularly significant in conventional land use which is greater than grassland. There is less of a difference between organically managed land, where arable rotations include grass leys more frequently. There is also a significant difference between the soil textural classes where overall the clayey and silty soils had an improved level of SOC in relation to coarse and medium soils ($p < 0.05$). This can, in part, be explained by the results of Loveland and Webb (2003) which suggests that the protective nature of the clayey soils reduces the amount of SOC decomposition.

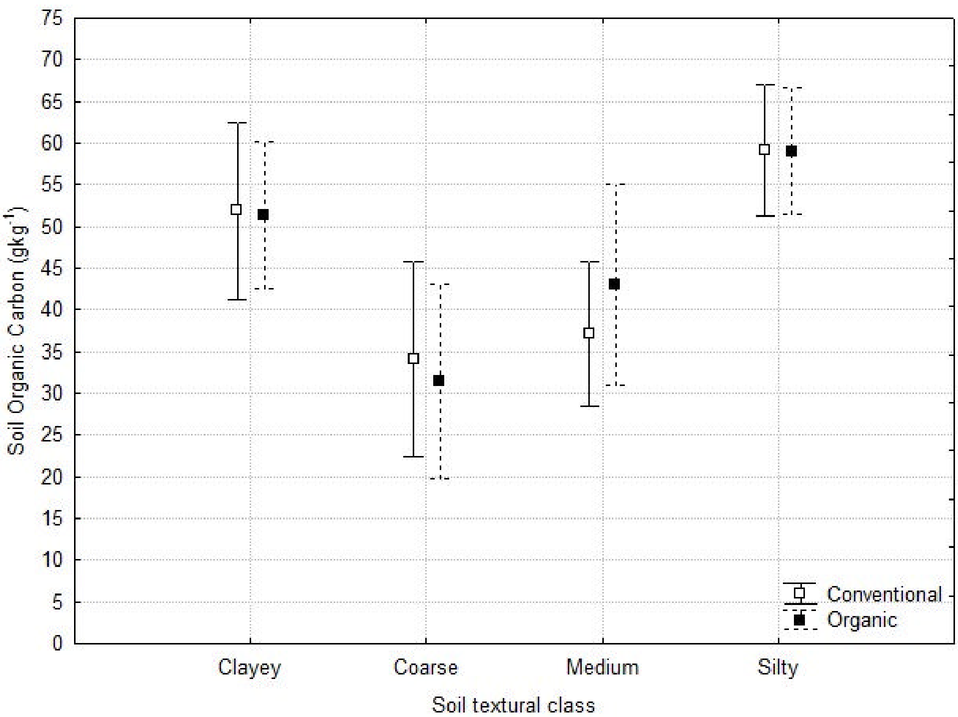


Figure 3.8: Box and whisker plot showing how soil organic matter varies according to textural class. The vertical bars indicate 95 % confidence levels for organic and conventional and do not show significant difference between treatments.

Table 3.7: The mean average SOC (g kg^{-1}) for each of the soil textures and land uses showing significant differences with different letters where $p < 0.05$. Numbers in brackets are the total number of samples in each category.

		Land use and Treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		**Mean**
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Soil Textural Class	Clayey (16)	**44.57**	3.21	**57.33**	11.61	**49.84**	16.29	**53.89**	18.87	**51.41^{a}**
	Silty (23)	**52.89**	11.24	**65.47**	16.37	**46.07**	13.64	**71.31**	20.37	**58.94^{a}**
	Medium (14)	**35.23**	2.10	**57.67**	0.00	**32.56**	3.94	**40.96**	9.50	**41.61^{b}**
	Coarse (11)	**31.11**	10.44	**29.13**	9.05	**26.39**	13.28	**64.77**	40.84	**37.85^{b}**
Mean		**40.95^{a}**		**52.40^{b}**		**38.72^{a}**		**58.98^{c}**		

An argument for the overall lack of difference between the arable treatments is that a reduction in biomass production for organic compared to non-organic fields could reduce the amount of crop residue available. However, the yield effect could be offset by the other inputs (ley and manure) and hence not be detected (Gosling and Shepherd, 2002). Schjønning *et al.* (2007) have recently shown that different land management practices will influence the level of SOM and the length of time the soils are managed can have a positive effect on the SOM level after 5-6 years.

3.7.2.3 Field Capacity Moisture Content

Field capacity is defined as the moisture content of the soil after excess gravitational water has drained (Smith and Mullins, 1991). It is affected by soil texture, soil structure, the amount of SOM and the type of clay present. The results in Table 3.8 show that there was no significant difference in field capacity between organic and conventional treatments for each of the four soil textural classes.

Table 3.8: The mean average Field Capacity moisture content (% mass, mass) for each of the soil textures and land uses showing significant differences with different letters where $p < 0.05$. Numbers in brackets are the total number of samples in each category. *shows differences only highlighted through REML.

		Land use and Treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		**Mean**
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Soil Textural Class	Clayey (16)	**35.84**	4.01	**38.03**	13.39	**31.95**	18.25	**36.09**	3.13	**35.48[a]**
	Silty (23)	**30.73**	3.26	**35.81**	9.80	**30.67**	4.79	**40.50**	11.31	**34.43[a]**
	Medium (14)	**28.22**	1.39	**43.35**	0.00	**27.65**	5.07	**32.37**	5.63	**32.90[a]**
	Coarse (11)	**22.59**	5.02	**21.85**	5.03	**16.67**	4.20	**29.42**	5.09	**22.63[b]**
Mean		**29.35[a]**		**34.76[b]**		**26.74[a]**		**34.60[b*]**		

However, as expected the results given in Table 3.8 show that there was a difference due to soil texture; where the coarse textured soils have a lower field capacity compared to the other textures. This was because the coarse textured soils have a smaller amount of clay which is the constituent that produces a larger surface area within the soil structure with more micropores for water absorption (Brady, 1990).

There is also a difference which could be attributed to land use, where all grass has a higher field capacity moisture content compared to arable ($p < 0.05$). The REML analysis proves that more specifically conventional grass has a higher field capacity moisture content compared to conventional arable. This is likely to be because there is a higher amount of SOC in the grassland fields that can help absorb and retain a larger volume of water. There is no significant difference between the organic and conventional grass.

3.7.2.4 Aggregate Stability

Aggregate stability is a measure of soil strength which is related to the soil texture (namely the percentage clay content), the amount of SOM present and the soil structure. It can greatly influence aeration, nutrient and water availability for plants (Tisdall and Oades, 1982). It can often show the impact of changes in land use before a change in the level of organic matter is observed (Haynes and Swift, 1990). The values shown in both Figure 3.9 and Table 3.9 are the amount of soil retained as a percentage of the original amount of soil before the test was performed, for example, the larger the percentage the higher the stability of the soil.

The results in Figure 3.9 show that there was no significant difference in aggregate stability between organic and conventional treatments for each of the four soil textural classes. This agrees with Williams and Petticrew (2009). However, with the exception of the coarse textured soils, the organically managed land tends to have a marginally higher aggregate stability than the conventionally managed soil. Even when the coarse textured soils are excluded from the analysis there was still no significant difference in aggregate stability.

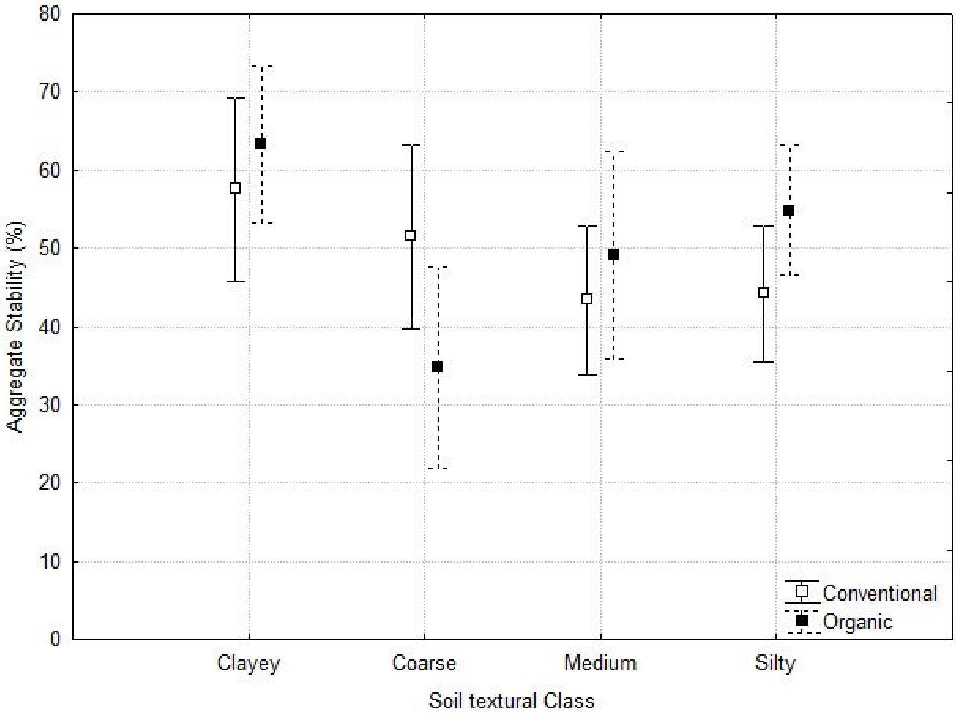


Figure 3.9: Box and whisker plot showing how aggregate stability varies according to textural class. The vertical bars indicate 95 % confidence levels for organic and conventional and do not show significant difference between treatments.

Table 3.9: The mean average aggregate stability (% mass, mass) for each of the soil textures and land uses showing significant differences with different letters where p<0.05. Numbers in brackets are the total number of samples in each category.

		Land use and Treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		**Mean**
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Soil Textural Class	Clayey (16)	**54.06**	18.86	**68.19**	19.67	**48.86**	11.67	**66.30**	6.69	**59.35^{a}**
	Silty (23)	**44.07**	16.57	**65.33**	11.56	**36.85**	18.13	**52.36**	17.74	**49.65^{a}**
	Medium (14)	**33.98**	8.57	**74.61**	0.00	**27.17**	5.79	**60.55**	9.62	**49.08^{ab}**
	Coarse (11)	**23.92**	3.12	**45.21**	35.28	**33.94**	26.92	**69.11**	9.13	**43.05^{b}**
Mean		**39.01^{a}**		**63.34^{b}**		**36.71^{a}**		**62.08^{b}**		

According to the data given in Table 3.9, there were significant differences related to land use for both organic and conventional treatments, where grass had a significantly higher proportion of stable aggregates compared to arable ($p < 0.05$). The REML analysis revealed that more specifically aggregate stability for both the conventional and organic grass was higher than in the conventional arable soil. There were also differences between soil textural class where the clayey, silty and medium soils were more stable than the coarse soils. The clayey and silty textured soils also had the highest amount of SOC; both this and the clay content help to bind the soil together, hence, improving the stability of the aggregates.

The management style of grassland such as the removal of grass as silage can also remove roots, SOM and binding ingredients (such as calcium ions) which reduces aggregate stability. For all of the fields, a mixture of practices were occurring, which could be masking any overall effect of organic or conventional treatments. The lack of significant difference between treatments agrees with a number of European studies which found no difference between conventional and organic land uses (Stolze *et al.*, 2000). However, at present it is not possible to relate the values determined within this report directly with other research values; as there is no standard method for assessing aggregate stability. Each method is slightly different and can lead to different results and unfair comparisons. This problem is not a new phenomenon and was discussed in some depth at the Defra Soil Research meeting in December 2008 (Godwin *et al.*, 2009).

3.7.2.5 Atterberg Limits

The Atterberg limits (plastic and liquid) determine the moisture content at the lower and upper end respectively of the moisture content range; over which the soil behaves in a plastic manner. Therefore, it provides an indication of the likely mechanical behaviour and hence workability of the soil. Plasticity is primarily a function of soil texture, clay type and chemical cation exchange capacity; however for a given soil where these factors are constant the amount of SOM present in the soil has an effect (Campbell, 1991).

The Atterberg Limits (plastic limit, liquid limit and plasticity index) for each of the soil types, land use and management are shown in Table 3.10. Whilst there were overall significant ($p < 0.05$) differences between the arable and grassland for the plastic limit and plasticity index; there was no significant difference in terms of plasticity index, plastic or liquid limits between organic and conventional agricultural management.

Table 3.10: The mean average Atterberg Limits (plastic limit, liquid limit and plastic index) in g kg^{-1} for each of the soil textures and land uses showing significant differences with different letters where p < 0.05. Numbers in brackets are the total number of samples in each category.

Plastic Limit (g kg^{-1})		Land use and Treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		**Mean**
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Soil Textural Class	Clayey (16)	**370.00**	28.28	**350.00**	63.70	**366.67**	35.12	**340.00**	45.83	**356.67[a]**
	Silty (23)	**250.00**	42.03	**334.00**	150.43	**192.00**	104.26	**340.00**	94.45	**279.00[b]**
	Medium (14)	**285.00**	110.91	**380.00**	0.00	**200.00**	49.50	**265.00**	66.58	**285.20[b]**
	Coarse (11)	**220.00**	50.00	**180.00**	56.57	**206.67**	51.32	**200.00**	52.92	**201.67[c]**
Mean		**281.25[a]**		**311.00[b]**		**241.33[a]**		**286.25[b]**		

Liquid Limit (g kg^{-1})		Land use and Treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		**Mean**
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Soil Textural Class	Clayey (16)	**580.00**	42.43	**526.25**	79.81	**596.67**	50.33	**530.00**	60.83	**558.23[a]**
	Silty (23)	**482.86**	28.70	**496.00**	134.28	**454.00**	87.35	**458.33**	136.74	**472.79[a]**
	Medium (14)	**415.00**	21.16	**560.00**	0.00	**358.00**	27.75	**407.50**	41.93	**435.13[a]**
	Coarse (11)	**300.00**	50.00	**385.00**	134.35	**363.33**	47.26	**286.67**	25.17	**333.75[b]**
Mean		**444.46[a]**		**491.81[a]**		**443.00[a]**		**420.63[a]**		

Plastic Index (g kg^{-1})		Land use and Treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		**Mean**
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Soil Textural Class	Clayey (16)	**210.00**	14.14	**176.25**	29.25	**230.00**	17.32	**190.00**	20.00	**201.56[a]**
	Silty (23)	**232.86**	18.90	**113.96**	84.08	**262.00**	88.99	**118.33**	44.46	**181.79[a]**
	Medium (14)	**130.00**	101.32	**180.00**	0.00	**158.00**	52.63	**142.50**	60.76	**152.62[a]**
	Coarse (11)	**80.00**	0.00	**205.00**	190.92	**156.67**	5.77	**86.67**	28.87	**132.10[b]**
Mean		**163.22[a]**		**158.13[b]**		**201.66[a]**		**134.38[b]**		

The ANOVA analysis shows that there was no significant difference between arable and grassland land uses for the liquid limits. However, the REML analysis reveals that there are some interactions present for the plastic limits and hence the plasticity index. Soil texture is very important for governing changes in Atterberg limits, although, following the ANOVA and REML tests, there were no significant differences between the soil texture for the plastic index or plastic limit. However, for the liquid limit there was a difference between soil textures where the coarse textural class has a significantly lower liquid limit than the other textures.

The REML analysis shows that:

i. There was a significant difference in the plastic limit where conventional grass was higher than conventional arable. This could be partly attributed to the clay content but there was a higher amount of SOM which could be raising the plastic limit for these soils; as plasticity could be dependent on polysaccharide gel within SOM (Soane *et al.*, 1972)
ii. The amount of SOM does not affect the plasticity index; however, it creates a strong bond with water raising the position for the plastic and liquid limits (Brady, 1990). Baver *et al.* (1972) suggested that SOM would cause a shift in the plasticity index extending the friability zone to fairly high moisture contents. The soil texture is very important for governing the effectiveness of SOM in changing the plasticity index (Archer, 1975).

The plasticity results can be used as a guide to determine the water content at which soil can be handled without causing damage (Marshal and Holmes, 1988). Ideally, the soil should only be worked when the moisture content is below the lower plastic limit to prevent soil damage and compaction. This is when the soil is in the optimum friable state. It is ideal for the field capacity of agricultural soils to be below the lower plastic limit as this enables field working to be conducted with a lower risk of soil damage. Table 3.11 summarises for each field whether this is the case.

Overall, there was no overriding management condition which actually makes a positive difference on soil working conditions. There appears to be no advantages in terms of land management for improving soil handling conditions from this data. However, a crude analysis of Table 3.11 shows that for 20 of the 32 pairs (66%) there was no difference in the relationship between field capacity (FC) and plastic limit (PL). This leaves 12 pairs where there was a change; five of these show an improvement for organic over conventional and seven the reverse. In the five beneficial sites, four of them were grassland and one was arable compared to the non-beneficial sites where five are arable and two are grassland. Hence, it might be concluded that there was a net shift of two grassland sites being positively benefited from organic management and four arable sites being negatively influenced. However, the soil texture also needs to be taken into consideration. For the grassland sites, the soil type was the same for both organic and conventional land management and one falls into the textural group of silty and the other clayey; hence the trend shown above was not due to soil texture. However, there is a more mixed soil textural classification for the arable sites where soils are medium, clayey, silty and coarse. There were only two arable sites where the soil texture was the same, one where the soil was silty and the other where the soil was medium textured in both cases there was a negative impact from organic farming.

Table 3.11: This shows whether the field capacity is below the plastic limit for each of the 64 fields measured. Key: Orange cells = clayey, yellow cells = silty, pink cells = medium and blue cells = coarse. ☒ = FC > PL, ☑ = FC < PL. The highlighted yellow cells for cluster ID 20 show that this is the only cluster with matching soil texture (silty clay loam).

Cluster ID	Treatment	Land use	FC < PL	Cluster ID	Treatment	Land use	FC < PL
2H	Organic	Arable	☒	12H	Organic	Arable	☒
2H	Conventional	Arable	☑	12H	Conventional	Arable	☒
2H	Organic	Grass	☑	12H	Organic	Grass	☒
2H	Conventional	Grass	☒	12H	Conventional	Grass	☒
2C	Organic	Arable	☒	12C	Organic	Arable	☒
2C	Conventional	Arable	☑	12C	Conventional	Arable	☒
2C	Organic	Grass	☑	12C	Organic	Grass	☒
2C	Conventional	Grass	☒	12C	Conventional	Grass	☒
6H	Organic	Arable	☑	16H	Organic	Arable	☒
6H	Conventional	Arable	☑	16H	Conventional	Arable	☑
6H	Organic	Grass	☒	16H	Organic	Grass	☑
6H	Conventional	Grass	☒	16H	Conventional	Grass	☒
6C	Organic	Arable	☑	16C	Organic	Arable	☒
6C	Conventional	Arable	☑	16C	Conventional	Grass	☒
6C	Organic	Grass	☑	16C	Organic	Grass	☒
6C	Conventional	Grass	☑	16C	Conventional	Arable	☒
9H	Organic	Arable	☒	21H	Organic	Arable	☑
9H	Conventional	Arable	☒	21H	Conventional	Arable	☒
9H	Organic	Grass	☒	21H	Organic	Grass	☑
9H	Conventional	Grass	☑	21H	Conventional	Grass	☒
9C	Organic	Arable	☒	21C	Organic	Arable	☒
9C	Conventional	Arable	☒	21C	Conventional	Arable	☑
9C	Organic	Grass	☒	21C	Organic	Grass	☒
9C	Conventional	Grass	☒	21C	Conventional	Grass	☒
20H	Organic	Arable	☒	23H	Organic	Arable	☒
20H	Conventional	Arable	☒	23H	Conventional	Arable	☒
20H	Organic	Grass	☑	23H	Organic	Grass	☒
20H	Conventional	Grass	☑	23H	Conventional	Grass	☒
20C	Organic	Arable	☒	23C	Organic	Arable	☑
20C	Conventional	Arable	☑	23C	Conventional	Arable	☑
20C	Organic	Grass	☒	23C	Organic	Grass	☒
20C	Conventional	Grass	☑	23C	Conventional	Grass	☒

Figure 3.10 focuses on the results from Cluster 20; which is unique in that it has the same soil texture (silty clay loam) in each location and hence is the most uniform of all clusters. When focusing on the cold spot; it was possible to see that both the conventional arable and grassland provides improved working conditions compared to

their organic counterpart. However, this could be attributed to slightly higher percentage clay contents in the soil rather than changes in SOC (as these contents are fairly consistent).

When focusing on the 'hot' spot, whilst there are differences between the absolute percentage moisture content (FC) for organic / conventional arable and grass, the effect of soil management does not change the condition with both grassland sites having FC < PL. Whilst this was not the case for the arable sites organic farming does substantially raise PL and reduce FC so that they are nearly even.

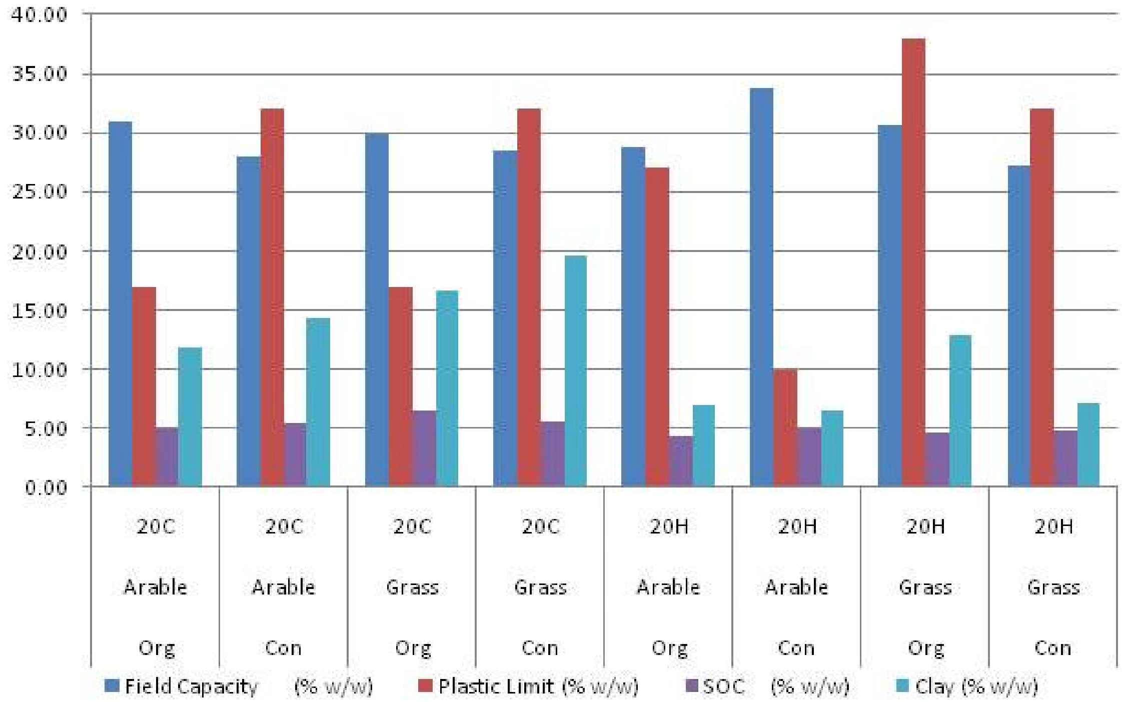


Figure 3.10: This graph shows field capacity and plastic limit for an example of cluster 20 with matching soil texture (silty clay loam).

3.7.2.6 Shear Strength

The strength of the soil will affect its behaviour 1) during the tillage operation and the energy required for the tillage operation, 2) vehicle movement causing compaction and 3) the ability for root penetration. The strength of a soil depends upon cohesive forces between the particles of soil and the amount of frictional resistance met by the particles as they slide over each other (Marshall and Holmes, 1988). These are influenced by soil density, soil moisture and SOC content (Smith and Mullins, 1991)

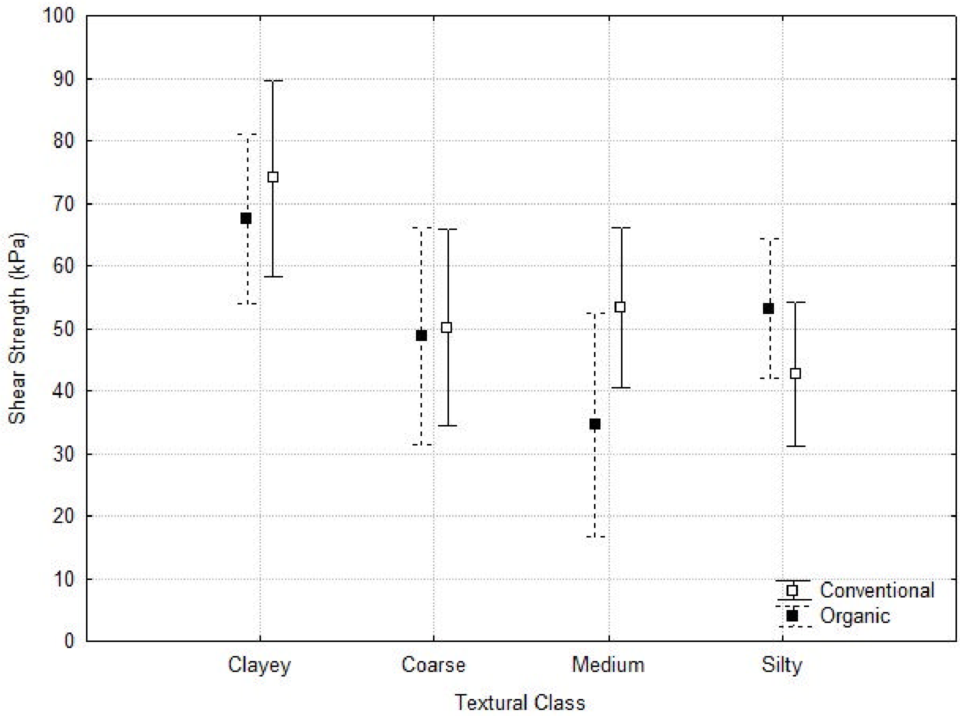


Figure 3.11: Box and whisker plot showing how shear strength varies according to textural class at field capacity moisture content. The vertical bars indicate 95 % confidence levels for organic and conventional and do not show significant difference between treatments.

The results in Figure 3.11 show that overall there were no significant differences in soil shear strength between the organic and conventional treatments. Whilst the analysis in Table 3.12 showed that the grass fields generally had higher shear strength due to the effect of the root mat binding the soil together and the lack of disturbance from tillage. The arable fields were more affected by the point at which the tillage was undertaken in the farming cycle, a few fields had just been tilled (namely organic arable fields in cluster 21) and hence the shear strength was lower than those that had settled over the winter. The soils were all sampled at field capacity and the higher clay fractions in the clayey group of soils have significantly higher shear strength. This is due to cohesion caused by the clay component which rises as the soil dries (Spoor and Godwin, 1979).

Table 3.12: The mean average shear strength (kPa) for each of the soil textures and land uses showing significant differences with different letters where p<0.05. Numbers in brackets show the total number of samples.

		Land use and Treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		**Mean**
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Soil Textural Class	Clayey (16)	**70.40**	10.66	**68.03**	19.97	**54.73**	34.60	**93.23**	11.80	**71.60[a]**
	Silty (23)	**50.19**	26.46	**62.50**	29.06	**41.60**	18.94	**43.3**	7.56	**49.40[b]**
	Medium (14)	**29.45**	6.45	**37.30**	11.03	**47.20**	15.70	**59.05**	5.48	**43.25[b]**
	Coarse (11)	**42.90**	24.39	**56.05**	3.75	**41.15**	10.96	**61.6**	13.62	**50.42[b]**
Mean		**48.24[a]**		**55.97[b]**		**46.17[a]**		**64.30[b]**		

3.7.2.7 Pesticides and Nutrients

Soil water samples were analysed for a range of pesticides from the major groups: carbonate (C), dicarboximides (D), organochlorine (OC), organophosphorus (OP), organonitrogen (ON), synthetic pyrethoids (SP) and triazoles (T). Table 3.13 shows the results of the analysis of residual agrochemicals in the soil water. Pesticides were present only in the soil water samples extracted from five of the clusters, in 15 out of the 64 fields measured.

Table 3.13: The number of fields which show a presence at trace level of the different types of pesticides.

Number of fields with pesticides present	Carbonate / Dicarboximides	Organo chlorine	Organo phosphorus	Organo nitrogen	Synthetic Pyrethoid	Triazole
Org Grass (16)	-	-	-	1	-	-
Org Arable (16)	-	1	-	-	-	-
Con Grass (16)	-	1	-	-	-	-
Con Arable (16)	-	1	-	9	-	2

Two organic fields showed levels of pesticides above the detection levels shown in Table 3.13. These were compounds of organochlorine (DDE) and organonitrogen (pendimethaline) with concentration of 0.3 and 0.02 mg kg^{-1} respectively. Sampling of the soil occurred in 2007, and these pesticide residues have remained since the farm converted to organic practice in 2000. Pesticides are degraded by the microbial community to form metabolites and its half life determines its persistence in the soil (Andreu and Pico, 2004). In Table 3.14, it can be seen that DDE has a large half-life (dt 50) equating to roughly 13 years which explains the presence of this pesticide in the organic farm. DDE is highly persistent and has a low leaching ability so is unlikely to cause ground or surface water pollution; however it has a high bioaccumulation factor which can cause problems as the pesticide can concentrate within the food chain.

On the other hand, pendimethaline has a lower half-life of only 90 days (PPDB Footprint, 2009). Therefore, this was not the reason for the presence of this pesticide. Pendimethaline has a high bioaccumulation factor (almost five times as high as DDE). Hence, this has probably accumulated to a high level in the soil as prior to conversion pendimethaline would have been applied every year (PPDB Footprint, 2009). It was surprising that the pendimethaline was not transformed or broken down by the soil micro-organisms, so there may have potentially been accidental contamination of this site from over application or drift from surrounding conventional fields. Pendimethaline has a low leaching potential, so would not pose a threat to ground or surface water supplies. Both the pesticides detected in the organic fields are persistent within the environment and, whilst not posing threats of pollution by leaching, there was potential for bioaccumulation within the food chain. The levels which were detected are well below the no observed effect concentration (NOEC) and hence would not pose environmental problems.

Thirteen conventional fields have shown levels of pesticides, which are believed to be related to the timings of application to the fields. Table 3.14 shows all the residues which were detected in the fields; all of which are persistent within the soil. None of the residues detected pose a leaching risk; however, all of the residues except chlorothalonil do pose an environmental impact through bioaccumulation within the food chain. Most of the levels reported were only marginally over the reporting limits; however, the fields which had DDE detected were almost 300 times greater than the reporting limits. This highlights the problem of persistence of this pesticide within the soil system due to the relatively long half life and lack of leaching (as a method of removal). However, the levels detected for all of the pesticides were well below the NOEC and so there should not be any environmental impacts.

Table 3.14: Shows the seven residues which were detected in soil water samples and their pesticide group reporting level, half life (dt 50) and environmental factors leaching potential and bioaccumulation potential (Adapted from PPDB Footprint, 2009).

Residue	Group *	Report Limit (mg kg^{-1})	dt 50 in soil (days)	NOEC** mg kg^{-1} (earthworm reproduction)	GUS Leaching potential***	Bio-accumulation factor
Chlorothalonil (fungicide)	OC	0.01	44 (18-77) Moderate persistent	25.0	1.44 Low leachability	100 Low potential
DDE (metabolite)	OC	0.02	5000 Very persistent	6.1	-2.59 Low leachability	1800 High potential
DDD (metabolite)	OC	0.02	1000 Very persistent	6.1	-3.53 Low leachability	3173 High potential
Flusilazole (pesticide)	T	0.02	300 (63-240) Moderate persistent	8.82	1.93 Transition State	250 Moderate potential
HCH (insecticide)	OC	0.02	121 Persistent	6.8	2.00 Transition State	1300 High potential
Pendimethaline (herbicide)	ON	0.02	90 (27-186) Moderate persistent	4.0	-0.39 Low leachability	5100 High potential
Trifluralin (herbicide)	OC	0.02	181 (81-375) Persistent	28.98	0.13 Low leachability	5674 High potential

*** Agrochemical group: OC - organochlorine, T - triazoles, ON – organonitrate**

**** NOEC is the no observed effect concentration this is based upon the reproductive behaviour of earthworms after 14 days of constant application at the rates above.**

***** GUS is the groundwater ubiquity score and is a measure of the mobility of pesticides it does not take into account soil or antecedent conditions (Gustafson, 1993).**

Soil water nutrients (total inorganic nitrogen, total phosphorus and total potassium) were measured using flame photometry. This is important for availability of nutrients for plant growth and uptake as well as potential for leaching and agricultural pollution.

The data in Table 3.15 shows the levels of total inorganic nitrogen (N), total phosphorus (P) and total potassium (K).

The data in Table 3.15 shows that there were no significant difference in levels of total phosphorus (mean 2176.9 +/- s.d. 970.7 g kg^{-1}) and total potassium (mean 863.6 +/ s.d. 304.3 g kg^{-1}) according to treatment, organic or conventional, at $p > 0.05$ and these are not affected by either soil texture or land use. For total inorganic nitrogen (ammonium and nitrate), there was a significant difference where the conventional arable (31 g kg^{-1}) is two to three times greater than the other land uses and treatments. This is shown in Figure 3.12. This difference was not surprising and could be attributed to the timings of fertiliser applications or manure applications which had been applied in the spring to the conventional arable land and not to the grassland. The organic arable had the lowest amount of total inorganic nitrogen compared to the other land uses, this could be related to the increased uptake of nitrogen into the crop which was harvested and not replenished with readily available nitrogen fertilisers as in the conventional land.

Table 3.15: The mean total nutrients for each of the soil textures and land uses showing significant differences with different letters where p<0.05. Numbers in brackets show the total number of samples.

Total inorganic N ($g\ kg^{-1}$)		Land use and Treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		**Mean**
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Soil Textural Class	Clayey (16)	**8.43**	5.45	**6.10**	6.42	**33.00**	10.65	**7.21**	0.75	**13.69[a]**
	Silty (23)	**12.67**	5.69	**12.75**	12.71	**31.41**	28.14	**21.38**	10.14	**19.55[a]**
	Medium (14)	**8.48**	0.96	**22.23**	3.92	**22.86**	15.47	**16.56**	3.26	**17.53[a]**
	Coarse (11)	**10.21**	6.98	**16.45**	5.67	**34.98**	16.75	**10.37**	6.77	**18.00[a]**
Mean		**9.94[a]**		**14.38[a]**		**30.56[b]**		**13.88[a]**		

Total P ($g\ kg^{-1}$)		Land use and Treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		**Mean**
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Soil Textural Class	Clayey (16)	**3189.50**	499.35	**2358.14**	981.51	**2462.00**	1418.00	**2144.00**	594.49	**2538.41[a]**
	Silty (23)	**1994.00**	636.77	**2140.00**	716.53	**2229.17**	1047.80	**257.57**	1279.83	**1665.19[a]**
	Medium (14)	**1423.66**	451.52	**3159.50**	3032.78	**2387.00**	930.73	**1562.00**	641.56	**2133.04[a]**
	Coarse (11)	**1364.66**	434.65	**1629.50**	562.15	**1348.66**	120.79	**2016.33**	837.23	**1589.79[a]**
Mean		**1992.95[a]**		**2321.79[a]**		**2106.70[a]**		**1494.95[a]**		

Total K ($g\ kg^{-1}$)		Land use and Treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		**Mean**
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
Soil Textural Class	Clayey (16)	**585.25**	145.12	**913.00**	290.48	**993.00**	130.10	**583.33**	202.65	**768.65[a]**
	Silty (23)	**1038.33**	299.39	**956.00**	191.74	**895.17**	343.62	**1059.27**	341.37	**987.19[a]**
	Medium (14)	**763.67**	290.89	**659.50**	256.68	**777.60**	351.48	**903.33**	552.40	**776.02[a]**
	Coarse (11)	**605.67**	160.79	**673.50**	258.09	**815.00**	189.30	**1063.00**	313.60	**789.29[a]**
Mean		**748.23 [a]**		**800.50[a]**		**870.94[a]**		**902.22 [a]**		

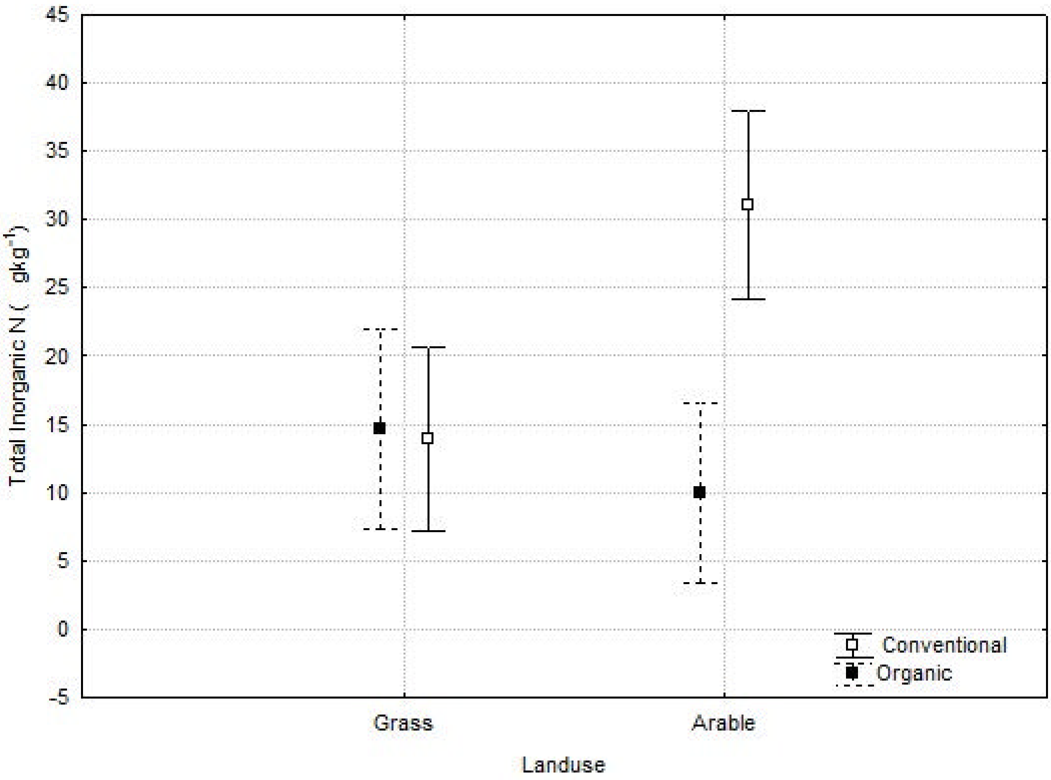


Figure 3.12: Box and whisker plot showing how total inorganic Nitrogen varies according to land use in each treatment. The vertical bars indicate 95 % confidence levels for organic and conventional and do show significant difference between treatments. (N.B. Texture not shown as it was not significant).

3.7.2.8 Soil Hydrological Properties

3.7.2.8.1 Infiltration Rate (Saturated Hydraulic Conductivity)

Infiltration rate (IR) is defined as the rate of movement of water into the surface soil layer (Brady, 1990). If the rainfall intensity is greater than the infiltration rate, water will accumulate on the surface and runoff will begin (this is also dependent upon depressional storage and slope angle). Therefore, improved infiltration rate is important in helping to reduce runoff and hence potential soil erosion and flooding (Godwin and Dresser, 2003). The infiltration rates for field soils range typically between 1 and 12 mm hr^{-1} (USDA, 1973). The level of variability in the soil surface conditions was compensated for by replicating the IR measurements ten times in each field using a 'w' sampling strategy across the field.

The statistical analysis of the IR data in Table 3.16 and Table 3.17 shows that despite a high level of infield variability; the IR of the conventional management was significantly lower than the others. There were also differences in the soil textural class, where IR in the clay (9.87 mm hr^{-1}) and sandy loam (7.52 mm hr^{-1}) soils were significantly greater than in the silty clay loam (4.35 mm hr^{-1}) and the clay loam (1.47 mm hr^{-1}) soils. This could be explained by the cracking nature of clay soils and the coarse texture of the sandy loam.

Table 3.16: Each treatment alongside details of soil series, management data and field observations.

Site	Land use	Soil Texture	Soil Series	Mean Infiltration rate (mm hr^{-1})	Management	Field Observations	HOST classification (**degraded)
2C	Conventional Grass	Silty Clay Loam	Panholes	0.78	Permanent pasture for 200 years. Grazed with 3.5 sheep / acre. No additions.	Tightly grazed by sheep, firm and compacted	1 (BFI 1%, SPR 2%)
2H	Conventional Arable	Silty Clay Loam	Upton	6.79	Synthetic fertilisers and herbicides. Tillage regime has 4 passes to a depth of 80mm using 2 discs, press roll, drill and roll.	Good visual structure	1 (BFI 1%, SPR 2%)
2C	Organic Grass	Silty Clay Loam	Panholes	5.67	Permanent pasture for 20 years. Topped and ragwort removal. Sucker cows (500kg). No additions.	Very large stocked field with patches of poaching	1 (BFI 1%, SPR 2%)
2C	Organic Arable	Silty Clay Loam	Panholes	4.18	No fertilisers, regular liming. Tillage regime has 5 passes to a depth of 150mm using plough, press, drill, harrow and roll.	Good soil structure, slight surface cap.	1 (BFI 1%, SPR 2%)
9H	Conventional Grass	Clay	Denchworth	6.38	Temporary pasture for 10 years. Topped once and used horse grazing. No additions.	Very poached in gateways and around feed areas. Soil structure very compact and firm. Horse paddock.	25 (BFI 0.17%, SPR 50%)
9H	Conventional Arable	Clay	Denchworth	4.89	Synthetic fertilisers and herbicides. Tillage regime has 4 passes to a depth of 180mm using plough, roll, drill and roll.	Moderately degraded	25 (BFI 0.17%, SPR 50%)
9H	Organic Grass	Clay	Denchworth	14.81	Permanent pasture for 100 years. Ridge and furrow, topped twice and used for rotational grazing of sheep. No additions.	Used for sheep grazing with old ridge and furrow still present.	25 (BFI 0.17%, SPR 50%)
9H	Organic Arable	Clay	Denchworth	13.42	FYM applied at 20t ha^{-1}. Tillage regime has 5 passes to a depth of 460mm using disc, roll, heavy tine, drill and roll with mole drainage.	Large surface cracks between crops with a slight surface crust.	25 (BFI 0.17%, SPR 50%)

Site	Land use	Soil Texture	Soil Series	Mean Infiltration rate (mm hr^{-1})	Management	Field Observations	HOST classification (**degraded)
21H	Conventional Grass	Clay Loam	Brockhurst	1.16	Permanent pasture for 50 years. Grazed with young stock (350kg). N additions and herbicides to control thistles.	Severe poached	24 (BFI 0.31, SPR 40%) **
21C	Conventional Arable	Clay Loam	Whimple	0.77	Synthetic fertilisers and herbicides, also FYM (16t ha^{-1}). Tillage regime has 2 passes to a depth of 230mm using plough and combi-drill.	Very degraded with obvious wheelings	21 (BFI 0.34, SPR 47%)**
21C	Organic Grass	Clay Loam	Whimple	1.57	Permanent pasture for 100 years. Grazed with cattle all year. Rotted FYM added and mechanical wedding with chain harrow.	Never ploughed, friable with strong grass sward	7 (BFI 0.79%, SPR 44%)
21C	Organic Arable	Clay Loam	Clifton	2.36	Rotten FYM. Tillage regime including mechanical weed control. There are 3 passes to a depth of 140mm using plough, power harrow and drill.	Previous damage from cattle poaching still visible	21 (BFI 0.34%, SPR 40%)
23H	Conventional Grass	Sandy Loam	Eardiston	1.80	Permanent pasture for 30 years. Used for silage production, two cuts a year; harrowed and rolled.	Localised poaching areas, around gateways and tracks.	4 (BFI 0.79%, SPR 2%)
23H	Conventional Arable	Sandy Loam	Eardiston	16.20	Synthetic fertilisers and herbicides. Tillage regime has 3 passes to a depth of 200mm using plough, power harrow, drill and roll.	Very weedy and compacted in patches	4 (BFI 0.79%, SPR 2%)
23C	Organic Grass	Sandy Loam	Salop	8.44	Permanent pasture for 10 years. Grazed cattle and sheep (2 weeks on 3 weeks off). Topped once and green waste compost added.	Seasonally waterlogged	9 (BFI 0.73%, SPR 25%)
23C	Organic Arable	Sandy Loam	Salop	3.64	No amendment. Tillage regime mechanical weed control. 4 passes to a depth of 250mm using plough power harrow, drill and roll.	Seasonally waterlogged	24 (BFI 0.31%, SPR 40%)

Table 3.17: The mean Saturated Hydraulic Conductivity (mm hr^{-1}) for each of the soil textures and land uses showing significant differences with different letters where p<0.05.

		Land use and Treatment								
		Organic				Conventional				
		Arable		Grass		Arable		Grass		**Mean**
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Soil Textural Class	Clay	**13.42**	0.17	**14.81**	0.16	**4.89**	0.48	**6.38**	0.37	**9.87^{a}**
	Silty Clay Loam	**4.18**	0.56	**5.67**	0.41	**6.79**	0.34	**0.79**	2.98	**4.35^{b}**
	Clay Loam	**2.36**	0.99	**1.57**	1.49	**0.77**	3.04	**1.16**	2.01	**1.47^{c}**
	Sandy Loam	**3.64**	0.64	**8.44**	0.28	**16.20**	0.14	**1.80**	1.30	**7.52^{a}**
Mean		**5.90^{a}**		**7.62^{a}**		**7.16^{a}**		**2.53^{b}**		

The results in Table 3.17 were anticipated when comparing these results with those obtained by Witzel (2008). Witzel (2008) used the same apparatus in controlled laboratory conditions in a sandy loam with a bulk density of 1.4 g cm^{-3} and three replicates yielding a mean value of 8.16 mm hr^{-1} with a standard deviation of 2.20. Chamen (2008) also used the Decagon to measure in field infiltration rates of a clay soil. These ranged between an average of 8.6 to 10.39 mm hr^{-1} depending upon the intensity of wheel traffic; there were 21 replicates undertaken, with standard deviations of 8.55 and 13.10 respectively. The variation in infiltration rates experienced with the *in situ* and laboratory measurements was very similar.

The data in Table 3.17 and Figure 3.13 show that the infiltration rate was lower for the conventional grassland compared to organic grassland. This difference between organic and conventional practices was also found in recent studies (Oquist *et al.*, 2006; Reganold and Palmer, 1995) those highlighted the issue of variability in collecting infiltration data. The conventional arable land use has a higher infiltration rate compared to conventional grass land use. This is shown in Figures 3.13 where conventional grass had a significantly lower infiltration rate compared to the other land use and management. For the organic land management there was no significant difference between the two land uses; this could be related to improvements in structure due to additions of FYM and other sources of SOM, which could potentially improve the soil biology especially the number of earthworms. It could also be related to an overall lower stocking density (where the average organic stocking density was 1.1 livestock units per ha compared to 1.3 livestock units per ha for the conventionally managed grassland (Sutherland *et al.*, 2011). Or fewer machinery passes on the arable land (Table 3.16).

There was an insignificant relationship between infiltration rate and SOC: where higher infiltration rates correspond with the highest SOC content except for arable silty clay loam. This could be because at this site, the soil structure was more compacted and hence the infiltration rate was reduced.

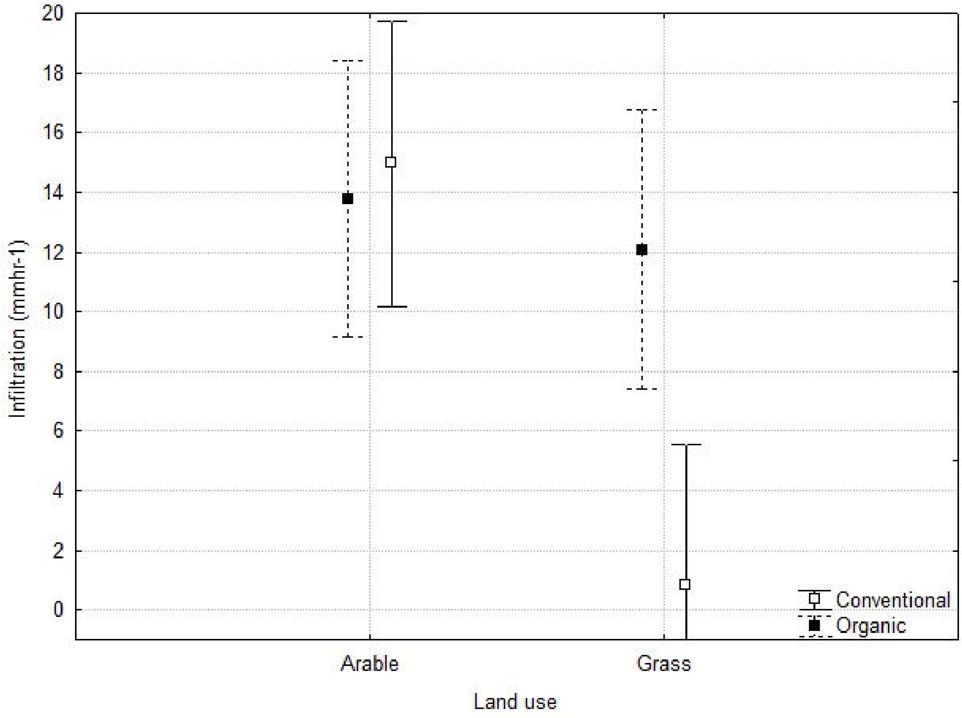


Figure 3.13: Box and whisker plot showing how infiltration rates vary according to land use and management. Covariant means for soil texture depending upon the percentage silt and clay were used to transform the data allowing for variation in soil texture. The vertical bars indicate 95 % confidence levels for organic and conventional. This difference was significant as $p < 0.05$.

Overall, it is possible to conclude infiltration was influenced by the local conditions such as the soil type and soil structural conduction which can occur regardless of the organic / conventional farming practices in place especially where the seasonal impacts of cracking, cultivation practices and crop rotation have more of an effect. Figure 3.14 shows some of the fields where infiltration were measured. It shows a well managed grass field for the conventional field where there may have been more traffic and compaction compared to the organic field above it. Figure 3.14 also shows a difference between the species richness of the sward which appears to be greater in the organic grassland; this would mean that there would be an increase in biomass helping prevent damage to the soil surface and structure hence improving infiltration rates in the organic grassland. There is little difference between the arable fields for organic and conventional (although it should be noted that the crops were different).

Figure 3.14: Conventional (top) and organic (bottom) managed land grass (left) and arable (right).

3.7.2.8.2 HOST

Hydrology of Soil Type (HOST) is the classification of the main soil types in the UK into 29 hydrological classes (Boorman *et al.*, 1995). These 29 classes are based upon the soil physical properties which are correlated with catchment scale hydrological variables and the dominant pathways of water movement through the soil and substrate (base flow index, BFI and standard percentage runoff, SPR respectively). BFI is the long-term average proportion of flow that comes from stored sources and SPR is the percentage runoff derived from event data, adjusted to standard rainfall and catchment moisture conditions (Boorman *et al.*, 1995). This model allows the level of degradation of soil to be an input and hence modifies the HOST class. A physically degraded soil, for example compacted, can lead to a significant change in the amount of runoff for most of the HOST classes (Godwin and Dresser, 2003).

The HOST classifications showed degradation of soil properties within 12 of the 64 fields and is summarised in Table 3.18 and presented in detail in Table 3.19a and 3.19b for the south and midlands groups respectively). This was indicated by an increase in the Standard Percentage Runoff (SPR) by approximately 10% and a decrease in the Base Flow Index (BFI) by 0.1 %. Overall there were less degraded organic than conventional fields and there were more degraded arable fields than grassland. This highlighted the poor soil structural quality of these fields which could be due to untimely tilling of the arable land or overstocking and hence poaching of the grassland.

Table 3.18: Table revealing the number of graded fields for each land use and management showing the soil textural group and the cluster location.

Land Use and Management	Number of degraded fields	Present in Clusters	Soil Textural Group
Organic Arable	3	12C, 16H, 21C	Silty, Medium, Coarse
Organic Grass	1	12C	Clayey
Conventional Arable	6	6C, 12C, 16C, 20H, 21C, 23C	Clayey, Medium, Silty, Silty, Medium, Coarse
Conventional Grass	2	20H, 21H	Silty, Medium
Total	12		

Table 3.19a: Host classifications for each field in the Midlands region together with an indication of true state if the field was damaged (Palmer, 2007).

Cluster	Hot/Cold	Management	HOST Class	BFI (%)	SPR (%)	Degraded State	Infiltration Rate (mm hr^{-1})
2	Hot	Organic Arable	1	1	2		
2	Hot	Organic Grass	1	1	2		
2	Hot	Conventional Arable	1	1	2		
2	Hot	Conventional Grass	1	1	2		
2	Cold	Organic Arable	1	1	2		
2	Cold	Organic Grass	1	1	2		
2	Cold	Conventional Arable	1	1	2		
2	Cold	Conventional Grass	1	1	2		
6	Hot	Organic Arable	2	1	2		4.18
6	Hot	Organic Grass	20	0.52	60		5.67
6	Hot	Conventional Arable	20	0.52	60		6.79
6	Hot	Conventional Grass	2	1	2		0.78
6	Cold	Organic Arable	25	0.17	50		
6	Cold	Organic Grass	23	0.22	60		
6	Cold	Conventional Arable	5	0.9	15	0.79 and 27	
6	Cold	Conventional Grass	23	0.22	60		
9	Hot	Organic Arable	25	0.17	50		13.42
9	Hot	Organic Grass	25	0.17	50		14.81
9	Hot	Conventional Arable	25	0.17	50		4.89
9	Hot	Conventional Grass	25	0.17	50		6.38
9	Cold	Organic Arable	1	1	2		
9	Cold	Organic Grass	24	0.31	40		
9	Cold	Conventional Arable	1	1	2		
9	Cold	Conventional Grass	8	0.56	44		
12	Hot	Organic Arable	21	0.34	47		
12	Hot	Organic Grass	24	0.31	40		
12	Hot	Conventional Arable	21	0.34	47		
12	Hot	Conventional Grass	24	0.31	40		
12	Cold	Organic Arable	21	0.34	47	0.22 and 58	
12	Cold	Organic Grass	21	0.34	47	0.22 and 60	
12	Cold	Conventional Arable	24	0.31	40	0.21 and 50	
12	Cold	Conventional Grass	21	0.34	47		

Table 3.19b: Host classifications for each field in the southern region together with an indication of true state if the field was damaged (Palmer, 2007).

Cluster	Hot/Cold	Management	HOST	BFI (%)	SPR (%)	Degraded State	Infiltration Rate (mm hr^{-1})
16	Hot	Organic Arable	1	1	2	0.90 and 10	
16	Hot	Organic Grass	1	1	2		
16	Hot	Conventional Arable	18	0.52	47		
16	Hot	Conventional Grass	18	0.52	47		
16	Cold	Organic Arable	1	1	2		
16	Cold	Organic Grass	1	1	2		
16	Cold	Conventional Arable	1	1	2	0.90 and 10	
16	Cold	Conventional Grass	1	1	2		
20	Hot	Organic Arable	1	1	2		
20	Hot	Organic Grass	1	1	2		
20	Hot	Conventional Arable	1	1	2	0.90 and 14	
20	Hot	Conventional Grass	1	1	2	0.90 and 15	
20	Cold	Organic Arable	1	1	2		
20	Cold	Organic Grass	1	1	2		
20	Cold	Conventional Arable	1	1	2		
20	Cold	Conventional Grass	1	1	2		
21	Hot	Organic Arable	18/21	0.52/0.34	47		
21	Hot	Organic Grass	7	0.79	44		
21	Hot	Conventional Arable	21	0.34	47		
21	Hot	Conventional Grass	24	0.31	40	0.21 and 49.6	1.16
21	Cold	Organic Arable	24	0.31	40	0.21 and 49.6	2.36
21	Cold	Organic Grass	21	0.34	47		1.57
21	Cold	Conventional Arable	21	0.34	47	0.22 and 59	0.77
21	Cold	Conventional Grass	21	0.34	47		
23	Hot	Organic Arable	3	0.9	15		
23	Hot	Organic Grass	3	0.9	15		
23	Hot	Conventional Arable	4	0.79	2		16.2
23	Hot	Conventional Grass	4	0.79	2		1.8
23	Cold	Organic Arable	24	0.31	40		3.64
23	Cold	Organic Grass	9	0.73	25		8.44
23	Cold	Conventional Arable	5	0.9	15	0.79 and 27	
23	Cold	Conventional Grass	3	0.9	15		

3.8 Summary of Results and Discussion

The results summarised in Table 3.20 show that despite a number of problems relating to site selection and the spatial separation of organically and conventionally managed fields that a number of significant effects could be determined. These are primarily due to the effects of soil texture and whether or not the fields were grass or arable. These results give confidence with respect to the findings as they are generally expected from the wealth of previous research.

The most critical finding with respect to the null hypothesis 'organic farming does not influence soil properties or physical condition' is that there is no evidence of SOC, field capacity, aggregate stability, the Atterberg limits (workability) or soil shear strength to support a rejection of this hypothesis. This gives weight to the findings of Armstrong Brown *et al.* (2000) and Stolze *et al.* (2000) that there was no evidence to show an improvement in soil conditions due to organic farming equally there is no detrimental effect. The fact that the effects of both soil type and cropping (i.e. grassland or arable) are often significant, as might be expected, gives confidence in the data. The data also provided a useful statement on the current status of soils under organic and conventional farming; provides baseline soil data to complete the agro-environmental study on the relative effects of organic farming on biodiversity (Gabriel *et al*., 2009) and supports the farm economy studies of the Rural Economy and Land Use project 'Effects of scale in organic agriculture' (Sutherland *et al.*, 2011).

In an ideal world matched pairs of immediately adjacent organic and conventional fields with the same soil texture and management practice would have been selected. This may have resulted in improved resolution to differentiate between organic and conventional soil management. It was essential however, that some latitude was shown in field selection to enable the multidisciplinary **RELU** project to be conducted. The fact that 50 % of the fields in this study were within 300 m and less than 30 % were greater than 2 km; was not unreasonable given the multidisciplinary nature of this study.

Overall there were fewer identified pesticides and herbicides in the soil water from two organic fields as opposed to 13 in conventional fields. It must be stressed that these were all at trace levels and below the No Observed Effect Concentration (NOEC). There were no differences in soil nutrients with the exception that the total inorganic nitrogen was significantly higher in the conventional arable compared to all the other land use and treatments. This would be expected as the samples were taken in the spring after at least one application of nitrogen to arable crops.

The infiltration rates were higher for clay and sandy loam soils, as would be expected, due to the ability of the clay to crack upon drying and the more porous texture and structure of the sandy loam. A significant effect was found where the conventional grassland had a lower infiltration rate than all other land uses and treatments. The field assessment of the Hydrology of Soil Types (HOST) classes showed that eight conventional fields were in a degraded state compared to only four organic fields.

The most useful finding for organic farmers is that organically managed grassland maintains a higher infiltration rate than conventional grassland (Table 3.17). Given the recent summer rainfall patterns of more and more extreme storm events, and their effects on runoff and flooding, the reduction in runoff could be beneficial to society (this will be explored further in Chapter 5). However, the benefits would only be accrued through a comprehensive unifying soil and water management plan for each catchment. But if, as is thought, the change in infiltration rate was due to slightly lower intensities of grazing then the same improvements could also result from better soil management on conventional grassland farms.

Table 3.20: Summary of the effects of soil type (texture), land use and organic/conventional management on soil, water, pesticide and nutrient status. The analysis of variance was performed at 95% confidence level.

Property	Soil Textural Class	Land use (Arable / Grass)	Management (Organic/Conventional)	Remarks
SOM / SOC	Clayey (51.41 +/- 11.61 g kg^{-1}) and silty (58.94 +/- 13.64 g kg^{-1}) soils significantly higher than medium (41.61 +/- 3.94 g kg^{-1}) and coarse (37.85 +/- 10.44 g kg^{-1}) soil	Grassland (52.48 +/- 9.05 g kg^{-1}) significantly higher than arable (38.72 +/- 13.21 g kg^{-1}) for both organic and conventional	No significant effect organic (46.67 +/- 8.12 g kg^{-1}) conventional (48.85 +/- 17.08 g kg^{-1})	Agrees with the findings of Gosling and Shepherd (2002)
Field Capacity	Coarse soil (22.63+/-5.02 %) significantly lower than other soil textures clayey (35.48+/-3.26 %) silty (34.43+/-4.79 %) medium (32.90+/- 5.07 %)	Grassland (36.6+/-5.63 %) significantly higher than arable (26.67+/-4.20 %) for both organic and conventional	No significant effect organic (32.05+/-5.24 %) conventional (30.67+/-7.18 %)	As expected given the SOM results
Aggregate Stability	Clayey (59.39+/-11.67 %) and silty (49.60+/-11.26 %) soils significantly higher than coarse soils (43.05+/-20.69 %). Medium (49.2+/-5.79 %) soil not significantly different from the other soils	Grassland (63.30+/-17.74 %) significantly higher than arable (36.70+/-9.62 %) for both organic and conventional	No significant effect organic (51.18+/-14.20 %) conventional (49.40+/-13.21 %)	As expected given the SOM results Agrees with the findings of Stolze *et al.* (2000)
Plastic Limit	No significant effect clayey (356.67+/-28.28 g kg^{-1}) silty (279.00+/ 42.03 g kg^{-1}) coarse (285.20+/-49.50 g kg^{-1}) medium (201.67+/-50.00 g kg^{-1})	Grassland (311.00+/-56.17 g kg^{-1}) significantly higher than arable (281.50+/-28.28 g kg^{-1}) for both organic and conventional	No significant effect organic (296.13+/-50.00 g kg^{-1}) conventional (527.58+/-51.32 g kg^{-1})	
Liquid Limit	Coarse soils (333.75+/-25.17 g kg^{-1}) are significantly lower than the other soils clayey (558.23+/-42.43 g kg^{-1}) silty (472.79+/-28.70 g kg^{-1}) medium (333.75+/-25.17 g kg^{-1})	No significant effect grassland (456.22+/-60.83 g kg^{-1}) arable (443.73 +/- 27.75 g kg^{-1})	No significant effect organic (468.14+/-50.00 g kg^{-1}) conventional (431.82+/-47.26 g kg^{-1})	
Plasticity Index	No significant effect clayey (201.56+/-14.14 g kg^{-1}) silty (181.79+/-44.46 g kg^{-1}) coarse (152.62+/-52.63 g kg^{-1}) medium (132.10+/-28.87 g kg^{-1})	No significant effect grassland (146.26+/-28.87 g kg^{-1}) arable (182.44+/-18.90 g kg^{-1})	No significant effect organic (160.68+/-29.25 g kg^{-1}) conventional (168.02+/-52.63 g kg^{-1})	

Property	Soil Textural Class	Land use (Arable / Grass)	Management (Organic/Conventional)	Remarks
Shear Strength	Clayey soils (71.59+/-10.66 kPa) are significantly higher than the other soil textural groups silty (49.40+/-18.94 kPa) coarse (50.42+/-10.96 kPa) medium (43.25 +/-11.03 kPa)	Grassland (55.97+/-7.56 kPa) significantly higher than arable (48.24+/-10.66 kPa) for both organic and conventional.	No significant effect organic (52.11+/-19.97 kPa) conventional (55.24+/- 18.94 kPa)	As expected where soil texture and presence of roots / non tillage in grassland would maintain strength.
Pesticides / Herbicides	Two organic fields showed traces (0.3 and 0.02 mg kg^{-1}) of organochlorine (DDE) and organonitrogen (pendimethaline) respectively. Two conventional fields showed organochlorine (DDE), nine organonitrogen (pendimethaline) and two triazoles. Levels detected below NOEC.			All below No Observed Effects Concentration (NOEC) levels.
Total Inorganic Nitrogen	No significant effect clayey (13.69+/-5.45 g kg^{-1}) silty (19.55+/-5.69 g kg^{-1}) medium (17.53+/-3.92 g kg^{-1}) coarse (18.00+/- 5.67 g kg^{-1})	Conventional arable (30.56+/-10.1 g kg^{-1}) significantly higher than all the other treatments.		As expected
Total Phosphorous	No significant effect clayey (2538.41+/- 594.49 g kg^{-1}) silty (1665.19+/-636.77 g kg^{-1}) medium (2133.04+/-641.56 g kg^{-1}) coarse (1589.79+/-434.65 g kg^{-1})	No significant effect grassland (1908.37+/- 594.94 g kg^{-1}) arable (2049.83+/-451.52 g kg^{-1})	No significant effect organic (2157.37+/-499.35 g kg^{-1}) conventional (1800.83+/- 930.73 g kg^{-1})	As expected
Total Potassium	No significant effect clayey (768.65+/- 145.12 g kg^{-1}) silty (987.19+/-191.74 g kg^{-1}) medium (776.02+/-256.68 g kg^{-1}) coarse (789.29+/-189.30 g kg^{-1})	No significant effect grassland (851.36+/- 191.74 g kg^{-1}) arable (825.25+/-130.10 g kg^{-1})	No significant effect organic (774.37+/-160.79 g kg^{-1}) conventional (886.58 +/- 202.65 g kg^{-1})	As expected
Infiltration Rate	Clay (9.89+/-0.17 mm hr^{-1}) and sandy loam (7.52+/-0.28 mm hr^{-1}) soils significantly higher than silty clay loam (4.35+/- 0.41 mm hr^{-1}) and clay loam (1.47+/- 0.99 mm hr^{-1})	Conventional grassland (2.53+/-0.37 mm hr^{-1}) significantly less than all the other treatments.		

3.9 Conclusions

The main conclusions which can be drawn are the following:

1) The analysis of the data, from a subset of organic and conventional farms, shows that, whilst it was possible to detect the effects of both soil texture and land use (grassland / arable) on a number of the soil properties, there is no evidence based upon soil organic matter, field capacity, aggregate stability, Atterberg limits/ workability and soil shear strength to reject the hypothesis that 'organic farming does not improve soil properties or physical condition.' Hence, in agreement with the results of a number of other studies, there is little direct benefit on the individual soil properties from organic farming practices – equally there is no detrimental effect.
2) There was evidence to support the suggestion that infiltration rates are greater on organically managed grassland than conventional grassland; such a difference might reduce runoff. This is in general agreement with the results of the HOST analysis which indicated fewer degraded fields under organic management.
3) Overall, there were fewer traces of pesticides or herbicides in the soil water from the organic fields compared with the conventionally managed fields. The conventional arable fields had higher levels of total inorganic nitrogen than the other land uses and treatments. There were no significant differences in total phosphorus and total potassium for any land use or treatment combinations.

4 Plot scale studies of organic farming practices and interactions with tillage regime

4.1 Introduction

Following the field-scale research (Chapter 3); these studies were established to determine the effect of tillage practices in both organic and conventional arable fields. This plot scale study at three different site locations allowed greater control of soil texture and soil series in the paired sites selected than the field scale study (Chapter 3). These paired sites were closer in proximity than in Chapter 3's paired fields with the furthest distance apart being 1500 m at East Grinstead. The plots on the remaining sites were approximately 350 m apart as shown in Table 4.1. There were three different soil textures: sandy loam, clay loam and clay. These studies were established and ran over two cropping seasons to see the short-term effects of converting tillage regime on both organic and conventional fields for the soil physical properties, infiltration rates and yields. These studies were intended to provide a link between the baseline data previously collected at the field scale (Chapter 3) and the **SCS-CN** modelling (Chapter 5).

The purpose of this study was to achieve the second objective outlined in Chapter 1. This was to determine the effects of soil management / tillage regime interactions on both organic and conventional farming systems, in terms of soil physical, chemical and hydraulic properties. As highlighted in the literature review (Chapter 2), there has been much research focusing on different types of tillage systems ranging from conventional plough, minimum non-inversion tillage to direct drilling. This has focused on many aspects of soil health including soil physical properties, soil hydraulics and nutrient cycling. There have also been studies investigating the effects of tillage economics and the cost benefit from reducing tillage intensity (Vozka, 2007). Reduced tillage is often avoided on organic farms due to the negative consequences for increasing weed populations (Vakali *et al.*, 2011). Peigné *et al.* (2007) specifically investigated changing tillage regime to minimum tillage on organic land to determine the impact upon weed populations and suggested methods to ensure that minimum tillage succeeded on organic farms. These included perennial mulches, the use of controlled traffic and rotational tillage. However, there is little research into the effect of changing tillage regime on soil properties in organically managed compared to conventionally managed land. This led to the formulation of two more specific objectives to address the lack of comparative research of tillage regimes on organic and conventional farms. These were to:

1. Identify fields that were more comparable in terms of soil texture and distance apart; so that the effects of the organic versus conventional arable management could be determined with a greater degree of confidence
2. Compare tillage regimes in terms of soil physical properties, infiltration rates and yield between organically and conventionally managed land over two cropping seasons and two different soil depths (0- 75 mm and 75 – 150 mm)

4.2 Methodology

This presents the second part of the study as outlined in Figure 1.1 (Chapter 1). Each of the three sites is described in detail explaining the experimental design and tillage treatments. This is followed by the common methodology for field sampling, laboratory and statistical analysis.

4.2.1 Site location and background information

Three focal farms were chosen using contacts of the Organic Research Centre and the Scottish Agricultural College. The locations of each of the farms in the UK (Figure 4.1) and their organic and conventional fields are shown (Figures 4.3-4.8). Prior to establishing the trials, soil samples were collected to determine the soil textural properties and current level of Soil Organic Carbon (SOC) (Table 4.1 and Figure 4.2). This was to ensure that the organic and conventional fields were similar in soil texture. The average value for SOC and soil texture for the two fields for each site is shown in Table 4.1.

Figure 4.1: Map of the UK showing the location of the three focal study sites: Aberdeen, Huntingdon and East Grinstead (Multimap, 2010).

Table 4.1: Soil textural properties for each site (both organic and conventional) prior to establishing the trials.

Soil Parameter	Aberdeen		East Grinstead		Huntingdon	
	Org	Con	Org	Con	Org	Con
Sand 2.00 - 0.063 mm (%)	20.75	24.43	27	30	7	5
Silt 0.063 - 0.002 mm (%)	68.35	65.44	55	50	36	36
Clay < 0.002 mm (%)	10.90	10.12	18	20	57	59
Textural Class	Sandy Silt Loam		Clay loam		Clay	
Soil Series/ Association (England and Wales / Scottish)	Countesswells (Dess Series)		Wickham 1 (711e)		Evesham 3 (411c)	
Organic Carbon (g kg^{-1})	35.44	37.21	16.24	10.05	25.00	25.00
Distance between fields (m)	400		1500		350	

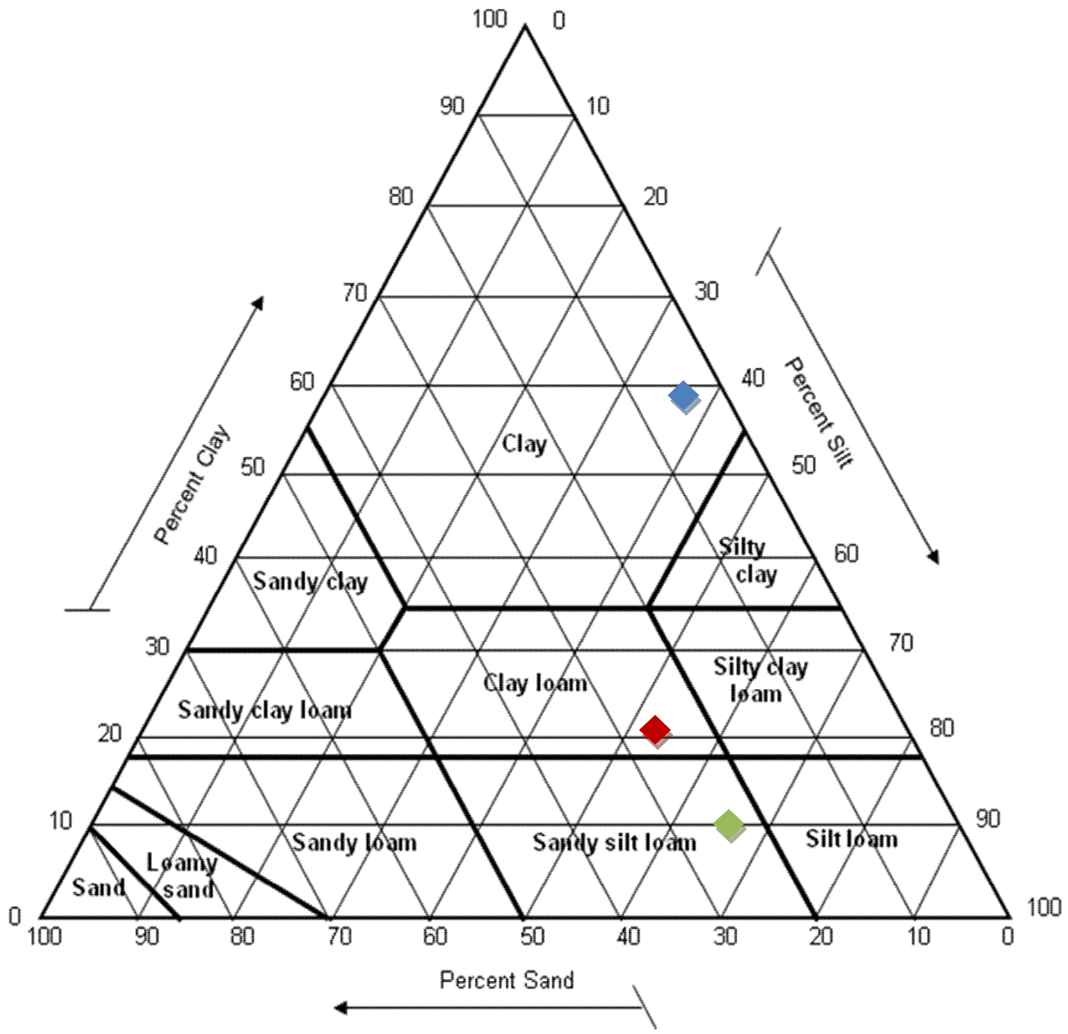


Figure 4.2: UK Soil textural triangle showing the three different soil textures for each site (McRae, 1988). (Key: ◆ = Huntingdon, ◆ = East Grinstead, ◆ = Aberdeen)

Details of each farm which include: the length of time of organic management, previous tillage regimes, previous cropping cycle, and the amendments / fertilisers to the land both organic and inorganic are shown in Table 4.2.

Table 4.2: Background information for each of the three sites (WW = winter wheat, SW= spring wheat, WO = winter oats, SO = spring oats, OSR = Oilseed Rape).

Site Location	Organic (years)	Previous Tillage	Residue Management	Previous crop	Amendments
Aberdeen					
Organic	20	Plough	Removed	Grass (3), cereal, legume, cereal	25% dry matter cattle manure 15 t/ha
Conventional	N / A	Plough	Removed	Cereal, cereal, legume, grass	Phosphate, Nitrogen (spray Pennant)
E.Grinstead					
Organic	50	Plough	Incorporated	Grass, SW, SO, legume	30 t/ha Farmyard manure
Conventional	N / A	Plough	Incorporated	WW, WO, OSR	Phosphate, Nitrogen (sprayed Comet)
Huntingdon					
Organic	8	Flat lift and min-till	Removed	WW, SO vetch, legumes	Spent mushroom compost (sewage sludge)
Conventional	N / A	Flat lift and min-till	Removed	WW, WW, OSR	Phosphate, Nitrogen (spray Pennant)

4.2.1.1 Aberdeen (Grid ref: NJ8725510493)

Two fields (one organic and one conventional) were located on soil with the same texture and soil series (shown in Figure 4.3). At each of the fields three different tillage treatments were implemented: traditional plough, reduced tillage rotavator and reduced tillage rotavator and disc (Table 4.3). The additional rotavator operation in the reduced tillage rotavator and disc, was required due to difficulties in forming a seedbed in grassland; it was maintained for consistency in the second year. In the organic field there was an additional treatment of ploughing, which was under-sown with a white clover mix because this is a common practice with organic farms for fertility building. There were three replicates of each tillage treatment in both the organic and conventional fields. The crop established in the first year (2008-2009) was spring barley *Riveria* in both the conventional and organic plots. In the second year (2009-2010), spring oats *Firth* were established in both the conventional and organic plots.

The plots sizes were 30 m length by 6 m width for all of the treatments on both the organic and conventional fields (the layout and treatments are shown in Figure 4.4).

Figure 4.3: Aerial Photograph showing the relative locations of the organic (☆) and conventional (☆) fields in Aberdeen (Multimap, 2010).

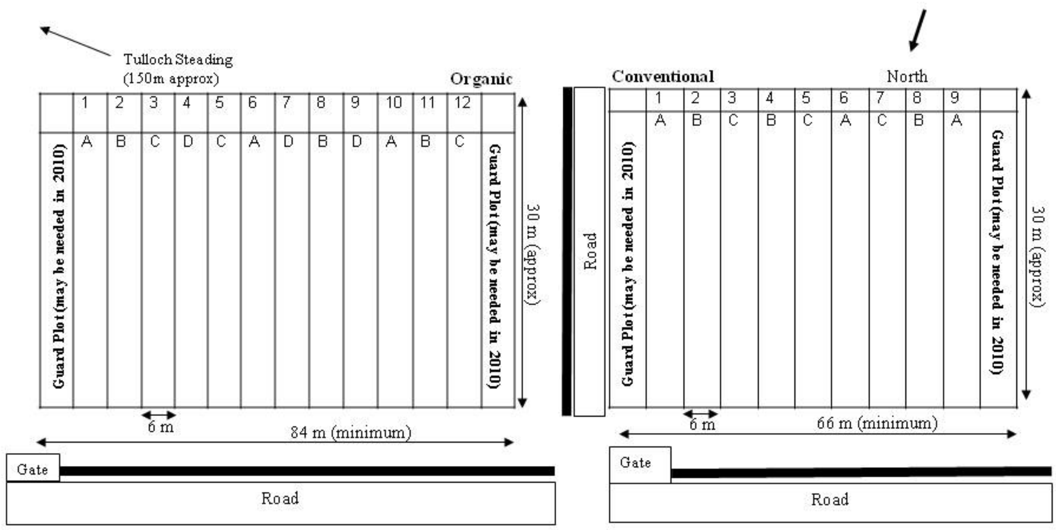


Figure 4.4: Experimental design in Aberdeen (Organic field left, Conventional field right). Treatments were randomised A= Plough B = Reduced tillage rotavator C = Reduced tillage disc D = Plough and under-sown (organic only). Not to scale.

Table 4.3: Primary and Secondary tillage information for each of the three different tillage treatments in Aberdeen.

Treatment	Plough	Reduced Rotavator	Reduced Disc
Primary Tillage	1 pass (200 mm depth, 1.2m width, 3 furrows) 	1 pass Rotavator (100 mm depth, 2m width) 	2 passes standard disc (80 – 100 mm depth, 3.5m width)  1 pass Rotavator (100 mm depth, 2m width)
Secondary Tillage	Power Harrow (1 pass) Roll 6m width (1 pass) Drill 3m width 40 mm depth	Power Harrow (1 pass) Roll 6m width (1 pass) Drill 3m width 40 mm depth	Power Harrow (1 pass) Roll 6m width (1 pass) Drill 3m 40 mm width depth
Tractor details for tillage	McCormick 118 hp (Tyres: Back 480/70R34, Front 360/70R24)	MF 59 hp (Tyres: Back 136/ 12-38, Front 7.5 – 16)	McCormick CX 105 hp (Tyres: Back 480/70R34, Front 360/70R24)
Harvester details	Plot Combine Deutz Fahr M660 56 hp	Plot Combine Deutz Fahr M660 56 hp	Plot Combine Deutz Fahr M660 56 hp

4.2.1.2 East Grinstead (Grid Ref: TQ4289935191)

Two fields (one organic and one conventional) were located on soil with the same texture and soil series (shown in Figure 4.5). At each of the fields two different tillage treatments were implemented: traditional plough (depth 200 mm) and reduced tillage (depth 150 mm) (Table 4.4). The crops established in the first year (2008-2009) were winter wheat (conventional and spring wheat (organic). In the second year (2009-2010) the crops were winter wheat (conventional) and spring barley (organic). Therefore, comparisons between organic and conventional yields cannot be made; they can only be made for different tillage regimes in organic or conventional management. The plots sizes were 25 m long by 24 m wide for all of the treatments on both the organic and conventional fields (Figure 4.6). This was not randomised due to the farmer implementing the trial and ease for access of machinery. There were three pseudo replicates (sub-sample areas from the larger plot) of each tillage treatment in both the organic and conventional fields.

Table 4.4: Primary and Secondary tillage information for each of the two different tillage treatments in East Grinstead.

Treatment	Plough	Minimum Tillage
Primary Tillage	1 pass (200 mm depth, 1.2m width, 3 furrows) 	None
Secondary Tillage	Power Harrow (1 pass) Roll 6m width (1 pass)	Ecodyn (3 passes) 150 mm depth 
Drill	Drill 3m width 40 mm depth	Drill 3m width 40 mm depth
Tractor details	John Deere 7800 170 hp	John Deere 7800 170 hp

Figure 4.5: Aerial Photograph showing the relative locations of the organic (★) and conventional (★) fields in East Grinstead. A) Organic field B) Conventional field (Multimap, 2010).

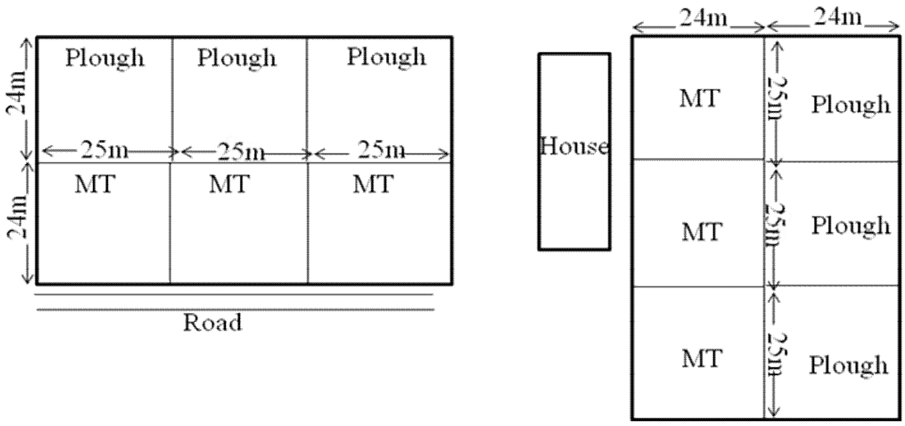


Figure 4.6: Experimental design in East Grinstead (Organic field right, Conventional field left) MT = minimum tillage. Not to scale.

4.2.1.3 Huntingdon (Grid Ref: TL2101280614)

Two fields (one organic and one conventional) were located on soil with the same texture and soil series (shown in Figure 4.7). At each of the fields three different tillage treatments were implemented: no tillage (direct drill), reduced tillage disc (150 mm) and ploughed (depth 300 mm) (Table 4.5). The crops established were winter wheat (conventional) and spring wheat (organic). Hence, it is not possible to compare yields between organic and conventional management. This trial was for one cropping season (2008-2009) because it was only possible to establish a one year trial at this site. The plots were 9 m long by 3 m wide and as shown in Figure 4.8. This was not randomised due to the farmer installing this trial, which required ease of access of machinery. There were three pseudo replicates (sub-sample areas from the larger plot) of each tillage treatment in both the organic and conventional fields.

Table 4.5: Primary and Secondary tillage information for each of the three different tillage treatments in Huntingdon.

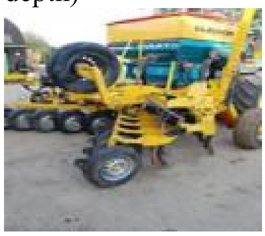
Treatment	Plough	Reduced Tillage (Disc)	Direct Drill
Primary Tillage	1 pass (200 mm depth, 1.2m width, 3 furrows) 	1 pass Rotavator (100 mm depth, 2m width) 	None
Secondary Tillage	Power Harrow (1 pass) Roll 6m width (1 pass)	Roll 6m width (1 pass)	None
Drill	Drill 3.45m width 40 mm depth	Drill 3.45m width 40 mm depth	Claydon driect v drill (3.45m width, 40 mm depth) 
Tractor details	John Deere 7800 170 hp	John Deere 7800 170 hp	John Deere 7800 170 hp

Figure 4.7: Aerial Photograph showing the relative locations of the organic (★) and conventional (★) fields in Huntingdon (Multimap, 2010).

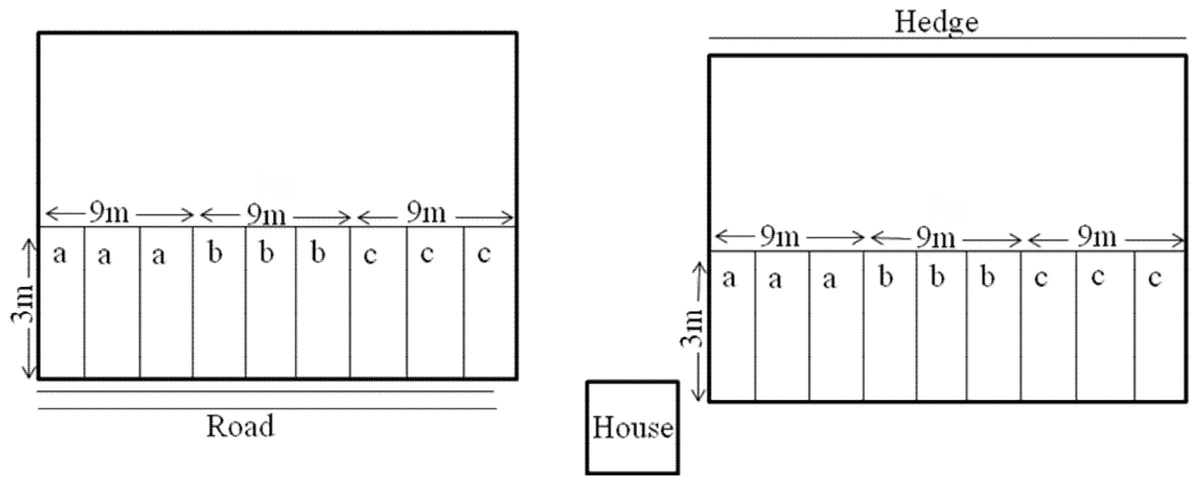


Figure 4.8: Experimental design in Huntingdon (Organic field right, conventional field left). Treatments were a= Plough b = Reduced tillage (disc) c = direct drill. Not to scale.

4.2.2 Field Methodology

Soil samples were collected at each of the three sites following the same methodology as outlined in *Phase 1*. Samples totalling 1 kg (wet weight) were taken at two different depths within the topsoil layer (0 -75 mm and 75 - 150 mm). These were collected at four different periods during the growing season for two crop cycles (except for Huntingdon); to enable seasonality to be accounted for (see Table 4.6). The different time periods are:

1. Prior to planting - the effect of tillage on infiltration and potential runoff
2. During preparation of land for planting – the workability of land
3. During crop growth – the effect of vegetation
4. Post harvest – the effect of traffic, compaction and effect of stubble/ crop residue

Table 4.6: Timings of sampling in each of the three focal farms and testing requirements.

Timing	Collection of soil for testing	*In Situ* Testing	Additional Information
Prior to land preparation (initial conditions) ***February 2009 (Aberdeen and East Grinstead) September 2008 (Huntingdon)***	Soil texture, Aggregate stability, Atterberg limits, SOC, Total C:N, pH	Shear strength, soil structure, bulk density	Inputs
Post land preparation and sowing ***April 2009 / 2010***	Porosity, Aggregate stability, plastic limit, SOC, Total C:N, pH, field capacity	Shear strength, infiltration, soil structure, bulk density	Inputs
During crop development (stem extension) ***June 2009 / 2010***	Aggregate stability, SOC, pH		Weed observation
Post Harvest ***September 2009/2010***	Porosity, Aggregate stability, plastic limit, SOC, Total C:N, pH, field capacity	Shear strength, infiltration, soil structure, bulk density	Yield estimates (dry matter contents)

One small profile pit was excavated (200 mm depth) within each treatment at all three sites to determine the soil structure and physical conditions of the topsoil. In Aberdeen, the first measurements of shear strength were collected using the torsional shear box (Payne and Fountaine, 1952). However, the shear vane was used for the remainder of the samples because of constraints in access to equipment. The shear vane was used as a measure of surface soil shear strength *in situ* (Franti *et al.*, 1985) as it is simple and quick to use within the field. Measurements were taken using a grid sampling technique allowing 30 samples to cover each treatment to a depth of (0 – 200 mm). Core samples were collected ensuring minimal disturbance to the soil (Hall *et al.*, 1977). These cylinders had a volume of 222 cm^{-3} and were used to determine the bulk density of the soil as well as the field capacity. At Aberdeen, five cores were taken across each treatment in both the organic and conventional fields; at the different time periods shown in Table 4.1. This allowed the calculation of bulk density, field capacity moisture content and water holding capacity. At Huntingdon and East Grinstead, three cores were taken across each treatment in both the organic and conventional fields.

At each site, infiltration (saturated hydraulic conductivity) was measured using the Decagon mini disk infiltrometer (see Figure 3.5). The advantages of this method are outlined in the field scale study (Chapter 3). In all three sites, five replicates were made in each treatment for both the organic and conventional fields along a 'w' shape avoiding atypical areas (Bodhinayake *et al.*, 2004). Each replicate was sampled for 15 minutes at 20 mm tension and the infiltration rate was calculated using the method developed by Zhang (1997) and the van Genuchten parameters (Carsel and Parrish, 1988). The soil moisture content was measured at each site using a ThetaProbe (Delta-T, 1999) with five replicates in each treatment.

Yield estimates (t ha^{-1} @ 85% Dry Matter) were calculated and recorded for the grain removed from each plot.

4.2.3 Laboratory Methodology

The soil samples were air dried, mixed ground and sieved (Allen, 1989). A 2 mm diameter mesh sieve was used for soil organic carbon (SOC), pH and texture, a 425 µm mesh sieve was used for Atterberg limits, total C: N and a combination of passing through a 5 mm and held on a 3.35 mm mesh sieves were used for aggregate stability. Soil texture was determined using the pipette method which separates the soil into three fractions: sand, silt and clay and by plotting these values onto a soil textural triangle the texture can be determined as shown in Figure 4.2 (BS 7755). SOM was established by dichromate digestion (BS 1377-3). Aggregate stability was determined through the wet sieving method outlined in Haynes and Swift (1990). Gravimetric moisture content was measured through oven drying at 105^{o}C until a constant weight was achieved (Gardner, 1986). The plastic limit (BS 1377-2) was determined. The pH was measured using a 1:1 distilled water solution, shaking the samples for 1 hour and standing for 1 hour prior to measurement with a pH probe. Total C:N ratio was measured using the CNS elemental analyser.

The soil cores analysed for dry bulk density were removed from their tins and oven dried at 105^{o}C for 24 hours. Then the volume of the soil within the core was determined as the volume of the tin was known (222 cm^{-3}). Total porosity was calculated; through Equation 4.1 (Hall *et al.*, 1977).

$$\text{Total porosity} = 1 - \frac{\text{bulk density of sample}}{\text{particle density (2.65)}} \times 100$$ **Equation 4.1**

The remaining cores were analysed for maximum (or total) water holding capacity and field capacity moisture content at 0.05 bar suction. Following the procedure in Smith and Mullins (1991) samples were saturated on a foam bath for twenty four hours and weighed periodically until there was no further weight gain. Then they were placed on a sand tension table to a suction of 0.05 bar to determine field capacity moisture content (Hall *et al.*, 1977). The water holding characteristics on a mass basis; were calculated using the following equations.

$$\text{WHCmax (\% m / m)} = \frac{\text{WHCa} - \text{WHCc} - \text{WHCf}}{\text{WHCc} - \text{WHCd}} \times 100$$ **Equation 4.2**

$$\text{WHCfc 0.05 bar (\% m / m)} = \frac{\text{WHCg} - \text{WHCc}}{\text{WHCc} - \text{WHCd}} \times 100$$ **Equation 4.3**

WHCa = mass of saturated sample, tin, mesh and elastic band.

WHCc = mass of oven dried sample, tin, mesh

WHCd = mass of tin and mess

WHCf = mass of elastic band

WHCg = mass of suction tin and mesh

4.2.4 Statistical Methodology

Statistical analysis was performed using Statistica (8.0). First, any data that showed deviation from normality was transformed (Box-Cox). Data analyses were conducted to test the null hypothesis that 'there were no significant differences in soil properties due to organic farming in arable fields (as discovered in Chapter 3) or different tillage regimes over time'. The alternative hypothesis is that organic farming and tillage regimes have an effect upon soil properties as shown by Peigné *et al.* (2007). The differences in soil quality between organic and conventional management and tillage treatments was testing using ANOVA, assuming that the measured variables (SOC, aggregate stability, plastic limits, shear strength, water holding capacity, bulk density, pH, total C:N ratio and infiltration rates) were normally distributed. Any outliers were identified and removed from the data set. As the experimental design was balanced with the same soil textures and treatments available for both organic and conventional management, factorial analysis was used. A general linear model (factorial analysis), including repeated measures, was used to determine whether there was a significant difference in soil properties between organic and conventional fields, tillage treatment and soil texture and the effect over time. The ANOVA was calculated using Least Squares (Statistica 9.0) and the results were further interpreted in using Fisher LSD.

4.3 Results and Discussion

This section presents the main findings for each of the soil properties measured for all three sites. The results are presented for each site to highlight differences between management (whether organic or conventional), treatment (different tillage regimes as described in Section 4.2) and over time. The three sites are then compared to indicate an effect of soil texture. The literature review (Chapter 2) showed there is a mixture of results for all soil properties both in favour and against organic farming. The results presented here are compared with the literature and highlighted where there is consensus.

4.3.1 Soil Organic Carbon (SOC)

The **RELU** field scale study (Chapter 3) showed that there was no significant difference in SOC content between organic and conventionally managed fields. However, there was a trend for organic arable fields to have a higher level of SOC. An issue raised in field study (Chapter 3), was that differences in tillage regimes and soil texture may mask any possible effect of organic management. Therefore, the plot scale study exercised more control over soil texture and spatial distance between organic and conventional fields. Tillage is thought to influence these SOC dynamics through changing the soil habitat for micro-organisms, incorporating SOC into the soil matrix (where clay particles can protect SOC from decomposition) and through the disruption of the soil structure (Balesdent *et al.*, 2000). Kemper and Koch (1966) indicated that for functioning agricultural soils there was a critical SOC level of 20 g kg^{-1}. However, this has been disputed as being too simplistic and not accounting for differences in soil texture or climate.

Table 4.7: Typical SOC range for each of the three sites (under arable land use) based upon soil texture and precipitation (adapted from LandIS (Keay *et al.*, 2009) and Glentworth and Muir, 1963).

Site	Clay	Rainfall mm yr^{-1}	SOC mean and standard deviation (g kg^{-1})
Aberdeen	0-10	545	44.5 + / - 14.8
East Grinstead	10-20	900	37.8 + / - 24.3
Huntingdon	50-60	650	31.4 + / - 7.8

Each plot scale study site is explored and their results for SOC are presented by location and then comparatively by soil texture.

4.3.1.1 Aberdeen (Sandy Silt Loam)

Figure 4.9 shows that the level of SOC is within the typical range outlined in Table 4.7; hence there is no issue of decreased SOC due to arable management. Towers *et al.* (2006) stated that Scotland's soils contain a much higher proportion of SOC compared with the rest of the UK. This can be related to climatic conditions (colder) during formation and reduced rates of decomposition; however this may change with the warmer and wetter climates predicted where decomposition would occur more rapidly (Towers *et al.*, 2006).

When comparing the overall effects of organic and conventional management practices irrespective of different tillage regimes; there was significantly less SOC ($p < 0.05$) in organically managed soil (41.61 g kg^{-1}) than the conventionally managed soil (44.82 g kg^{-1}). The land has been managed organically for 20 years; differences between organic and conventional management are shown. Stolze *et al* (2000) reported more studies with an increase in SOC under organic management and two with no significant difference. This was not supported in this research. In February 2009, the two fields recorded similar levels of SOC with conventional management being slightly higher. In the years before the trial commenced, the conventional farmer regularly applied organic manures on the land, which most likely have helped to up build organic matter contents. The effect could be due to previous applications of SOM to the land, helping to compensate for any reduction in SOC which would be anticipated due to higher yields (see Section 4.3.11 for yield data).

Figure 4.9 shows how SOC varies over the two year sampling period for both organic and conventional management. The SOC increased post tillage (April 2009) and then reduced gradually during stem extension (June 2009) until it reached the lowest level post harvest (September 2009). This trend was repeated during the second year with an increase immediately post tillage (April 2010) with a further increase during stem extension (June 2010) before reducing post harvest (September 2010). There appears to be a cyclic trend where there is no stabilisation of SOC content such as under long- term management but SOC is in a constant state of flux (Bhogal *et al.* 2009). This could be due to tillage interactions where oxidation occurs during crop establishment (April 2009 / 2010) and increases until slight compaction during harvest (September 2009 / 2010) reducing the SOC content. Alternatively, it could be related to the soil temperature, which would normally increase during the season and influence the amount of microbiological activity occurring which would mineralise SOC. The largest value for SOC was measured during stem extension (June 2010) and was significantly larger than the other values. This difference could be due to the crop rotation from spring barley to spring oats which could have increased the SOC pool during the second year of the study.

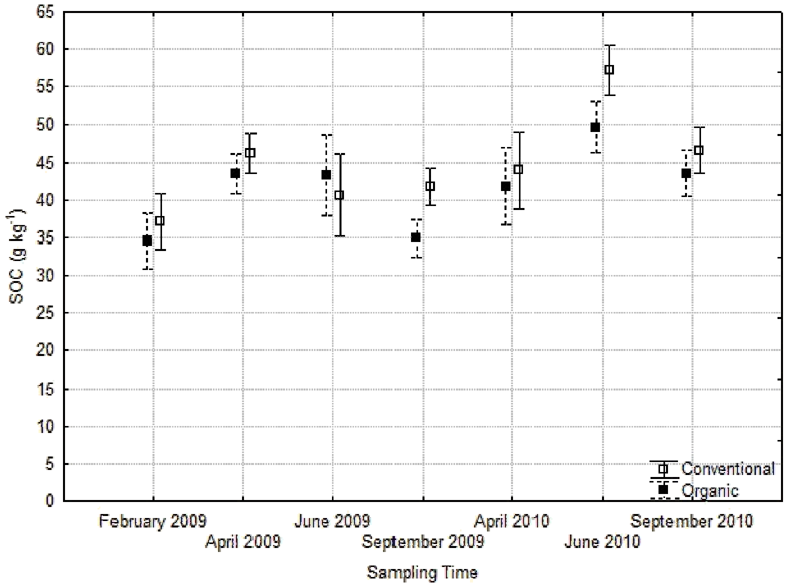


Figure 4.9: Mean value of SOC (g kg^{-1}) in Aberdeen at each sampling point (the bars show 95 % confidence interval). The SOC values are not corrected according to differences in bulk density as this did not influence the results. LSD = 5.05

The effects of different tillage regimes and their interaction with management (organic and conventional) are shown in Figure 4.10. Conventional reduced tillage (disc) was significantly higher (47.38 g kg^{-1}) than all the organic treatments ($p < 0.05$). The conventional reduced tillage (rotavator) was significantly lower (42.75 g kg^{-1}) than the other conventional treatments but was not significantly different to the organic treatments. An additional treatment of ploughing and undersowing in the organic land, as a fertility building system, was included. It was not significantly different to any of the other treatments. These differences are supported in the literature where Kingery *et al.* (1996) found that tillage can significantly impact SOC contents even in the short-term (two year study duration).

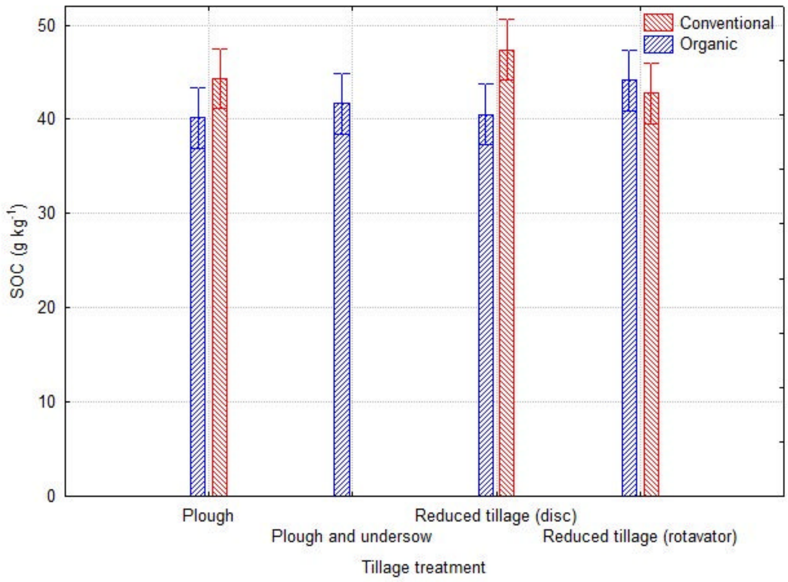


Figure 4.10: Mean values for SOC (g kg^{-1}) in Aberdeen according to management and tillage treatment (the bars show 95 % confidence interval). LSD = 4.44

There was no significant difference ($p > 0.05$) between SOC for top soil depths (0 – 75 and 75 – 150 mm) or any interaction with land management (organic and conventional) or tillage treatment (ploughed or reduced tillage). There was no significant interaction between sample timings during the two years and tillage regime type ($p > 0.05$). However, the same cyclical trend was present as shown in Figure 4.9.

4.3.1.2 East Grinstead (Clay Loam)

Figure 4.11 shows that both the organic and conventional fields are slightly below the typical level shown in Table 4.7. This could suggest that SOC contents were not enhancing soil workability or crop growth; so increased sustained additions of organic matter (FYM) should be introduced to improve the level. As Bhogal *et al.* (2009) suggest that once there is a change in management (tillage regime or land management) SOC changes towards a new equilibrium. Any changes or reductions in the amount of organic matter added to the land can cause another shift; often to a level lower than the build up previously achieved. Therefore, changing land management and amendments need to be carefully monitored but may help to improve SOC on these clay loam soils.

When comparing the overall effect of organic and conventional management irrespective of different tillage regimes there was significantly less ($p < 0.05$) SOC in the conventionally managed soil (11.73 g kg^{-1}) than organically managed soil

(15.29 g kg^{-1}). The land has been farmed organically for the longest period of time; and according to Schjønning *et al.* (2007) the effects of management on SOC should be felt after this time. There was a higher SOC content in the organically managed soil which would support the review of Stolze *et al.* (2000) which reported similar findings in five trials.

Figure 4.11 shows how SOC varies with time during the cropping season for both organic and conventional management. In September 2008, there was a significant difference between organic and conventionally managed soils; with SOC being higher for the conventional management. Post tillage (March 2009) there was an increase in SOC, which reduced slightly during stem extension (June 2009) and post harvest (August 2009). The same trend existed during the second year; with a more pronounced decrease post harvest (August 2010) which was no longer significantly different between organic and conventionally managed land. There was a seasonal effect which although not as pronounced as that shown in Aberdeen, shows a similar cyclical trend, with the highest amounts of SOC during crop establishment (June 2009 / 2010) before decreasing post harvest (August 2009 / 2010). This could be related to compaction issues or due to lack of organic inputs; reducing the amount of SOC. There is an issue which needs to be noted that the crop on the conventional land was a winter cereal and so in June 2009, it would have been at a different stage of crop growth compared to the organic crop.

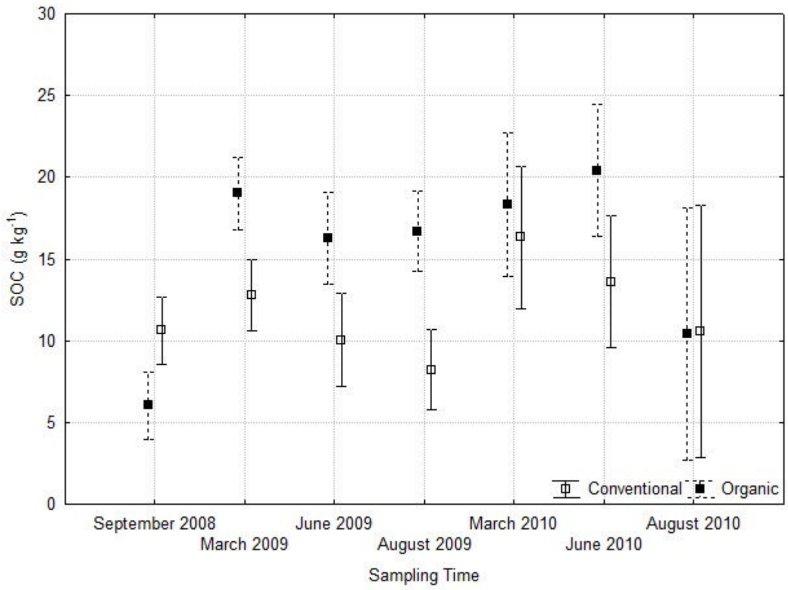


Figure 4.11: Mean value of SOC (g kg^{-1}) in East Grinstead at each sampling point (bars show 95 % confidence interval). The differences are significant with $p < 0.05$. There was no correction of SOC content due to differences in bulk density. LSD = 5.69

The effects of different tillage regimes are shown in Figure 4.12; where the conventional ploughing resulted in significantly less SOC (10.19 g kg^{-1}) than the other treatments. There were no other significant differences between either the conventional minimum tillage or organic plough and organic minimum tillage. Organically managed minimum tillage provided the highest SOC content (15.60 g kg^{-1}) compared to the other treatments; but this was not significantly greater than organically managed ploughed soil. The ploughed conventional treatment had a lower SOC content due to the mechanics of tillage which turns over the topsoil and exposes it to rapid drying, mineralising SOC and reducing the amount present.

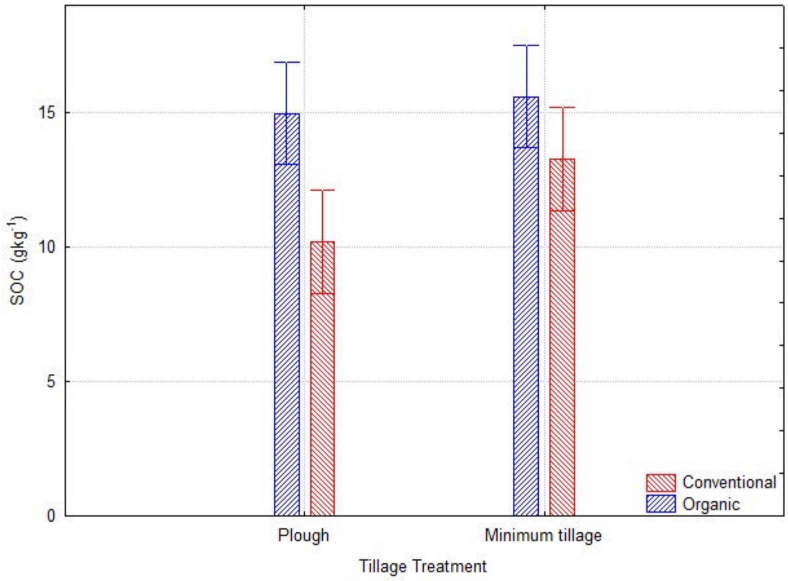


Figure 4.12: Mean values for SOC (g kg^{-1}) at East Grinstead according to management and tillage treatment (the bars show 95 % confidence interval). LSD = 3.04

Soil samples were collected at two different depths (0- 75 mm and 75 – 150 mm); there was a significant difference between soil depths for SOC content with 75- 150 mm having a lower content. This could be related to the depth of tillage allowing SOC to oxidise. There was no significant interaction between sample timings during the two years and tillage regime type ($p > 0.05$). However, the same cyclical trend is present shown in Figure 4.12.

4.3.1.3 Huntingdon (Clay)

Figure 4.13 shows that both the organic and conventional fields are marginally below the typical level shown in Table 4.7. This would suggest that SOC was not being stored within the system. This could be due to a changing management (tillage regime) which created a shift towards a new equilibrium (Bhogal *et al.*, 2009). Therefore, it would be suggested that there were further additions of SOM, to improve levels to the ideal range.

When comparing the overall effect of organic and conventional management irrespective of different tillage regimes; there was no significant difference ($p > 0.05$) between organically managed soil (17.79 g kg^{-1}) and conventionally managed soil (17.48 g kg^{-1}). The land has been managed organically for eight years; and no difference was found between the two management systems which disagree with Schjønning *et al.* (2007). However, this is in agreement with the research in the field scale study (Chapter 3) but also with Gosling and Shepherd (2002) who found little difference in SOC between organic and conventional management.

Figure 4.13 shows the variation in SOC with time for both organic and conventional management. The initial values for SOC were significantly higher ($p < 0.05$) for conventionally managed soil (19.67 g kg^{-1}) compared to organically managed soil (11.47 g kg^{-1}). Post tillage (April 2009) there was a decrease in SOC before an increase during stem extension (June 2009) and post harvest (September 2009). There was a very marginal trend for the level of SOC in the organically managed soil to be higher than the conventionally managed soil. There appears to be a reduction from the initial sample to the post tillage which then increases over the last two sampling points to a significantly higher SOC content than the initial value (Figure 4.13). This is because the farmer had just incorporated spent mushroom compost prior to the final sampling to both the organic and conventional fields. The lack of significant difference between the organically and conventionally managed soils could be explained through the nature of the clay which protects SOC from decomposition (Webb *et al.*, 2003).

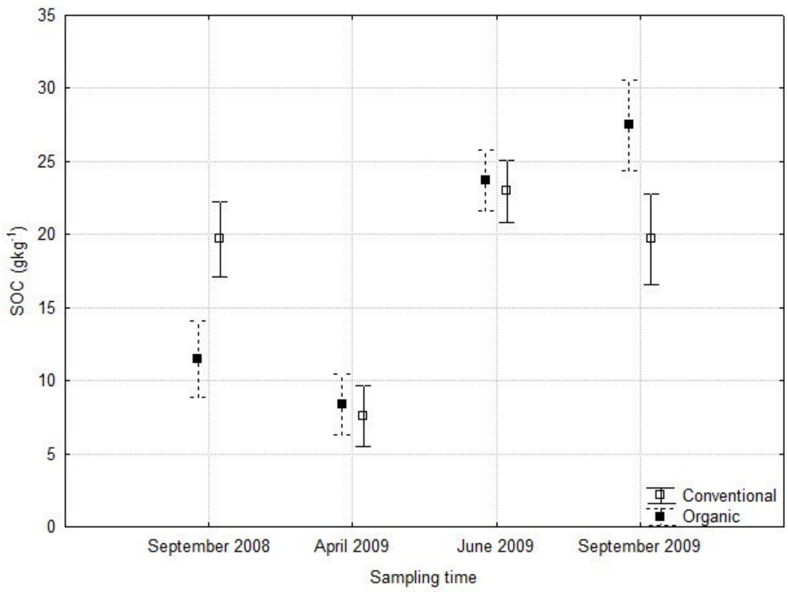


Figure 4.13: Mean value of SOC (g kg^{-1}) in Huntingdon at each sampling point (bars show 95 % confidence interval). LSD = 5.69

The effects of different tillage regimes are shown in Figure 4.14 ($p < 0.05$); the organically managed reduced tillage was significantly higher (20.04 g kg^{-1}) than the organically managed plough (14.91 g kg^{-1}). There were no other significant differences between either the conventional or organic treatments or tillage regimes. Conventionally managed direct drill provided the highest amount of SOC (19.54 g kg^{-1}) compared to the other conventional treatments. This was due to non-inversion of the soil, hence not exposing the topsoil for mineralisation allowing SOC to build up (Jones *et al.*, 2005).

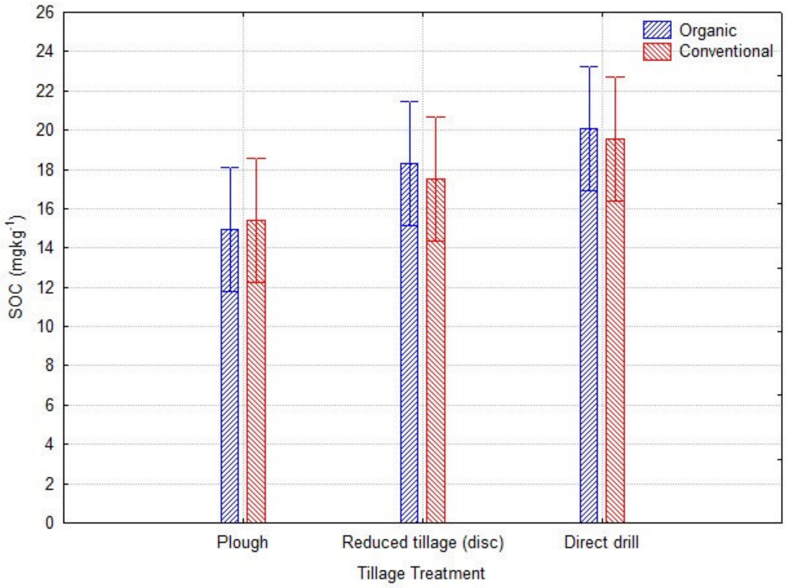


Figure 4.14: Mean values for SOC (g kg^{-1}) in Huntingdon according to management and tillage treatment (the bars show 95 % confidence interval). LSD= 3.03

Soil samples were collected at two different depths (0- 75 mm and 75 – 150 mm); there was no significant difference between soil depths for SOC content with 75- 150 mm having a lower content ($p > 0.05$). There was a significant interaction between sample timings during the two years and tillage regime type ($p < 0.05$); whereby sampling in September 2008 and April 2009 were significantly lower than June and September 2009. The interaction with tillage regime revealed that ploughed treatments both organically and conventionally managed were lower during the first two sampling times compared to reduced tillage treatments.

4.3.1.4 Comparative Summary

Overall, there was no outright trend for either organic or conventional to have a higher amount of SOC. The sandy silt loam had a significantly higher amount of SOC (40.96 g kg^{-1}) compared to clay loam (11.21 g kg^{-1}) and clay (17.47 g kg^{-1}). The sandy silt loam had the highest SOC content as the sample was taken in Aberdeen (Scotland), which contains a much higher proportion of SOC compared with the rest of the UK

(Towers *et al.*, 2006). Although the other soil textures have higher percentage clay which is thought to improve the SOC content; this was not supported in this study. The different SOC contents due to soil texture were also shown in field scale study (Chapter 3), whereby coarse and medium textured soils had a lower level compared to clayey and silty soils.

The three sites were compared using only two treatments (reduced tillage and plough) as these were present at each site; but only for the first year. In Figure 4.15, the ploughed treatment, with the exception of the clay loam, showed that the organically managed land has a similar or slightly lower SOC content compared to conventionally managed land. This trend is reversed for the reduced tillage treatment where the organically managed land had a higher SOC content compared to the conventionally managed land. For all of the soil textures (excluding sandy silt loam conventional minimum tillage); there was a higher SOC content in the minimum tillage treatment. This is due to a reduction in turning over the soil; which reduces losses of SOC through mineralisation (Jones *et al.*, 2005). The heaviest textured clay showed the smallest response to changing tillage regime or management on SOC content in the short–term; this is could be explained by the nature of the clay soil which protects SOC and prevents decomposition (Webb *et al.*, 2003).

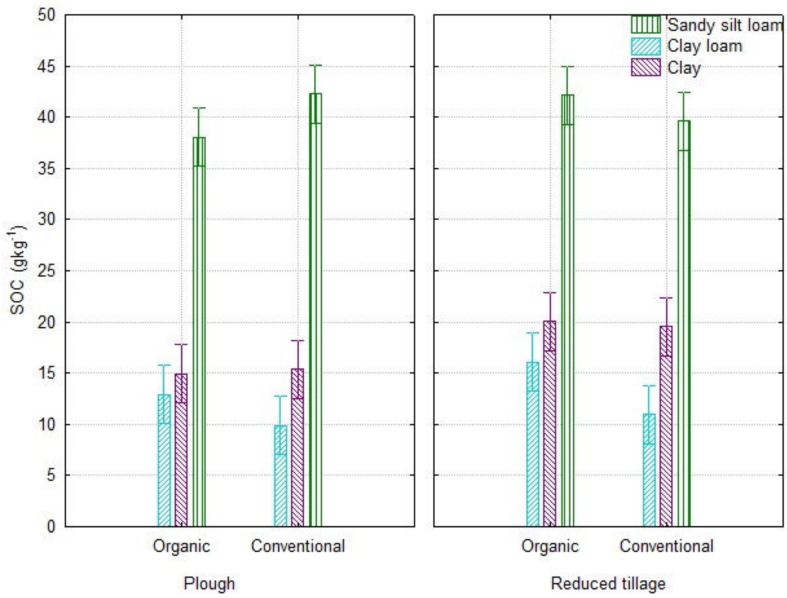


Figure 4.15: Mean values for SOC (g kg^{-1}) for all three soil textures, management (organic / conventional and tillage treatments (reduced tillage / plough). (The bars show 95 % confidence interval). LSD = 7.32

4.3.2 Maximum Water Holding Capacity and Field Capacity

This section looks at both field capacity moisture content and saturation or maximum water holding capacity. These were calculated from soil cores collected in the field at one depth (0- 50 mm). The field capacity was also used in conjunction with plastic limits to determine the workability of soils in Section 4.1 10.

This research has focused only upon saturation (maximum water holding capacity) and field capacity as the difference between these two values gives the transmission water (Figure 2.5 – Chapter 2). According to Godwin and Dresser (2003), if soils are at or slightly below field capacity prior to a rainstorm event; the ability of the soil to store 'transmission water' is greater and hence could help prevent flooding.

4.3.2.1 Aberdeen (Sandy silt loam)

Figure 4.16 shows the average water holding capacity at maximum and field capacity for both organically and conventionally managed soils. It shows that the field capacity (WHC FC 0.05) between tillage treatments was not significantly different ($p > 0.05$). There was no significant difference between organically (49.08 %) and conventionally (50.41 %) managed for field capacity (WHC FC 0.05). This would be anticipated as the field capacity is more dependent upon soil texture than physical properties which can be manipulated through management (Brady, 1990). There was no difference in field capacity with time of samples ($p > 0.05$). Hence, the full data is not shown here. There were significant differences between maximum water holding capacity which will now be discussed (these are expanded in Table 4.8).

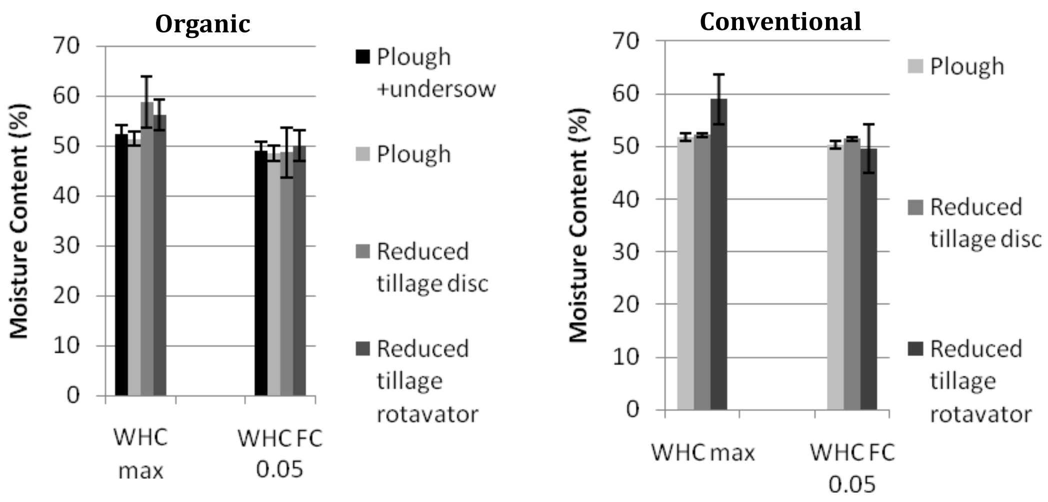


Figure 4.16: Maximum water holding capacity for Aberdeen at 0 bar (WHC max) and at field capacity 0.05 bar (WHC FC 0.05 bar) for the different tillage treatments and land management. Error bars show the standard error. LSD = 2.25

As shown in Table 4.8, there was no significant difference ($p < 0.05$) in maximum water holding capacity between organically managed (58.51 %) and conventionally managed land (57.94 %). There was an effect of tillage treatment, where organic ploughed and organic ploughed and undersown treatments (52.60 %, 52.33 %) had a lower maximum water holding capacity compared to the other treatments ($p > 0.05$). This corresponds with other findings highlighted in Strudley *et al.* (2008) who found that ploughing reduces the water holding capacity of a soil. This would suggest that increasing tillage intensity (ploughing) reduced the maximum water holding capacity; this could be due to changes in soil structure induced by tillage such as compaction. However, the ploughed samples had a lower bulk density (not significantly) so this was not the case. Zeiger and Fohrer (2009) stressed that differences in maximum water holding capacity were mostly due to changes in continuity and connectivity of macropores which would not be disrupted through tillage. There was a significant difference in maximum water holding capacity over time ($p < 0.05$). Although, there was a general increase over time rising post tillage (April 2009 and 2010) and decreasing post harvest (September 2009 and September 2010). These differences in maximum water holding capacity of the soil are important; as the difference between them and field capacity indicates an increase in water storage capacity for 'transmission water'. If the field is at field capacity during a heavy rainstorm, the organically managed soil would be able to hold more water compared to the conventionally managed soil. This would have implications for flood mitigation.

Table 4.8: All tillage treatments, management types and sampling times for maximum water holding capacity (%) in Aberdeen. Different letters show a significant difference (p value > 0.05).

Time	Organic				Conventional			Mean
	Plough	Plough and undersow	Reduced tillage (disc)	Reduced tillage (rotavator)	Plough	Reduced tillage (disc)	Reduced tillage (rotavator)	
Post Tillage	51.37	52.44	58.83	56.29	51.67	52.18	58.99	54.88^{a}
Post Harvest	60.07	51.57	64.49	71.28	56.12	67.14	70.28	64.89^{b}
Post Tillage	45.55	57.95	55.71	61.68	53.11	57.89	61.23	55.86^{a}
Post Harvest	53.45	47.37	59.73	63.78	54.84	52.47	59.35	57.27^{a}
Mean	52.60^{a}	52.33^{a}	59.69^{abc}	63.26^{c}	53.93^{ab}	57.42^{abc}	62.46^{bc}	

4.3.2.2 East Grinstead (Clay loam)

Figure 4.17 shows the average water holding capacity at maximum and field capacity. It shows that the field capacity (WHC FC 0.05) between land management was significantly different ($p < 0.05$) with organic having a higher field capacity compared to conventional land use. This data is not shown but will be developed further in the workability Section 4.3.10. There were differences between maximum water holding capacity (shown in Table 4.9).

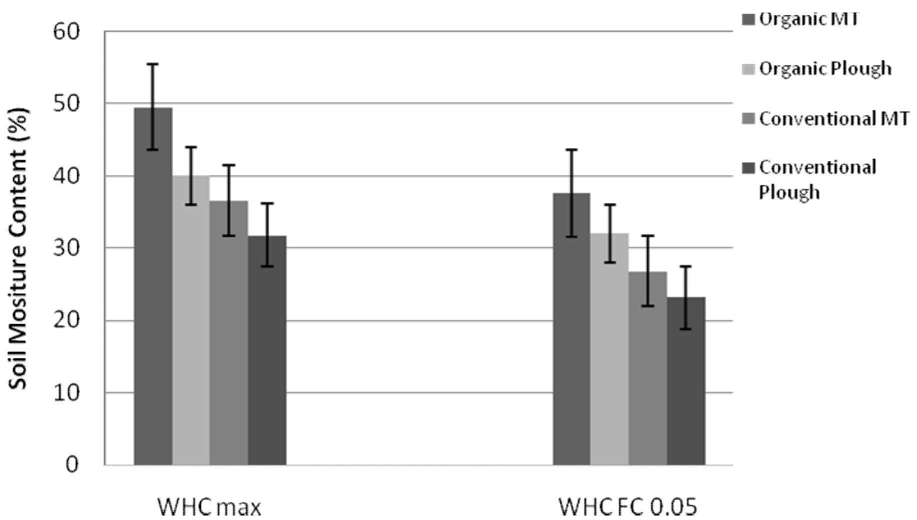


Figure 4.17: Maximum water holding capacity in East Grinstead at 0 bar (WHC max) and at field capacity 0.05 bar (WHC FC 0.05) for the different tillage treatments and land management. LSD = 3.52

As shown in Table 4.9, there was significant difference in maximum water holding capacity between organic (44.77 %) and conventional land (33.7 %) management ($p < 0.05$). There was an effect of tillage treatment, where organic minimum tillage treatment (49.69 %) had higher total water holding capacity compared to the other treatments ($p < 0.05$). This corresponds with other findings highlighted in Strudley *et al.* (2008) who found that ploughing reduces the water holding capacity of a soil. There was no significant difference in maximum water holding capacity over time ($p > 0.05$), although there is a general trend for an increase over time. As in Aberdeen, these differences in maximum water holding capacity of the soil are important; increasing the maximum water holding capacity would have implications for flood mitigation.

Table 4.9: All tillage treatments, management types and sampling times for total water holding capacity (%) in East Grinstead. Different letters show a significant difference (p value > 0.05).

Time	Organic		Conventional		Mean
	Plough	Minimum Tillage	Plough	Minimum Tillage	
Post Tillage	40.00	49.53	31.83	36.46	37.26[a]
Post Harvest	41.83	43.16	31.66	36.76	38.35[a]
Post Tillage	43.02	54.9	35.40	34.21	39.45[a]
Post Harvest	34.55	51.19	30.42	32.86	41.88[a]
Mean	39.85[a]	49.69[b]	32.33[ac]	35.07[c]	

4.3.2.3 Huntingdon (Clay)

Figure 4.18 shows the average water holding capacity at maximum and field capacity. It shows that the field capacity (WHC FC 0.05) between land management were not significantly different ($p > 0.05$). Therefore, this data is not shown. There were differences between maximum water holding capacity (shown in Table 4.10).

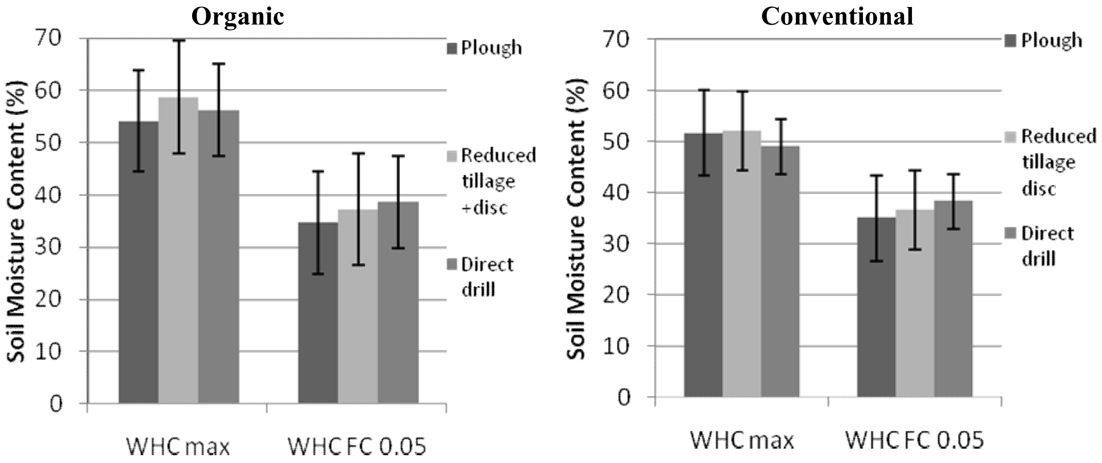


Figure 4.18: Total water holding capacity in Huntingdon at 0 bar (WHC max) and at field capacity 0.05 bar (WHC FC 0.05) for the different tillage treatments and land management. LSD = 2.54

As shown in Table 4.10, there was no significant difference in maximum water holding capacity between organic (56.61 %) and conventional land (53.39%) management ($p > 0.05$). There was an effect of tillage treatment, shown only on the conventionally managed land; where reduced tillage (disc) (55.02 %) was greater than the other two treatments. This corresponds with other findings highlighted in Strudley *et al.* (2008) who found that ploughing reduces the water holding capacity of a soil. There was no significant difference in maximum water holding capacity over time ($p > 0.05$), although there was a general trend for an increase over time. This corresponds with the findings in both Aberdeen and East Grinstead; highlighting the importance differences in maximum water holding capacity of the soil and the implications for flood mitigation.

Table 4.10: All tillage treatments, management types and sampling times for maximum water holding capacity (%) in Huntingdon. Different letters show a significant difference (p value > 0.05).

Time	Organic			Conventional			Mean
	Plough	Reduced tillage (disc)	Direct drill	Plough	Minimum tillage (disc)	Direct drill	
Post Tillage	54.20	58.83	56.29	51.67	52.18	48.99	53.69[a]
Post Harvest	56.31	55.10	58.93	55.59	57.86	54.10	56.31[a]
Mean	55.26[a]	56.96[a]	57.61[a]	53.63[b]	55.02[a]	51.45[b]	

4.3.2.4 Comparative Summary

For field capacity moisture content, there was no significant difference due to organic or conventional management of land or due to different tillage regimes in the clay or sandy silt loam. There were differences on the maximum water holding capacity of the soils between organic and conventional management systems. The organically managed soils (58.52 %, 44.77 % and 56.61 %) have a higher maximum water holding capacity compared to conventionally managed soils (57.94 %, 33.70 % and 53.39 %) for sandy silt loam, clay loam and clay respectively. There was also an interaction with tillage regimes, where reduced tillage regimes have a higher maximum water holding capacity compared to the ploughed treatment. This could be due to better soil structure, although it was not thought that this would be the case in this two year trial. The organically managed fields have an increased amount of grassland and fertility building leys in their rotation, which may help build a more continuous network of pores. Therefore, if maximum water holding capacity is compared with field capacity there is an implied increase in water storage on organically managed land, which has implications for flood alleviation.

4.3.3 Aggregate Stability

Soil aggregate stability is an important measure of soil quality and sustainability (Bronick and Lal, 2005). The values for aggregate stability shown are the amount of soil retained as a percentage of the original amount of soil before the test was performed; for example, the larger the percentage the higher the stability of the soil. In the field scale study (Chapter 3) the results showed no significant difference between organic and conventional management. This agrees with Williams and Petticrew (2009) who compared macro and micro aggregate stability between organic and conventional farms. This did not consider the effects of different tillage systems; however it is widely acknowledged that increasing tillage intensity reduces the macro-aggregate stability (Shepherd *et al.*, 2003).

The field scale study (Chapter 3) also showed that there were differences, which could be attributed to soil textural group. The coarse textured soils were the least stable (43.05 %) compared to the clayey (59.35 %) silty (49.65 %) and medium (49.08 %). This is due to having both lower SOC and clay contents, which would have helped to bind the soil together. In this section, the three sites different tillage schemes are explored and their results for aggregate stability are presented by site and then comparatively by soil texture.

4.3.3.1 Aberdeen (Sandy silt loam)

Figure 4.19 shows that at the initial sample (February 2009), there was a large significant difference between organically and conventionally managed samples. This difference remains over time however the difference between the two managements tends to coalesce with time. There was a reduction in stability after the initial samples but it steadily increases over time until stem extension (June 2010) where there is a slight reduction in the final post harvest (September 2010) measurement. However, this significant difference could be a residual effect as the difference is present in the initial samples (prior to commencing the trial). Although, when this sample was removed and the analysis re-run, the significant difference between the two land management (organic and conventional) remained. Overall the organically managed land had a significantly ($p < 0.05$) higher aggregate stability (46.00 %) compared to conventional management (42.62 %). This result contrasts with the field scale study (Chapter 3) because of greater soil and site variability, but agrees with Shepherd *et al.* (2003) and Maidl *et al.* (1988), who both found that managing the land organically increases aggregate stability. As the soil textures of both the organically and conventionally managed soils were identical, differences in aggregate stability could have contributed to an increase in SOC. However, aggregate stability can show a difference between land management systems before any change in SOC can be detected (Haynes and Swift, 1991).

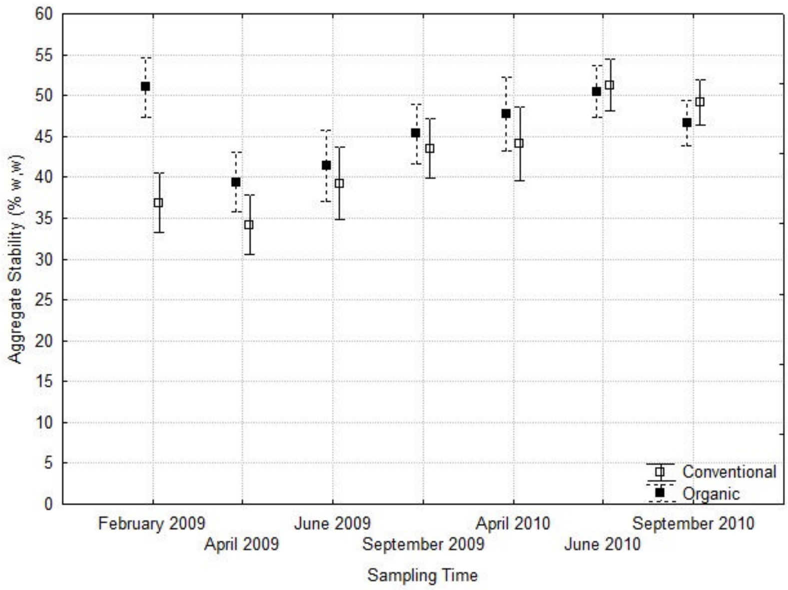


Figure 4.19: Mean value of aggregate stability in Aberdeen (% w, w) at each sampling point (bars show 95 % confidence interval). LSD = 4.80

The effects of different tillage regimes ($p < 0.05$) are shown in Figure 4.20; organic reduced tillage was significantly higher (48.01 %) than the conventional plough (39.33 %). The organic plough had the second lowest aggregate stability but the other organic treatments were both higher than their conventional partner (Figure 4.20). The additional treatment on the organic land (plough and undersow) was not significantly different from the other organic ploughed treatment (42.60 %). It is thought that changes in aggregate stability caused by tillage are associated with the dynamics of SOC (altering the amount of each fraction present) particularly at the soil surface (Douglas and Goss, 1982). As shown in the previous section, SOC did increase over the two years in the two forms of reduced tillage (reduced tillage (disc), reduced tillage (rotavator)). Therefore, this could be attributed to the improvement in aggregate stability felt for the reduced tillage under organic management.

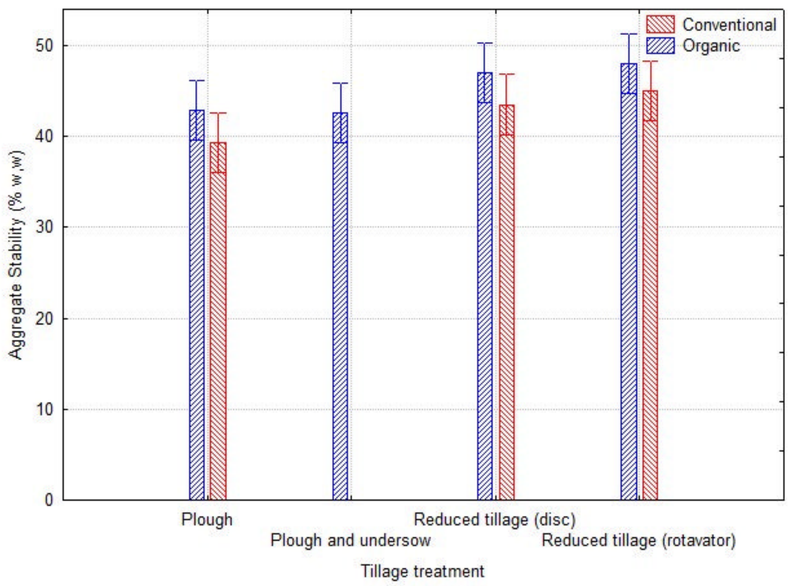


Figure 4.20: Mean values for aggregate stability (%) in Aberdeen according to management and tillage treatment (bars show 95 % confidence interval). LSD = 4.84

Soil samples were collected at two different depths (0- 75 mm and 75 – 150 mm); there was no significant difference between soil depths for aggregate stability with 75- 150 mm having a lower stability ($p > 0.05$). There was no significant interaction between sample timings during the two years and tillage regime type ($p > 0.05$).

4.3.3.2 East Grinstead (Clay loam)

Overall, there was no significant difference ($p > 0.05$) in aggregate stability between organically managed land (52.13 %) and conventional management (50.89 %). This agrees with research by Diez *et al.* (1991). Figure 4.21 shows that the initial measurements (February 2009) for aggregate stability in both organically and conventionally managed soils are similar; with the conventionally managed soil being marginally higher. There was no significant difference over time for aggregate stability; equally there was no clear trend as shown in Aberdeen. As the SOC was significantly higher for organically managed soil, it was anticipated there would be a significant difference in aggregate stability especially as the clay content is very similar between the two land management systems as SOC helps to bind aggregates. However, this was not the case in this research. Williams and Petticrew (2009) found that any differences between organically and conventionally managed lands were primarily due to additions of SOC rather than synthetic fertilisers, which helped to provide a better soil structure.

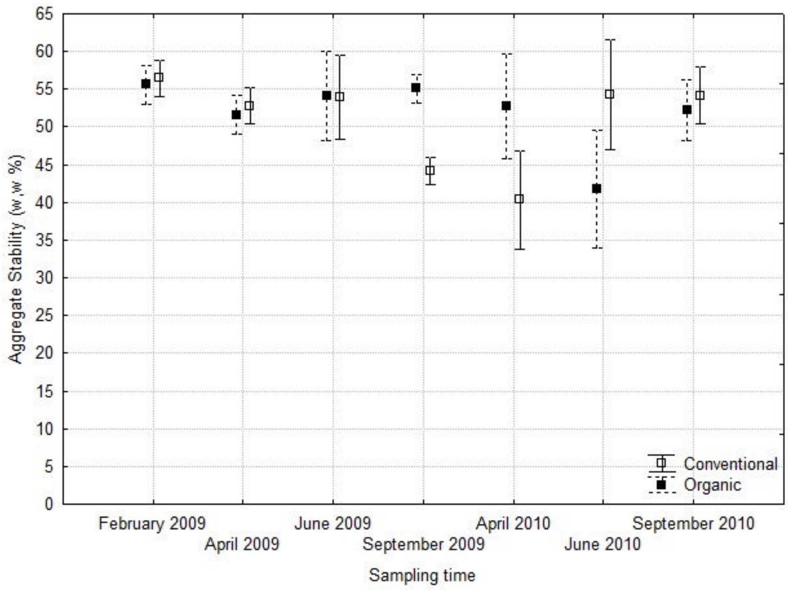


Figure 4.21: Mean value of aggregate stability (%) in East Grinstead at each sampling point (bars show 95 % confidence interval). LSD = 6.72

The effects of different tillage regimes ($p > 0.05$) are shown in Figure 4.22. Whilst there was a trend for the plough (50.58 %) to have a slightly lower aggregate stability than minimum tillage (52.30 %) it was not significant. However, the organic ploughed soil (49.59 %) had a significantly lower aggregate stability than all the other treatments. This is because clay soils under more intense cultivation (ploughing) lose their aggregate stability quicker than the reduction in SOC (Troeh and Thompson, 1993).

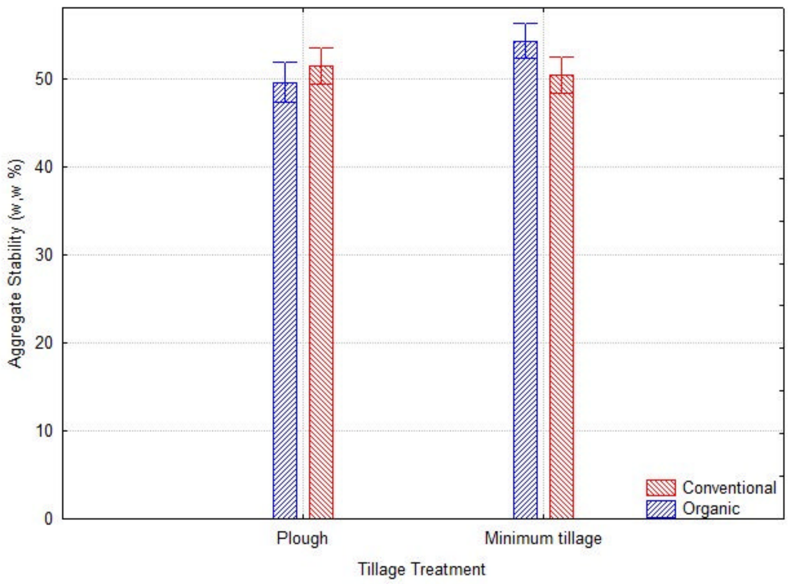


Figure 4.22: Mean values for aggregate stability (%) in East Grinstead according to management and tillage treatment (bars show 95 % confidence interval). LSD = 2.68

Soil samples were collected at two different depths (0- 75 mm and 75 – 150 mm); there was no significant difference between soil depths for aggregate stability content with 75- 150 ($p > 0.05$). There was a significant interaction between sample timings, management (organic or conventional) and tillage regime type ($p < 0.05$). This showed that conventional ploughed soils during the first year of sampling (February to September 2009) had a lower aggregate stability compared to the other samples.

4.3.3.3 Huntingdon (Clay)

Figure 4.23 shows that there was a significant reduction ($p < 0.05$) in aggregate stability for organically managed land (47.95 %) compared to conventionally managed land (68.72 %) over time (one year sampling). There was no significant difference in aggregate stability over time for organically managed land. However, for conventionally managed land there was a significant increase in stability from 57.75 % (September 2008) to 75.81 % (post harvest, September 2009). Both the organic and conventionally managed land have similar SOC and clay contents; so it would be though that there would be no difference between organically and conventionally managed soils. This however was not the case; and this soil texture rejects the findings of Williams and Petticrew (2009) whereby soils which had synthetic fertilisers applied would have a lower aggregate stability. Therefore, the differences could be due to changing bulk density between organically and conventionally managed soils. However there was no significant difference in bulk density but there was a trend for the conventionally managed soil to have a higher value.

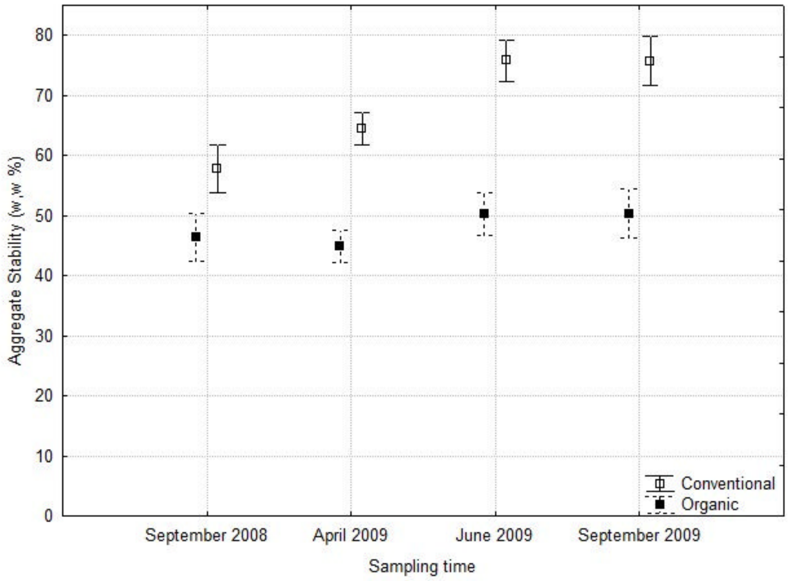


Figure 4.23: Mean value of aggregate stability (%) in Huntingdon at each sampling point (bars show 95 % confidence interval). LSD = 5.94

The effects of different tillage regimes ($p < 0.05$) are shown in Figure 4.24. For the conventionally managed land, the reduced tillage treatment (disc) (71.85 %) produced significantly higher aggregate stability than the ploughed treatment (64.96 %). The organically managed tillage treatments are not significantly different, but there is a trend for the organic reduced tillage to have the highest stability (48.76 %). This is the same trend that was found at both the Aberdeen and East Grinstead sites and agrees with work by Pagliai *et al.* (2004) which was found that reduced tillage (minimum tillage) had a significantly greater aggregate stability than conventional deep ploughing.

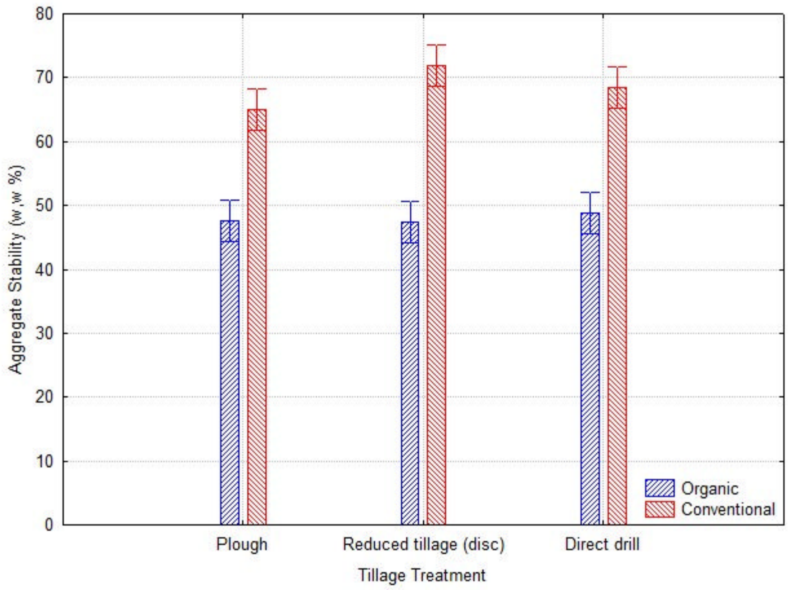


Figure 4.24: Mean values for aggregate stability (%) in Huntingdon according to management and tillage treatment (bars show 95 % confidence interval). LSD = 5.13

Soil samples were collected at two different depths (0 – 75 mm and 75 – 150 mm); there was no significant difference between soil depths for aggregate stability content with 75 – 150 ($p > 0.05$). There was a significant interaction between sample timings, management (organic or conventional) and tillage regime type ($p < 0.05$). This shows that conventionally managed soils (both ploughed and reduced tillage) had a significantly higher aggregate stability which increased with time.

4.3.3.4 Comparative Summary

Overall, there was no outright trend for either organically or conventionally managed soils to be more stable. The sandy silt loam had a significantly lower aggregate stability (40.94 %) compared to both clay loam (53.25 %) and clay (57.45 %). These values are comparable to the field scale study (Chapter 3) where the clayey soils had an average aggregate stability of 59.35 %. The three sites were compared using only two treatments (reduced tillage (disc) and plough) as these were present at each site; and only the first year of data because only one year of data was available from Huntingdon.

In Figure 4.25, it is possible to see that there was no significant difference between tillage treatments for organically and conventionally managed land. This does not support research by Kasper *et al.* (2009) who found that soil aggregation is influenced by tillage systems. Although aggregate stability is primarily governed by the content of clay and SOC; it was shown here that the sandy silt loam (where the SOC content was high) with reduced tillage improves the level of aggregate stability. This helps to show the impact of different tillage systems which affect the level of SOC; with differences being felt in the measured topsoil as this is where root action and residue mulches can influence soil stability (Abid and Lal, 2008a).

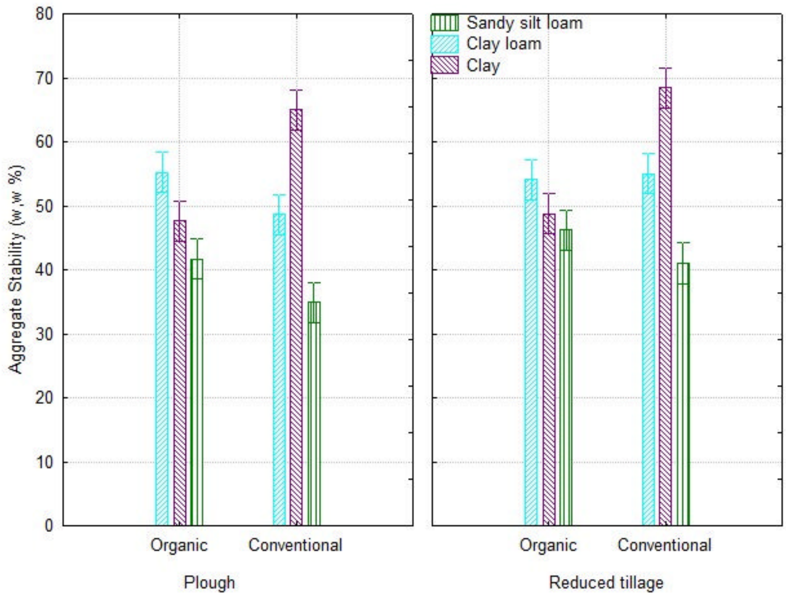


Figure 4.25: Mean values for aggregate stability (%) for all three soil textures, management (organic / conventional) and tillage treatment (reduced tillage / plough) (bars show 95 % confidence interval). LSD = 9.86

4.3.4 Plastic Limit

The plastic limit forms part of the two Atterberg measurements (plastic and liquid limits) shown in the field scale study (Chapter 3). These indicate the plastic range of consistency of the soil. Due to the time consuming nature of this method; it was deemed that only the lower plastic limits would be measured as together with the field capacity this helps to describe the workability of the soil. According to Baver *et al.* (1972), changing soil management and increasing SOC would cause a shift in the plasticity index (through increasing the plastic limit). This was calculated to help provide an indication of the mechanical behaviour of the soil and its changes over the cropping season due to different management (organic and conventional) or tillage regimes. As there has been no other research in this area; the data will be compared against typical values for plastic limits measured by Archer (1975).

Table 4.11: Plastic limits for the soil textures measured (adapted from Archer, 1975).

Soil Texture	Clay Content (%)	Plastic Limit (g kg^{-1})
Sandy Silt Loam	10	160
Clay Loam	20	250
Clay	59	360

Further work linking these measurements to field capacity moisture content indicating the workability of the soils is shown in Section 4.3.10.

4.3.4.1 Aberdeen (Sandy silt loam)

Studying the plastic limits given in Table 4.12 and comparing them to the values in Table 4.11 for sandy silt loam; shows that they were very high and also above the values obtained in the field scale study (Chapter 3). This can be attributed to the high SOC content which would increase the amount of water needed for the soil to act in a plastic manner. Campbell (1991) explains that there must be total hydration of SOC in the soil before any water is available for film formation on soil particles (causing plasticity). Table 4.12 shows that when comparing organic and conventional soils irrespective of different tillage regimes, there was no significant difference ($p > 0.05$) between organic soil (236.32 g kg^{-1}) and conventionally managed soil (255.65 g kg^{-1}). There was a significant difference between the tillage systems ($p < 0.05$) with the conventional plough having a higher plastic limit (305.11 g kg^{-1}) compared to the other systems. The organically managed reduced tillage rotavator (225.20 g kg^{-1}) had the lowest plastic limit. The plough and undersown treatment was not significantly different from any of the other organic treatments. There was a significant difference due to the time of sampling, with post harvest being lower than post tillage (Table 4.12). This could be attributed to changes in soil structure and mineralisation of SOC which was cyclical as shown in Figure 4.6. There were no interactions between tillage treatment, management (organic or conventional) and time for plastic limit ($p > 0.05$). There was no significant difference between plastic limit for the two soil depths measured ($p > 0.05$).

Table 4.12: All tillage treatments, management types and sampling times for plastic limit (g kg^{-1}) in Aberdeen. Different letters show a significant difference ($p < 0.05$).

Time	Organic				Conventional			Mean
	Plough	Plough and undersow	Reduced tillage (disc)	Reduced tillage (rotavator)	Plough	Reduced tillage (disc)	Reduced tillage (rotavator)	
Post Tillage	265.73	213.22	284.83	235.52	402.82	227.69	238.43	275.83^{a}
Post Harvest	231.00	243.93	258.06	230.44	220.29	230.72	236.16	234.45^{b}
Post Tillage	229.62	243.27	221.77	223.70	372.28	228.95	236.72	252.17^{ab}
Post Harvest	212.53	219.27	231.52	211.15	225.03	219.59	229.17	221.50^{b}
Mean	234.72^{a}	229.92^{b}	249.05^{a}	225.20^{b}	305.11^{c}	226.74^{b}	235.12^{a}	

4.3.4.2 East Grinstead (Clay loam)

When comparing the values of plastic limit in Table 4.13 with those shown in Table 4.11 for a clay loam; the values are above average. This could be attributed to the SOC content or the nature and mineralogy of the clay being slightly different from those measured by Archer (1975). Table 4.13 shows when comparing organic and conventional soils irrespective of different tillage regimes, the organic soil (376.3 g kg^{-1}) was significantly less than the conventionally managed soil (396.3 g kg^{-1}). There was a significant difference between the two tillage systems; with minimum tillage being higher on both organic land and conventional land. This correlates with higher amounts of SOC found in the minimum tillage treatments. There was a significant difference due to the time of sampling – the plastic limit increased slightly with time (although it reduces in the final post harvest reading).

There were no interactions between tillage treatment, management (organic or conventional) and time for plastic limit ($p > 0.05$). There was no significant difference between plastic limit for the two soil depths measured ($p > 0.05$).

Table 4.13: All tillage treatments, management types and sampling times for plastic limit (gkg^{-1}) in East Grinstead. Different letters show a significant difference (p value < 0.05).

Time	Organic		Conventional		Mean
	Plough	Minimum Tillage	Plough	Minimum Tillage	
Post Tillage	361	332.8	392.8	425.6	378.1^{a}
Post Harvest	298.5	401	352.3	395.6	361.85^{a}
Post Tillage	361.8	424.5	454.6	412.3	413.3^{b}
Post Harvest	391.8	439.3	350.8	386	391.9^{a}
Mean	353.3^{a}	400.0^{b}	387.6^{a}	404.9^{b}	

4.3.4.3 Huntingdon (Clay)

Table 4.11 shows average values for plastic limit; comparing these to the values in Table 4.14 they are slightly above average but this is explained by the higher levels of SOC present in these clay soil compared to the ones measured by Archer (1975). Table 4.14 shows that when comparing organic and conventional soils irrespective of different tillage regimes, there were no significant differences ($p > 0.05$). There was a significant difference between the tillage treatments for both organic and conventional management for the minimum tillage to have the highest plastic limit. It was also significant that plastic limit decreases over time between the post tillage and post harvest.

There was an interaction between tillage treatment, management (organic or conventional) and time for plastic limit ($p > 0.05$). There was no significant difference between plastic limit for the two soil depths measured ($p < 0.05$).

Table 4.14: All tillage treatments, management types and sampling times for plastic limit (g kg^{-1}) in Huntingdon. Different letters show a significant difference (p value < 0.05).

Time	Organic			Conventional			Mean
	Plough	Minimum tillage (disc)	Direct drill	Plough	Minimum tillage (disc)	Direct drill	
Post Tillage	392.6	387.1	476.1	452.1	349.1	347.6	400.8^{a}
Post Harvest	451.5	371.0	372.0	273.0	303.8	488.3	376.6^{b}
Mean	390.5^{a}	379.1^{a}	424.1^{b}	362.5^{a}	326.5^{a}	418.0^{b}	

4.3.4.4 Comparative Summary

Figure 4.26 shows that overall there was no outright trend for either organic or conventional soil to have a higher plastic limit. The three sites were compared using only two treatments (reduced tillage and plough) as these were present at each site; and only the first year of data because only one year of data was available from Huntingdon. Sandy silt loam had a significantly lower plastic limit (257.65 g kg^{-1}) compared to both clay loam (399.85 g kg^{-1}) and clay (401.54 g kg^{-1}). This is as would be expected according to Archer (1975). There were no significant differences between organic and conventional management; as some are higher or lower depending upon the tillage regime and soil texture. For example, the ploughed treatment shows that organic management had a lower plastic limit for both sandy silt loam and clay loam but is higher for clay. This highlights the importance of soil texture (predominately the clay content) in affecting the plastic limit.

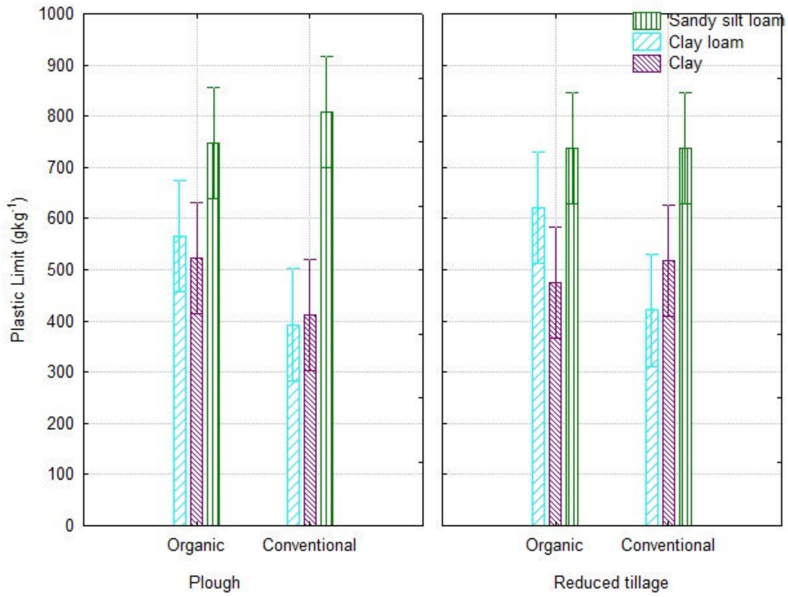


Figure 4.26: Mean values for plastic limit (g kg^{-1}) for all three soil textures, management (organic / conventional) and tillage treatment (reduced tillage / plough). LSD = 175.27

4.3.5 Shear Strength

High shear strength can limit root growth (Barley *et al*., 1965) which would reduce crop yields. Soils are tilled to provide a suitable seedbed, reduce competition from other plants and change soil structure to enable roots to penetrate. The shear strength indicates the quality of seedbed, structure and is related to macroporosity (Carter, 1990). Therefore, low shear strength is helpful during seedbed formation as it allows shoots to penetrate; whereas higher shear strength helps provide vehicle access without causing structural damage. The effects of different tillage regimes are best shown in the top 0 - 100 mm (Benjamin and Cruse, 1987); hence measurements shown here are for the topsoil only.

4.3.5.1 Aberdeen (Sandy silt loam)

A torsional shear box was used for the first sampling time (post tillage 2009). However, due to the lack of availability of this equipment, the soil strength for the three remaining sampling times was determined using a shear vane. Therefore, the first sampling time will be presented separately and analysed for both cohesion and angle of internal shearing resistance (friction). For the remaining three sampling dates shear strength data only is presented. These two different measurements were not combined and should be interpreted independently from each other.

Table 4.15 shows there was no significant difference ($p > 0.05$) in cohesion or angle of internal friction between organic (25.09^o / 17.80 kPa) and conventionally managed land (29.73^o / 16.07 kPa). However, there was a significant difference ($p < 0.05$) between tillage treatments for both cohesion and angle of internal friction. Where the organically managed reduced tillage had a lower cohesion (16.14 kPa) compared to organic plough (19.58 kPa) and conventional plough (32.3^o) and minimum tillage and disc (33.15^o) have a larger angle of internal friction compared to the other treatments.

Table 4.15: Torsional shear values for internal friction (^{o}) and cohesion (kPa) for post tillage (April 2009) in Aberdeen.

	Organic				Conventional		
	Plough	Plough and Undersow	Reduced tillage (disc)	Reduced tillage (rotavator)	Plough	Reduced tillage (disc)	Reduced tillage (rotavator)
Internal Friction (^{o})	26.35^a	27.68^{ab}	23.74^a	22.59^a	32.3^b	33.15^b	23.74^a
Cohesion (kPa)	19.58^a	22.38^b	16.14^{ac}	13.13^c	18.08^{ac}	14.85^{ac}	15.28^{ac}

Figure 4.27 shows that there was a significant difference ($p < 0.05$) in shear strength (τ) with organically managed land (64.44 kPa) having a greater shear strength than conventionally managed soils (55.24 kPa). There was a slight trend for a decrease in shear strength over the cropping season; this could be related to a decrease in bulk density or due to *in field* higher moisture contents during sampling post harvest (September 2010).

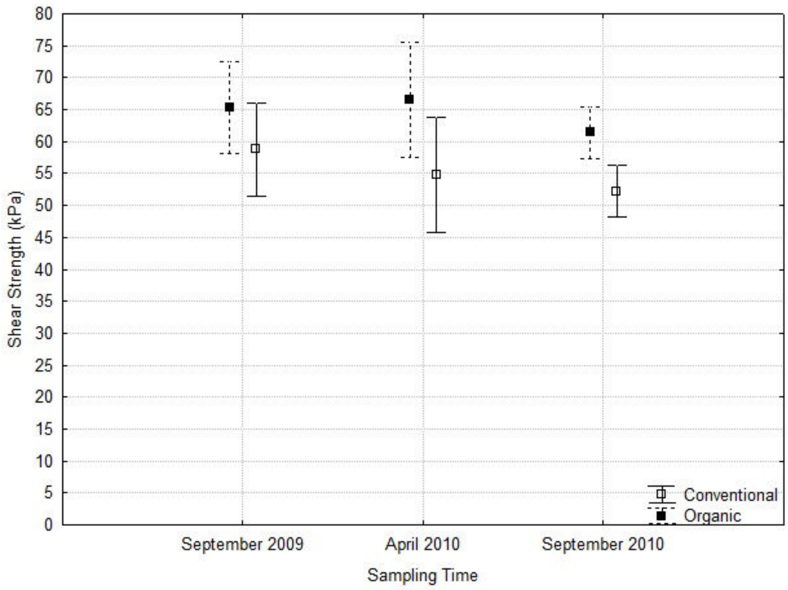


Figure 4.27: Mean value of shear strength (kPa) at each sampling point (bars show 95 % confidence interval) in Aberdeen. LSD= 9.88

The effects of different tillage regimes ($p < 0.05$) are shown in Figure 4.28. The ploughed (38.9 kPa) treatments in both organic and conventionally managed land were significantly lower than the other treatments. The additional treatment on the organically managed land of plough and undersown (42.5 kPa) was also significantly lower than the other organic treatments but was not different to ploughing. This corresponds with work by Ball *et al.* (1997) who showed that shear strength was four times greater under non- ploughed land compared to ploughed land. These differences can be attributed to soil structural compaction, soil moisture content, SOC and clay content (Smith and Mullins, 1991). The measurements were taken on the same day and post tillage measurements were when the soil was at field capacity moisture content; so variation in soil moisture content was minimised. Correlation matrices were calculated between shear strength and soil moisture content for each of the sampling times and there was no significant correlation (see Appendix C). However, there was an exception in the post tillage treatment (April 2010) where there was a positive correlation (0.60) as shear strength increased moisture content decreased (Ball *et al.*, 1997). There was no significant difference between moisture content and tillage treatments so this was not thought to be causing the effect. There was no difference in the clay content (10%) of the soil between the tillage treatments. Therefore, differences can be attributed to increasing bulk density (or compaction) and increasing SOC content (as shown Section 4.3.1.1 SOC increases under reduced tillage regimes).

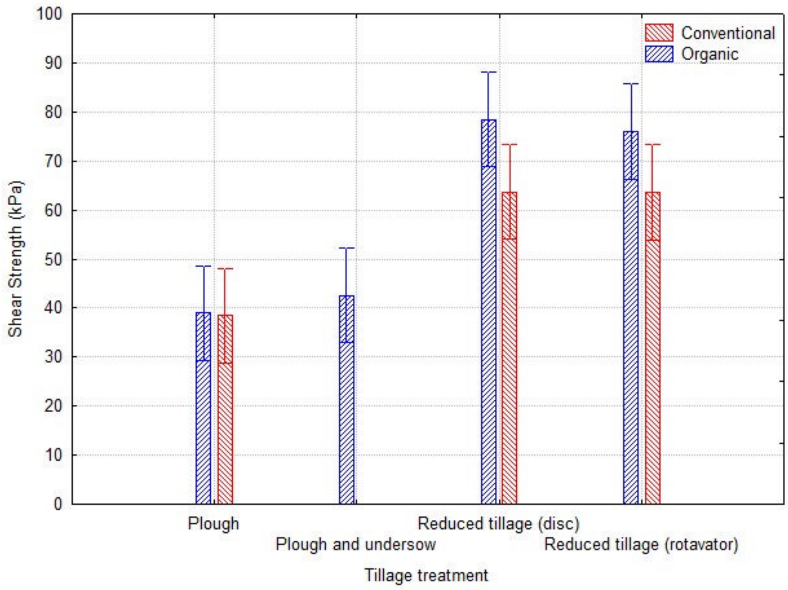


Figure 4.28: Mean values for shear strength (kPa) in Aberdeen according to management and tillage treatment. Bars show 95 % confidence intervals. LSD = 14.94

4.3.5.2 East Grinstead (Clay loam)

Figure 4.29 shows that there was no significant difference ($p > 0.05$) in shear strength (τ) between organically managed land (86.17 kPa) and conventionally managed land (83.06 kPa). Post tillage (September 2009 and 2010) is significantly lower than post harvest (for both years) as Figure 4.29. This would be expected as soil tillage would reduce bulk density and compaction, whereas soil is compacted during harvest which increases soil shear strength (Hamza and Anderson, 2005). There was an overall increase in shear strength over two cropping seasons as expected.

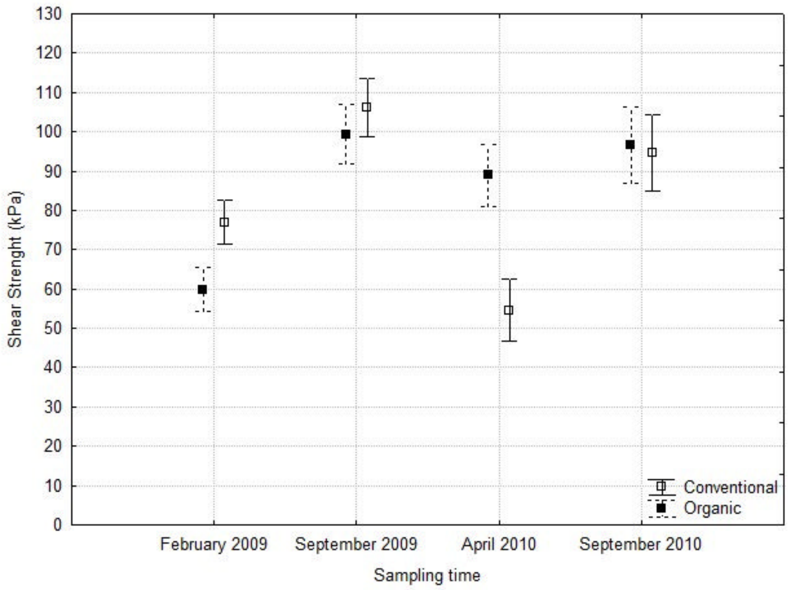


Figure 4.29: Mean value of shear strength (kPa) in East Grinstead at each sampling point (bars show 95 % confidence interval). LSD = 10.29

The differences between tillage regimes ($p < 0.05$) are shown in Figure 4.30. All the treatments were significantly different from each other with organic minimum tillage having the highest shear strength (100.9 kPa) and the lowest was organic plough (71.44 kPa). Correlation matrices were calculated between shear strength and soil moisture content for each of the sampling times and there was no significant correlation (see Appendix C). Hence, the differences between tillage treatments are more likely to be related to SOC content. There was a significant interaction ($p < 0.05$) between management (organic or conventional), tillage treatment and time; whereby organic minimum tillage at the final post harvest sampling has the highest shear strength.

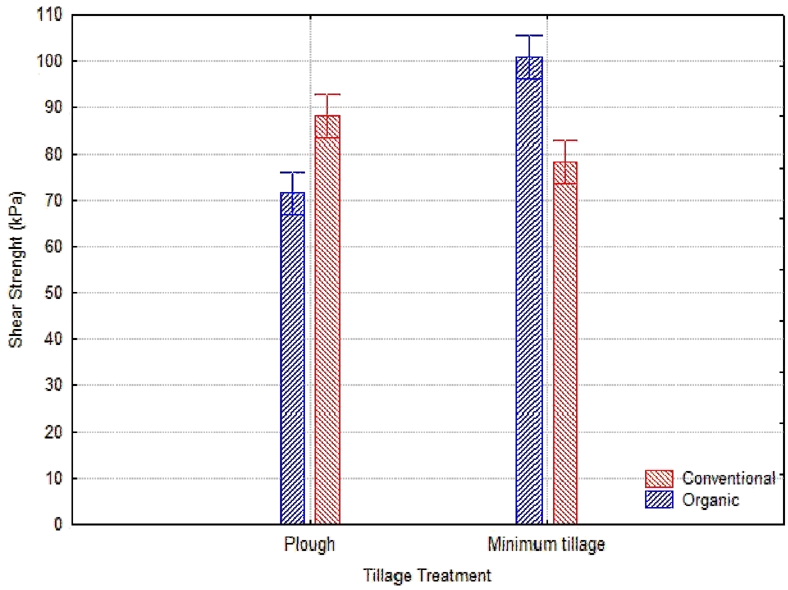


Figure 4.30: Mean values for shear strength (kPa) in East Grinstead according to management and tillage treatment. Bars show 95 % confidence intervals. LSD= 6.15

4.3.5.3 Huntingdon (Clay)

Figure 4.31 shows that organically managed land (83.71 kPa) had a significantly higher ($p < 0.05$) shear strength compared to conventional management (64.61 kPa). This difference was not identified between arable fields in the field scale study (Chapter 3); this was thought to be due to sampling occurring at different stages within the tillage regime. Most notably, some fields were sampled after tillage (which would reduce shear strength) and other fields were sampled where direct drilling was used. This plot scale study allowed differences in shear strength as an indicator of soil structure to be identified. The main difference between organically and conventionally managed land was during the first sampling time (April 2009), the conventionally managed shear strength increases considerably post harvest (September) to a similar level to the organically managed soil. Post tillage (April 2009) had a significantly ($p < 0.05$) lower shear strength than post harvest (September 2009) as expected. This was more apparent in the conventionally managed soil.

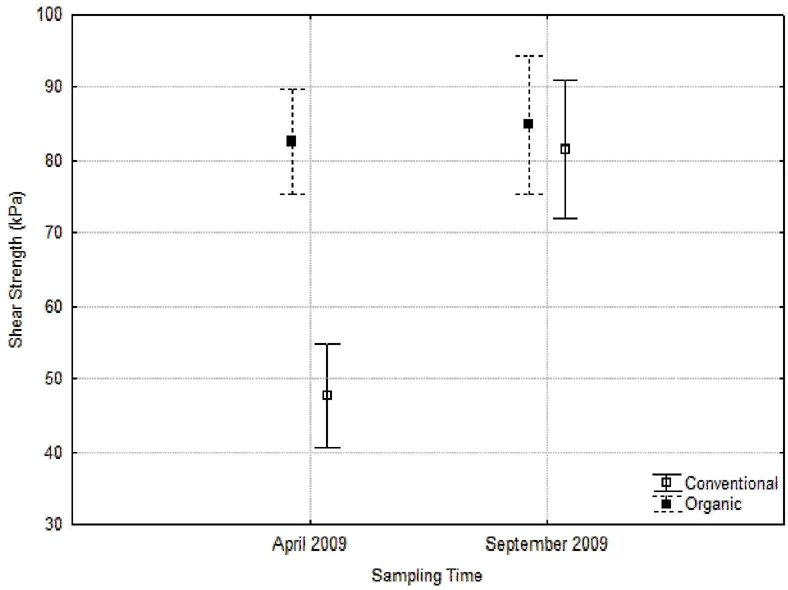


Figure 4.31: Mean value of shear strength (kPa) in Huntingdon at each sampling point (bars show 95 % confidence interval). LSD = 11.87

The differences between tillage regimes ($p < 0.05$) are shown in Figure 4.32. All the treatments were significantly different from each other with organic reduced tillage having the highest shear strength (100.9 kPa) and the lowest was organic plough (71.44 kPa). Correlation matrices were calculated between shear strength and soil moisture content for each of the sampling times and there was no significant correlation. Therefore, the difference can be explained through differences in SOC; the organic minimum tillage had a significantly higher SOC content (20.04 g kg^{-1}) compared to the other conventional tillage treatments. Increasing levels of SOC help to improve soil structure and increases in soil bulk density also help to improve soil shear strength (Ball *et al.*, 1997). This is a positive due to increasing vehicle access during changing climatic conditions without causing damage to soil structure. There was no significant interaction ($p > 0.05$) between management (organic or conventional), tillage treatment and time.

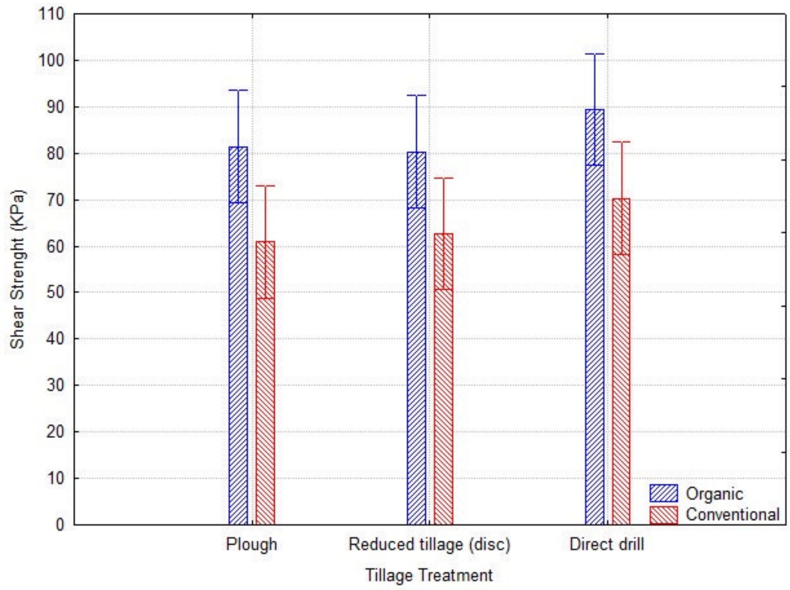


Figure 4.32: Mean values for shear strength (kPa) in Huntingdon according to management and tillage treatment. Bars show 95 % confidence interval. LSD= 17.05

4.3.5.4 Comparative Summary

The three sites were compared using only two tillage treatments (reduced tillage and plough) and one sampling point (post harvest - September 2009) as this data was available for all three sites. Overall, there was no outright trend for either organic or conventional soil to have higher shear strength. In Figure 4.33, it is possible to see that there was a significant difference ($p < 0.05$) in shear strength between the soil textures. Whereby, clay loam had the highest (103.66 kPa), clay (88.22 kPa) and the lowest was sandy silt loam (55.45 kPa). These values correspond with the data presented in the field scale study (Chapter 3) where the clayey soils had a significantly higher shear strength (71.60 kPa) compared to the other soil textures. The main difference in tillage regime was shown for the sandy silt loam where the ploughed treatment reduces the shear strength by almost 50 % compared to the reduced tillage. This finding is similar to work by Ball *et al.* (1997) who also noted a decrease in shear strength with increasing tillage intensity.

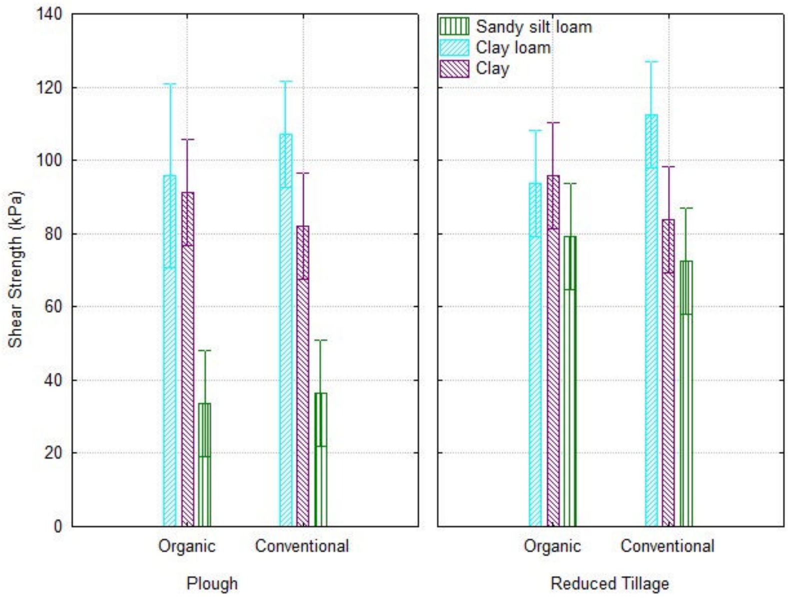


Figure 4.33: Mean values for shear strength (kPa) for all three soil textures, management (organic / conventional) and tillage treatment (reduced tillage / plough). Bars show 95 % confidence intervals. LSD = 10.27

4.3.6 Bulk Density (ρ_b) and Total Porosity

Bulk density (ρ_b) is a combination of solid and pore spaces (Brady, 1990). It reveals the ease of root penetration and water transmission which can be altered by management practices and land use (Ashman and Puri, 2002). ρ_b is affected by texture, structure, compaction and the SOC content. ρ_b can be used to determine the current state of the soil structure, for example, the level of compaction. However, depending upon the sample size, it may omit macropores between peds are significant in structure and can be more controlling in terms of water movement (Smith and Mullins, 1991).

4.3.6.1 Aberdeen (Sandy silt loam)

Table 4.16 shows that when comparing organically and conventionally managed soils irrespective of different tillage regimes, there was no significant difference ($p > 0.05$) between organically managed soil (1.02 g cm^{-3}) and conventionally managed soil (1.03 g cm^{-3}). There was a significant difference between the tillage systems ($p < 0.05$) with the conventionally managed reduced tillage (rotavator) having the lowest bulk density (0.99 g cm^{-3}) compared to the other systems. There was a significant difference between the tillage treatments on organically managed land; whereby the reduced tillage and rotavator had the lowest bulk density (0.98 g cm^{-3}). The undersown treatment was not significantly different from any of the other organic treatments. There was a significant difference ($p < 0.05$) due to the time of sampling – the bulk density increased over time from post tillage to post harvest. Abid and Lal (2008b) suggest that bulk density is usually higher under reduced tillage systems; it agrees with Lipiec *et al.* (2006) who found that ploughed soils had higher bulk density.

Total porosity is directly related to bulk density, as bulk density increases total porosity decreases and vice versa. The data for total porosity is not shown for this reason; however some differences are as follows. There was no significant difference ($p > 0.05$) in total porosity when organically managed soil (61.30 %) was compared with conventionally (60.95 %) managed soil. This is mostly due to the length of time of this study; where differences in total porosity are not shown in the short term. There was a significant difference ($p < 0.05$) in porosity due to tillage treatment where ploughed (58.87 %) for both organic and conventional was lower than all the other treatments. There was a decrease in porosity over the two cropping seasons between post tillage and post harvest.

Table 4.16: Tillage treatment, management and sampling timings for bulk density (g cm^{-3}) in Aberdeen. Different letters are significantly different ($p < 0.05$).

Time	Organic				Conventional			Mean
	Plough	Plough and Undersow	Reduced tillage (disc)	Reduced tillage (rotavator)	Plough	Reduced tillage (disc)	Reduced tillage (rotavator)	
Post Tillage	0.99	1.03	0.89	0.84	0.94	0.89	0.90	0.91^{a}
Post Harvest	1.15	1.17	1.06	1.06	1.18	1.12	1.03	1.10^{a}
Post Tillage	1.11	0.99	0.98	0.98	1.02	0.98	0.93	1.00^{b}
Post Harvest	1.09	1.21	1.11	1.05	1.21	1.08	1.11	1.11^{b}
Mean	1.08^{a}	1.10^{a}	1.01^{a}	0.98^{a}	1.09^{a}	1.01^{a}	0.99^{ab}	

4.3.6.2 East Grinstead (Clay loam)

Table 4.17 shows that when comparing organically and conventionally managed soils irrespective of different tillage regimes, there was a significant difference ($p < 0.05$) where the organically managed soil (1.05 g cm^{-3}) has a lower density than the conventionally managed soil (1.32 g cm^{-3}). There was no significant difference between the tillage systems ($p > 0.05$). There was a significant difference ($p < 0.05$) due to the time of sampling. Post tillage in the first year (1.09 g cm^{-3}) had the lowest value; then post harvest the bulk density increases considerably and is significantly different. This indicates a loosening and compaction of soil by farm equipment during harvesting in the first year of sampling. In the second year, post tillage the bulk density is reduced (1.18 g cm^{-3}) but remains constant with post harvest. This is because the differences in bulk density between tillage systems usually disappear at the end of the growing season due to consolidation (Moret and Arrue, 2007). There was a significant difference ($p < 0.05$) in porosity where organic (60.19 %) was higher than conventionally (50.05 %) managed land. There was no significant difference in porosity that could be attributed to time of sampling or tillage treatments.

Table 4.17: Tillage treatment, management and sampling timings for bulk density (g cm^{-3}) in East Grinstead. Different letters are significantly different ($p < 0.05$).

Time	Organic		Conventional		Mean
	Plough	Minimum Tillage	Plough	Minimum Tillage	
Post Tillage	1.11	1.02	1.07	1.14	1.09[a]
Post Harvest	1.15	1.12	1.51	1.34	1.29[b]
Post Tillage	1.11	0.98	1.24	1.39	1.18[ab]
Post Harvest	0.94	0.97	1.34	1.47	1.18[ab]
Mean	1.08[a]	1.02[a]	1.29[b]	1.35[b]	

4.3.6.3 Huntingdon (Clay)

Table 4.18 shows that when comparing organically and conventionally managed soils irrespective of different tillage regimes, there was no significant difference ($p > 0.05$) between the organically managed soil (1.22 g cm^{-3}) and the conventionally managed soil (1.23 g cm^{-3}). There was a significant difference between the tillage systems ($p > 0.05$). In the conventionally managed soils; the reduced tillage (disc) has a lower bulk density compared to the other treatments. In the organically managed soil, the direct drill had a significantly higher bulk density compared to both the other treatments. This agrees with Lipiec *et al.* (2006); who determined that bulk density decreased under ploughed tillage regimes but this disagrees with Abid and Lal (2008b).

This also affected the total porosity which increased under ploughing compared to direct drill. There was a significant difference ($p < 0.05$) due to the time of sampling; as bulk density increased between the two sampling times from post tillage to post harvest which could be related to soil compaction during harvest.

There was no significant difference ($p > 0.05$) in porosity between organic (60.05 %) and conventionally (60.61 %) managed land. There was a significant difference ($p < 0.05$) in porosity due to tillage treatment where direct drill (53.93 %) was lower than all the other treatments in both organically and conventionally managed soils. There was a decrease in porosity over the cropping season. This would be as expected due to compaction during harvesting.

Table 4.18: Tillage treatment, management and sampling timings for bulk density (g cm^{-3}) in Huntingdon. Different letters are significantly different ($p < 0.05$).

Time	Organic			Conventional			Mean
	Plough	Reduced tillage (disc)	Direct drill	Plough	Reduced tillage (disc)	Direct drill	
Post Tillage	1.05	1.20	1.30	1.20	1.00	1.15	1.15^{a}
Post Harvest	1.15	1.12	1.51	1.39	1.10	1.51	1.28^{b}
Mean	1.10^{a}	1.16^{a}	1.41^{b}	1.30^{b}	1.05^{a}	1.33^{b}	

4.3.6.4 Comparative Summary

The three sites were compared using only two tillage treatments (reduced tillage and plough) and one cropping season. Overall, there was no outright trend for either organic or conventional soil to have higher bulk density. Reganold and Palmer (1995) found that organic farms had a significantly lower bulk density when compared with conventional farms; this research does not support this finding. In Figure 4.34, it is possible to see that there was no significant difference ($p > 0.05$) in bulk density between the soil textures. It would be anticipated that there should be a difference between soil textures; with clay and clay loam having a higher bulk density however this was not found in this research. As total porosity is related to bulk density; there was also no significant difference ($p > 0.05$) between different soil textures. There was also no significant interaction with tillage regime for the three different soil textures and land management (organic or conventional).

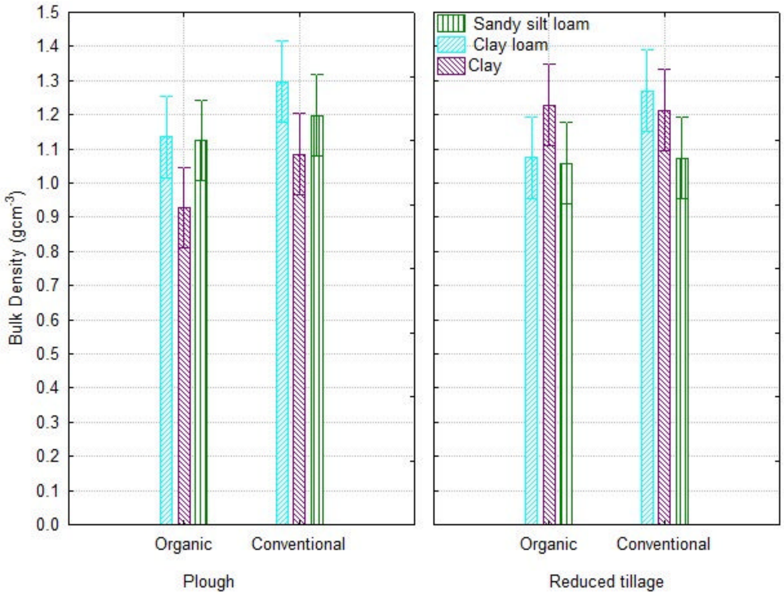


Figure 4.34: Mean values for bulk density (g cm^{-3}) for all three soil textures, management (organic/ conventional) and tillage treatment (reduced tillage / plough). (Bars show 95 % confidence levels). LSD = 0.32

4.3.7 pH

Armstrong Brown (2000) proposed that pH was a good indicator of soil health and sustainability of a farming system. Soil pH is governed by inherent soil properties including clay content and SOC which may be affected through land management, such as rotations and plant residues (Clark *et al*., 1998). Soil buffering (capacity of a soil to resist change) is highly significant as it helps to maintain equilibrium within the soil (Brady, 1990). Soil pH controls the release of nutrients and the effects of increasing acidity on crop production and biological activity have been well documented (Brady, 1990).

4.3.7.1 Aberdeen (Sandy silt loam)

Figure 4.35 shows that there was a significantly ($p < 0.05$) lower pH for organically managed land (pH 6.06) compared to conventional management (pH 6.44). It is important to note that the trend for organically managed land to have a lower pH was present in the initial sampling (pre- tillage treatments). This difference was maintained over the sampling season and there was a significant trend ($p < 0.05$) for the pH to increase over time from the initial sample (February 2009) to final post harvest (September 2010) for both organic and conventionally managed land. Differences in pH over time can be due to decomposition of SOC during warming weather (in June 2009) or due to a build up of salts which subsequently leach during wetter periods (Brady, 1990).

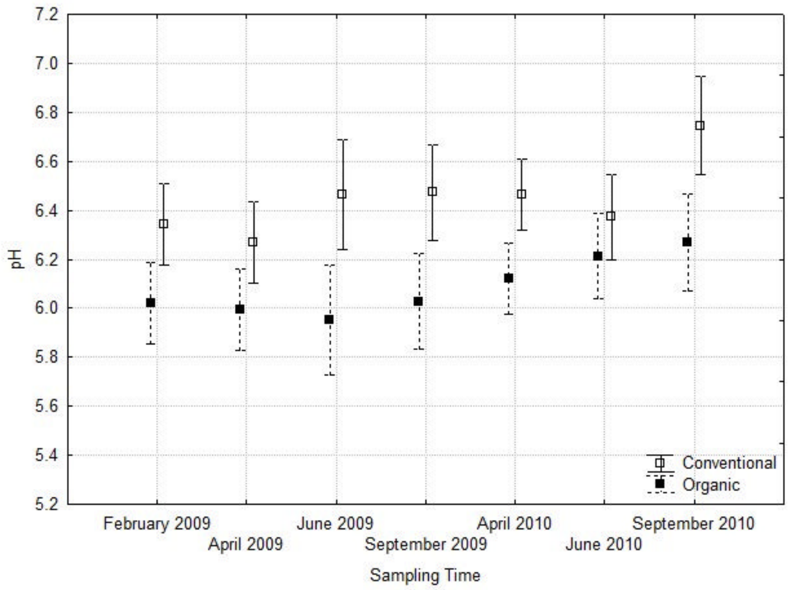


Figure 4.35: Mean value of pH in Aberdeen at each sampling point (bars show confidence 95 % interval). LSD = 0.15

The effects of different tillage regimes ($p < 0.05$) are shown in Figure 4.36. There was no difference between tillage treatments; however the additional treatment on the organically managed land (plough and undersow) had a significantly lower pH (5.93) but it was not different from the organically managed ploughed treatment. The lack of difference between tillage treatments supports the findings of Edwards *et al.* (1992).

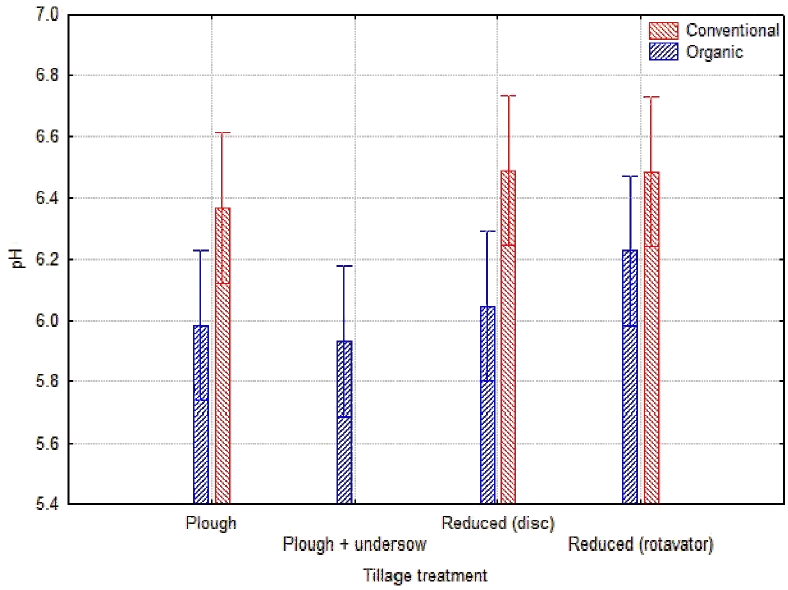


Figure 4.36: Mean values for pH in Aberdeen according to management and tillage treatment (bars show confidence interval 95 %). LSD = 0.38

There was no significant difference ($p > 0.05$) for pH between top soil depths (0 – 75 and 75 – 150 mm). There was no significant interaction ($p > 0.05$) between land management (organic and conventional), sampling time or tillage treatment (ploughed or reduced tillage).

4.3.7.2 East Grinstead (Clay loam)

Figure 4.37 shows that overall organically managed land (pH 6.43) has a significantly lower ($p < 0.05$) pH compared to conventional management (pH 6.75). It is important note that this difference is present in the initial sampling (February 2009) and it has been maintained over the cropping seasons. There was a significant difference in pH due to sample timing with a small decrease over time. For the organically managed land, the pH increased slightly after tillage (April 2009 and 2010) before decreasing through to post harvest (September 2010). This was because there are seasonal variations due to soil moisture content and the ionic concentration of soil solution; which increase the levels of salts over time reducing soil pH (Edwards *et al.*, 1992).

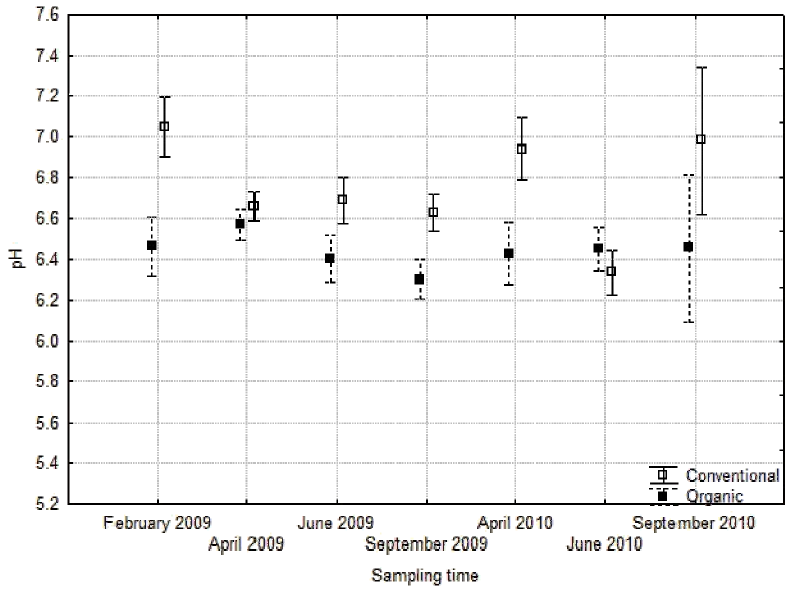


Figure 4.37: Mean value of pH in East Grinstead at each sampling point (bars show 95 % confidence interval). LSD = 0.23

Figure 4.38 shows the effect of tillage regime on soil pH ($p < 0.05$). The ploughed and minimum tillage treatments in organically managed land had significantly lower pH than the other treatments (pH 6.42 and pH 6.45 respectively). The conventionally ploughed soil had significantly higher pH than the other treatments (pH 6.92). Changes in pH can be due to changing rotation and plant residue management; however these were the same on the tillage plots so this is not the contributing factor (Edwards *et al.*, 1992). Therefore, the differences can be linked to the starting conditions whereby the organically managed land had a lower pH. Doran (1980) suggested that pH lowered as total N increases as this increases the microbial biomass. However there was no significant difference in total N between organic and conventionally managed land or between different tillage regime (see total C:N ratio Section 4.3.8).

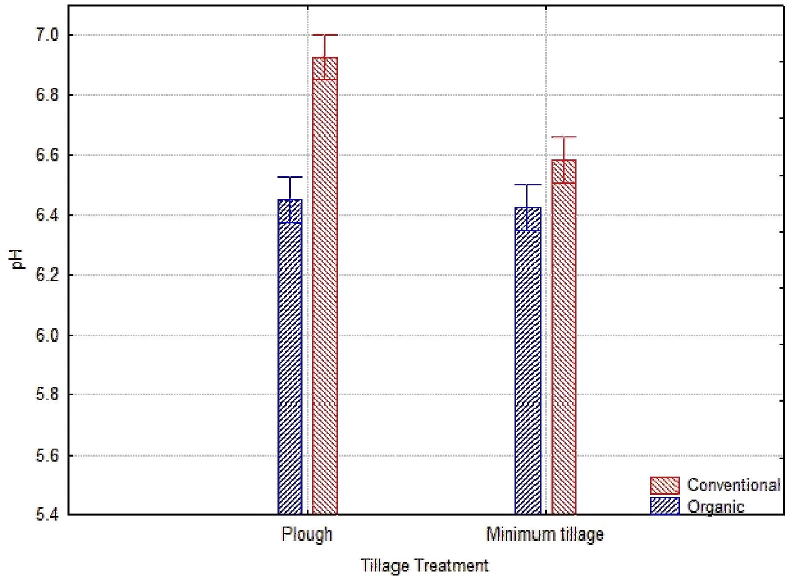


Figure 4.38: Mean values for pH in East Grinstead according to management and tillage treatment (bars show 95 % confidence interval). LSD = 0.10

There was no difference ($p > 0.05$) for pH between top soil depths (0 – 75 and 75 – 150 mm). There was no interaction ($p > 0.05$) between land management (organic and conventional), time of sampling and tillage treatment (ploughed or reduced tillage).

4.3.7.3 Huntingdon (Clay)

Figure 4.39 shows that there was no significant difference ($p > 0.05$) in pH between organically managed land and conventional management. There was a significant seasonal effect on pH for organically managed land with post tillage (April 2009) increasing the pH which then decreases over time. The seasonal effect is slightly different for the conventionally managed land which remains almost constant with a small decrease during stem extension (June 2009). The buffering capacity (resistance to change) of a clay soil is greater and hence there was no significant difference between organic and conventionally managed soils (Brady, 1990).

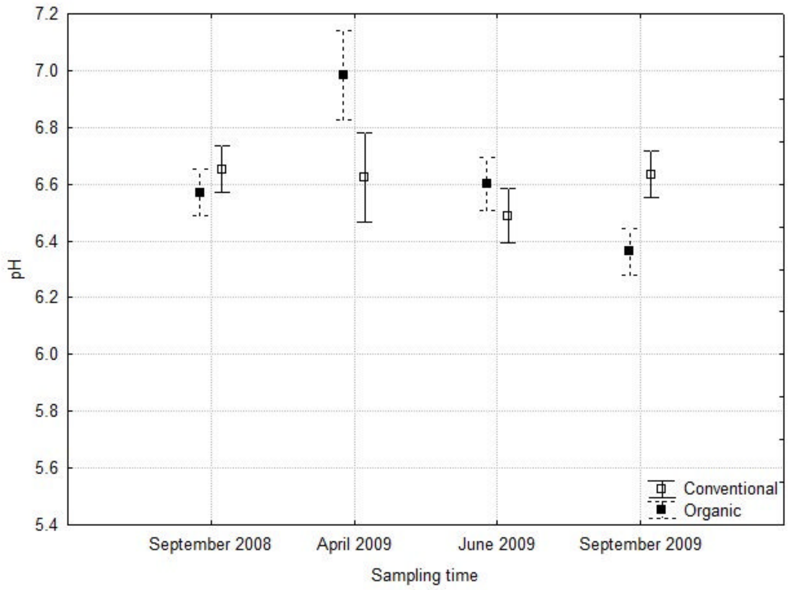


Figure 4.39: Mean value of pH in Huntingdon at each sampling point (bars show 95 % confidence interval). LSD =0.15

The effects of different tillage regimes ($p > 0.05$) are shown in Figure 4.40. The treatments were not significantly different from each other. There was a trend for the organic land in plough and direct drill to have a slightly higher pH but this was not significant. This lack of difference can again be attributed to the nature of the clay soil which is more resistant to changes in pH (Brady, 1990).

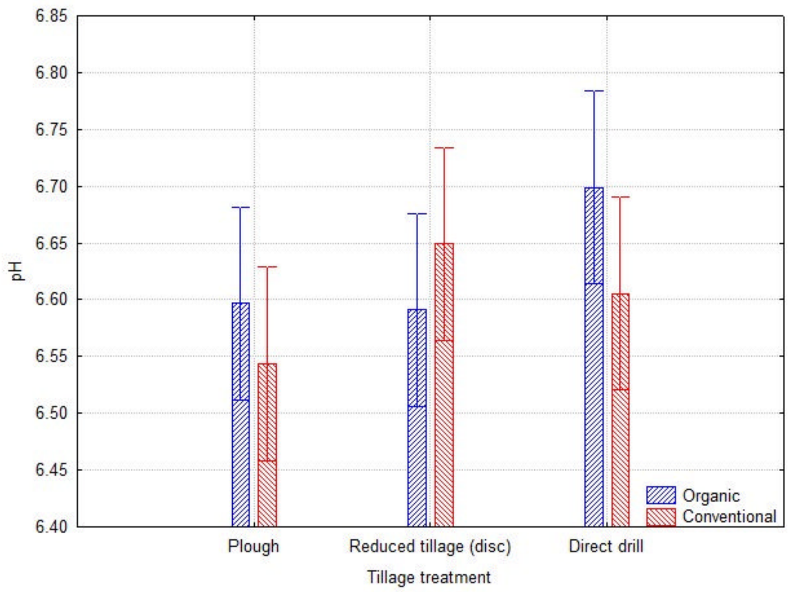


Figure 4.40: Mean values for pH in Huntingdon according to management and tillage treatment (bars show 95 % confidence interval). LSD = 0.12

There was no difference (p value > 0.05) for pH between top soil depths (0 – 75 and 75 – 150 mm). There was a significant interaction between sample timings during the two years, management (organic or conventional) and tillage regime type ($p < 0.05$). This showed decreasing pH from post tillage samples to post harvest.

4.3.7.4 Comparative Summary

The three sites were compared using only two tillage treatments (reduced tillage and plough) and the first year of data. Overall, there was a significantly lower pH for organically managed land (6.36) compared to conventionally managed land (6.56). This was due to the initial conditions; in both the sandy silt loam and clay loam where organically managed land had a lower pH and this trend continued throughout the season. In Figure 4.41, it is possible to see there was a significant difference ($p < 0.05$) in pH between the soil textures. Whereby, the sandy silt loam (pH 6.19) was lower than the other two textures which were not significantly different from each other (pH 6.61 and 6.59 clay and clay loam respectively). This was due to their soil series and association; the sandy silt loam (Countesswells) is inherently slightly acidic. Whereas, the clay (Evesham 3) is naturally calcareous and the clay loam (Wickham 1) which can be calcareous. The soils are all slightly acidic which is influenced by the crops grown previously mainly grass which thrives in these soil conditions (Brady, 1990).

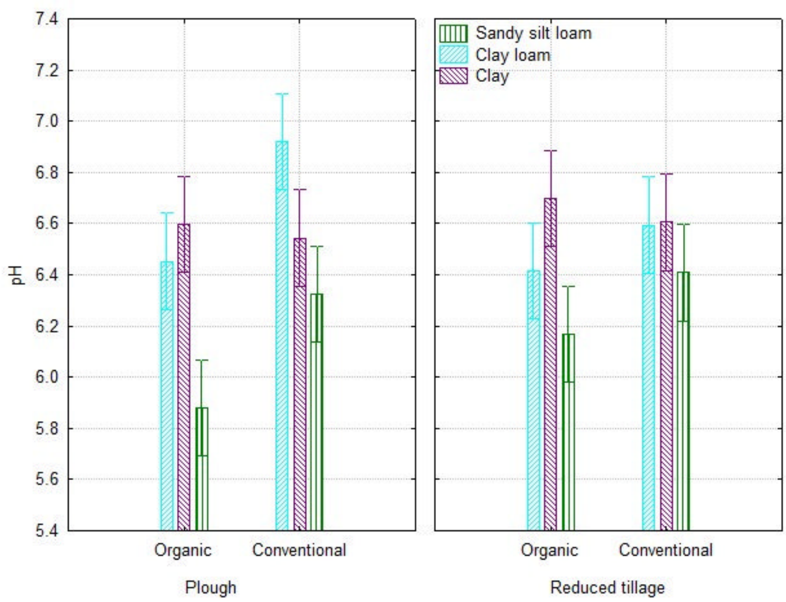


Figure 4.41: Mean values for pH for all three soil textures, management (organic / conventional) and tillage treatment (reduced tillage / plough). Bars show confidence 95 % interval. LSD = 0.308

4.3.8 Total C:N ratio

The SOC stored in the soil is dependent on the balance between the inputs of SOM and the outputs of mineralization. The total C:N ratio provides information regarding the degree of humification of SOC and the availability of nutrients (Martins *et al*., 2011). Typically, the total C:N ratio of arable (cultivated soils) ranges between 8 and 15 (Brady, 1990). The amount of SOC and its degree of humification can be affected by land use or tillage regime (Lettens *et al.,* 2004).

4.3.8.1 Aberdeen (Sandy silt loam)

Table 4.19 shows that when comparing organically and conventionally managed soils irrespective of different tillage regimes, there was a significant difference ($p < 0.05$) between organically managed soil (13.03) and conventionally managed soil (13.83). The total C:N ratio was within the naturally occurring norm as described by Brady (1990). The higher values for total C:N ratio would correspond with the measurements of SOC which were greater under conventionally managed soils. Martins *et al.* (2011) suggest that the higher the total C:N ratio the lower the amount of humification; allowing a build up of SOC. There was no significant difference between the tillage systems ($p > 0.05$). The undersown treatment was not significantly different from any of the other organic treatments. This was because the plot scale study was a short duration (two years) and hence differences in total C:N ratio was not identified in this time frame. There was a significant difference ($p < 0.05$) due to the time of sampling – the total C:N ratio increased over time. There were no significant interactions between sampling time, tillage regime and management (organic or conventional).

Table 4.19: Tillage treatment, management and sampling timings for Total C:N in Aberdeen. Different letters are significantly different (p< 0.05).

Time	Organic				Conventional			Mean
	Plough	Plough and undersow	Reduced tillage (disc)	Reduced tillage (rotavator)	Plough	Reduced tillage (disc)	Reduced tillage (rotavator)	
Post Tillage	12.82	12.77	12.72	12.84	13.60	13.57	13.62	13.19[a]
Post Harvest	13.15	12.77	13.08	13.26	13.82	14.07	13.41	13.46[b]
Post Tillage	13.40	13.26	13.28	13.36	14.02	14.08	14.20	13.66[c]
Post Harvest	13.20	13.54	12.96	13.17	14.19	14.18	14.27	13.72[c]
Mean	13.06[a]	13.09[a]	12.94[a]	13.08[a]	13.82[b]	13.90[b]	13.82[b]	

4.3.8.2 East Grinstead (Clay loam)

Table 4.20 shows that when comparing organically and conventionally managed soils irrespective of different tillage regimes, there was no significant difference ($p > 0.05$) between organically managed soil (10.59) and conventionally managed soil (10.52). The measured values for total C:N ratios are within the natural norms for arable land as described by Brady (1990). There was no significant difference between the tillage systems ($p > 0.05$). There was a significant difference due to the time of sampling – the initial level was significantly lower ($p < 0.05$) and there was a general increase in total C:N ratio over the two cropping seasons. There were no significant interactions between sampling time, tillage regime and management (organic or conventional).

Table 4.20: Tillage treatment, management and sampling timings for Total C:N in East Grinsteaad. Different letters are significantly different (p < 0.05).

Time	Organic		Conventional		Mean
	Plough	Minimum Tillage	Plough	Minimum Tillage	
Post Tillage	9.90	9.57	9.76	9.75	9.75[a]
Post Harvest	10.96	10.89	11.01	10.41	10.69[b]
Post Tillage	10.74	10.31	10.75	10.96	10.82[b]
Post Harvest	11.20	11.11	10.86	10.62	10.96[b]
Mean	10.70[a]	10.47[a]	10.59[a]	10.44[a]	

4.3.8.3 Huntingdon (Clay)

Table 4.21 shows that when comparing organically and conventionally managed soils irrespective of different tillage regimes, there was no significant difference ($p > 0.05$) between organically managed soil (9.43) and conventionally managed soil (9.48). The value of total C:N ratios are within the natural norms outlined by Brady (1990). There was a significant difference between the tillage systems ($p < 0.05$) with the conventional direct drill having a lower total C:N ratio (9.28) compared to the other systems. This aligns with the research by Kasper *et al.* (2009); who determined that total C:N ratio was highest under traditional ploughed systems. This difference was attributed to less total N being lost from the system under conventional plough compared to reduced tillage systems. There was no significant difference due to the time of sampling or any interactions with tillage treatments.

Table 4.21: Tillage treatment, management and sampling timings for Total C:N in Huntingdon. Different letters are significantly different (p< 0.05).

Time	Organic			Conventional			Mean
	Plough	Reduced tillage (disc)	Direct drill	Plough	Minimum tillage (disc)	Direct drill	
Post Tillage	9.38	9.57	9.43	9.70	9.58	9.24	9.43^{a}
Post Harvest	9.56	9.47	9.47	9.34	9.39	9.33	9.48^{a}
Mean	9.47^{ab}	9.52^{a}	9.45^{ab}	9.52^{a}	9.49^{ab}	9.28^{b}	

4.3.8.4 Comparative Summary

The three sites were compared using only two tillage treatments (reduced tillage and plough) and one cropping season. Figure 4.42 shows that overall, there was a significantly lower total C:N ratio ($p < 0.05$) for organically managed land (10.87) compared to conventionally managed land (11.11). This indicated a greater level of humification in organically managed land and potentially lowers nutrient availability (Martins *et al.*, 2011). In Figure 4.42, it was possible to see there was a significant difference in total C:N between the soil textures ($p < 0.05$). Whereby, the lowest total C:N ratio was in the clay soil (9.43), followed by clay loam (10.22) and the highest was the sandy silt loam (13.31). This agrees with research by Hassink *et al.* (1992) who found that clay and clay loam soils protect SOC from humification by the location of SOC in small soil pores; hence reducing the total C:N ratio. There was no significant difference between different tillage systems ($p > 0.05$).

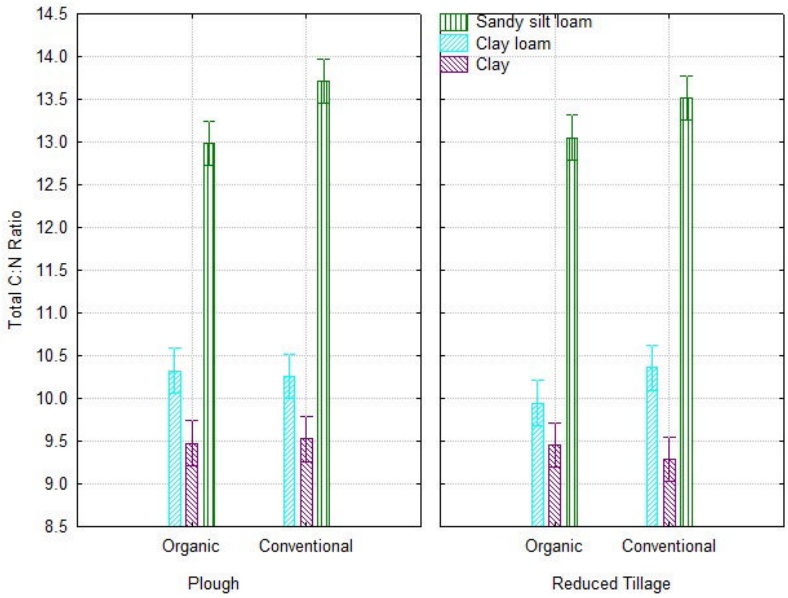


Figure 4.42: Mean values for Total C:N ratio for all three soil textures, management (organic / conventional) and tillage treatment (reduced tillage / plough). Bars show 95 % confidence interval. LSD= 0.48

4.3.9 Infiltration Rate

Infiltration rate was measured *in situ* using a Decagon mini disc tension infiltrometer. It is important to state that there is a caveat with this method; it is based on a small surface area (45 mm diameter). However, it provided a viable method within the time and budget constraints. Therefore, five replicates were measured on each plot at each site, as a means to obtain a more representative estimate.

4.3.9.1 Aberdeen (Sandy silt loam)

Overall, when comparing the effects of organic and conventional management of soils irrespective of different tillage regimes, there was a significant difference ($p < 0.05$) between organically managed soil (10.32 mm hr^{-1}) and conventionally managed soil (5.45 mm hr^{-1}). A similar difference was found by Zeiger and Fohrer (2009) who monitored rainfall runoff and infiltration on organic and conventional arable farms; where organic farms had a significantly higher infiltration rate. This is in contrast to the field scale study (Chapter 3) where there was no difference between organic and conventionally managed arable land; whereas organically managed grass land was higher than conventional grass land.

Table 4.22 shows that there was a significant difference between the tillage systems ($p < 0.05$) with the organically managed plough having higher infiltration rates to the other organic systems. This does not agree with research by Abid and Lal (2008b) who stated that infiltration rates were higher under no tillage compared with ploughing. This is due to increasing continuity of pores especially macropores; which under this short-term trial would not have been fully established in the reduced tillage systems. However, in the ploughed system soil structure would be altered and improve in the short-term and reducing the bulk density of the soil which would increase total porosity (Lipiec *et al*., 2006). Moret and Arrue (2007) determine that infiltration rate is governed by macropores and even though these form a small proportion of total porosity; they are very sensitive to compaction. Moret and Arrue (2007) found that infiltration rate could be related to tillage intensity, increasing intensity (ploughing) would decrease infiltration rate; this research does not support this. This could be due to ploughing allowing more water to flow through the vertical cracks and pore spaces compared to the more compacted reduced tillage treatments. However, in longer duration experiments reduced tillage treatments form a more porous soil structure which would improve infiltration rates; this short duration study does not show this.

There was a significant difference ($p < 0.05$) due to sampling time – where the post tillage (April 2009 and 2010) infiltration rate was higher than the post harvest (September 2009 and 2010). This difference was significant across all tillage treatments and management (organic and conventional). This research agrees with Cameira *et al.* (2003) who found that infiltration rates were always greater at the beginning of the cropping season; which can be related to a reduction in compaction during tillage operations.

Table 4.22: Tillage treatment, management and sampling timings for infiltration rate (mm hr^{-1}) in Aberdeen. Different letters are significantly different ($p < 0.05$).

Time	Organic				Conventional			Mean
	Plough	Plough and undersow	Reduced tillage (disc)	Reduced tillage (rotavator)	Plough	Reduced tillage (disc)	Reduced tillage (rotavator)	
Post Tillage	18.36	24.25	12.66	12.66	10.98	6.24	4.87	10.96^{a}
Post Harvest	9.78	10.44	7.50	9.72	6.42	4.62	3.90	6.99^{bc}
Post Tillage	14.80	21.18	4.22	7.98	10.26	4.98	5.82	8.01^{b}
Post Harvest	11.70	12.82	7.38	7.08	2.04	2.20	1.89	5.38^{c}
Mean	13.66^{a}	17.17^{a}	7.94^{b}	9.36^{b}	7.42^{b}	4.51^{c}	4.12^{c}	

4.3.9.2 East Grinstead (Clay loam)

Overall, when comparing organically and conventionally managed soils irrespective of different tillage regimes, there was a significant difference ($p < 0.05$) between organically (3.02 mm hr^{-1}) and conventionally managed soil (0.94 mm hr^{-1}). This was expected and correlates with Zeiger and Fohrer (2009) and Lampurlanés and Cantero-Martínez, (2006).

Table 4.23 shows that there was a significant difference between the tillage systems ($p < 0.05$) with the organic minimum tillage and plough having higher infiltration rates to the other conventional systems. The organically managed ploughed treatment had a higher infiltration rate compared to minimum tillage. This was the same trend as found in Aberdeen, whereby under the minimum tillage the benefit of improved pore continuity had not developed in this short-term trial. There was no difference between the conventional treatments. This lack of difference was also shown by Lal and Vandore (1990) who found that tillage intensity did not have an effect on equilibrium infiltration rates. There was a significant difference ($p < 0.05$) due to sampling time – where the post harvest infiltration rate in the first year was lower than the other times. This can be related to compaction post harvest and a decrease in infiltration capacity (Dunn and Phillips, 1991).

Table 4.23: Tillage treatment, management and sampling timings for infiltration rate (mm hr $^{-1}$) in East Grinstead. Different letters are significantly different ($p < 0.05$).

Time	Organic		Conventional		Mean
	Plough	Minimum Tillage	Plough	Minimum Tillage	
Post Tillage	2.38	0.93	0.97	0.65	1.23^{a}
Post Harvest	3.65	3.26	0.91	0.83	2.13^{b}
Post Tillage	3.93	2.80	0.90	0.91	2.17^{b}
Post Harvest	4.47	2.74	1.42	0.88	2.38^{b}
Mean	3.61^{a}	2.43^{b}	1.05^{c}	0.82^{c}	

4.3.9.3 Huntingdon (Clay)

Overall, when comparing infiltration in organically and conventionally managed soils irrespective of different tillage regimes, there was no significant difference ($p > 0.05$) between organically managed soil (3.35 mm hr^{-1}) and conventionally managed soil (3.21 mm hr^{-1}). Table 4.24 shows there was a significant difference between the tillage systems ($p < 0.05$) with the organic plough having higher infiltration rates compared to the other organic treatments. There was no difference between the conventional treatments. There was no significant difference ($p > 0.05$) due to sampling time. It is thought that soil compaction, due to the nature of the Evesham clay, was a contributing factor to the lower levels of infiltration rates and lack of significant differences and interactions between treatments.

Table 4.24: Tillage treatment, management and sampling timings for infiltration rate (mm hr^{-1}) in Huntingdon. Different letters are significantly different ($p < 0.05$).

Time	Organic			Conventional			Mean
	Plough	Reduced tillage (disc)	Direct drill	Plough	Reduced tillage (disc)	Direct drill	
Post Tillage	3.91	2.45	3.01	3.91	2.45	3.01	3.12^{a}
Post Harvest	5.09	2.86	2.78	3.60	2.82	3.46	3.43^{a}
Mean	4.50^{a}	2.65^{b}	2.90^{b}	3.75^{ab}	2.64^{b}	3.24^{ab}	

4.3.9.4 Comparative Summary

The three sites were compared using only two tillage treatments (reduced tillage and plough) and only one cropping season. Overall, there was a higher infiltration rate ($p < 0.05$) for organically managed land (5.68 mm hr^{-1}) compared to conventionally managed land (3.82 mm hr^{-1}). This can be related to an improved maximum water holding capacity for organically managed land. This result was not found in the field scale study (Chapter 3) as differences between organic and conventionally managed land were only found in grass land. In Figure 4.43, it is possible to see there was a significant difference ($p < 0.05$) in infiltration rate between the soil textures. Whereby, the lowest was clay loam (1.7 mm hr^{-1}) compared the other two textures (3.5 mm hr^{-1} and 8.94 mm hr^{-1} clay and sandy silt loam respectively). These values correspond to the measured infiltration rate in the field scale study; where clay loam was the lowest (1.47 mm hr^{-1}) and the clay was higher (9.87 mm hr^{-1}). There was no sandy silt loam measured; however the sandy loam had a high infiltration rate (7.52 mm hr^{-1}). This could be explained by the cracking nature of clay soils and the coarse texture of the sandy loam.

There was an effect due to tillage treatment ($p < 0.05$) where the minimum tillage was significantly lower (3.65 mm hr^{-1}) compared to ploughed treatment (5.85 mm hr^{-1}). Minimum tillage systems usually improve infiltration rates due to increases in both total porosity (not shown in this research) and improving continuity of pores this has not established in this two year study. There was no significant difference between the two sampling times for the first year of cropping.

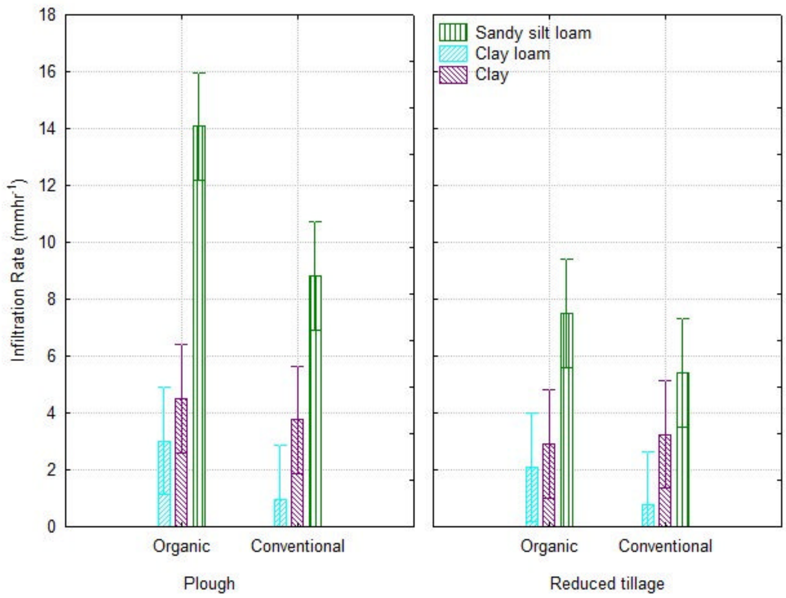


Figure 4.43: Mean values for infiltration rates (mm hr^{-1}) for all three soil textures, management (organic / conventional) and tillage treatment (minimum tillage / plough). Bars show 95 % confidence intervals. LSD = 2.2

4.3.10 Workability

This section looks at the effect that changing land management (organic) and tillage regime have on soil workability. Knowledge of the workability of an arable soil, whether managed organically or conventionally, is important as it provides an estimation of the number of days when different soils are workable for cultivation and seedbed preparation (Rounsevell, 1993; Droogers *et al.*, 1996). This governs the ease of creation of seedbeds suitable for seed germination and crop growth. Workability is not a precise soil condition as it does depend on both the operator and the available machinery. If the soil is worked when the conditions are unsuitable it can cause damage to the soil structure which can persist for years (Earl, 1997). Good workability provides a longer window of opportunity for working the land (work days) without causing damage to soil structure, especially compaction or smearing of clay soils (Cooper *et al.*, 1997). This window of opportunity is altered by changing climatic conditions in the UK namely warmer wetter winters; with different rainfall patterns altering both duration and intensity of rainstorms (Godwin and Dresser, 2003).

Whilst, there has been much literature produced during the 1970s and 1980s (see Rounsevell, 1993); less workability research has been reported in recent years. Watts and Dexter (1998) related soil physical properties and friability through tensile strength for different soil texture but tensile strength was not explored in this project. Kouwerhoven *et al*. (2002) investigated the effect of changing to shallow ploughing for workability in organic farming in the Netherlands. However, there had been no attempts to investigate differences in workability due to changing tillage regime and conversion to organic status in the UK. Hence this research fills this gap by investigating soil workability (and number of work days available) of three different arable soils; sandy silt loam, clay loam and clay, under both organic and conventional management.

4.3.10.1 Model Options and Methodology

Rounsevell (1993) indentified two main types of workability models: empirical and deterministic. Deterministic models combine processes to derive soil moisture status and create simulations (Toro and Hansson, 2004). This can present a large disadvantage; as a relationship between soil water potential, work-days and hydraulic conductivity must first be determined empirically (Rounsevell, 1993). Hence, the models used in this research were empirically based. Thomasson (1987) developed a model that is based on long-term median weather data (such as Smith and Trafford, 1976), which is then made site specific through altering the number of workdays based upon soil properties. Thomasson (1987) suggested a relative value to determine the ease of soil workability giving a specific soil a rating between *a* to *d* (based on soil wetness and water retention with *a* being lowest and *d* being highest). These values are based upon wetness class, and retained water capacity (through inherent soil physical properties such as SOC content, percentage clay content and soil structure). The numbers of spring and autumn workdays, for both organic and conventionally managed land on two soil textures (clay loam and clay), were calculated using Thomasson (1987) (see Appendix C for the detailed methodology).

Two of the many empirical models for determining workability; are outlined and the reasons for not using in this study highlighted. Smith (1977) developed a simple model which classified land into three textural classes and suitability of operations during a spring day were determined. However, large soil variability within the soil textural classes meant that there was a large amount of error. Hence, this method was not used. Soil moisture budgets are also used to determine workability such as the Versatile Soil Moisture Budget (Baier and Roberston, 1966). This method divided soil into six moisture zones; allowing the potential soil moisture deficit based upon daily precipitation and evapotranspiration to be calculated. A work-day existed if the calculated moisture content in each of the top three zones was less than 99.5 % of field capacity (Rutledge and Russell, 1971). This method is very labour intensive requiring detailed field knowledge of soil moisture contents at different depths and hence this method was not used.

Firstly, the number of work-days was calculated using Thomasson (1987). Then the following two methods were used to determine the workability using measured data from the three soil textures.

1. The optimum moisture content for tillage (determined by Mueller *et al.*, 2003) is characterised as being 90 % of the field capacity (pF2) moisture content. This value was compared against actual soil moisture contents in the field to determine whether operations could take occur. This method was chosen as provides a snapshot of workability at the time of sampling.

Optimum moisture for tillage (%) = $0.9 \times pF2$ **Equation 4.4**

2. The workability index (Boekel, 1963) shown in equation 4.5 was calculated for each of the three soil types, different tillage regimes and management combinations. This is based upon field capacity (pF2) and lower plastic limit (LPL) measurements. For good workability the index value should be greater than 1. This method was chosen as it provides a snapshot of workability at the time of sampling and incorporates soil textural properties.

Workability index = LPL/pF2 **Equation 4.5**

4.3.10.2 Work-days (Thomasson, 1987)

This section presents the findings from applying Thomasson's (1987) model of work days to the two different areas and soil textures (clay loam and clay). As the climate data in Smith and Trafford (1976) is limited to the England and Wales it was not possible to model the effects of climate changing on the soils in Aberdeen (sandy silt loam). This model does not have high enough resolution to distinguish between organic and conventional management. Therefore, more work is needed to determine this through the relationship with SOC contents. However, it is able to depict yearly differences due to change in annual precipitation. Soil moisture content governs workability of a soil and is strongly related to the amount and timing of precipitation. Changing climatic conditions suggest that increasing winter rainfall may alter the timings of autumn work days and push spring work days further back into April (Cooper *et al.*, 1997).

Cooper *et al.* (1997) describe the effects of changing climatic conditions on four different soil types in Scotland. The results of Cooper *et al.* (1997) show that there was a substantial decrease in the number of autumn work days in the modified climatic conditions due to increased rainfall. This agrees with the modelling of clay and clay loam soils; whereby increasing precipitation between the sampling years reduced the number of work days. The precipitation data collected in Aberdeen shows the variability in rainfall during winter with total rainfall between September to December in 2009 (545 mm) compared to 2010 (396 mm). Cooper *et al.* (1997) also suggest a slight improvement of the number of work days in April due to an increase in temperature and potential evapotranspiration. This would imply that the workability specifically for seedbed creation would be better during spring. Organic farmers grow more spring cereals, to reduce competition of weeds during establishment (Vakali *et al.*, 2011). Therefore, changing climatic conditions towards improved work days in April would be beneficial for spring crops.

4.3.10.3 Optimum Water Content for Tillage (Mueller *et al.*, 2003)

The percentage moisture content of the three different soils was measured *in situ* using a theta probe. This was measured at two different times during the cropping season; firstly close to the time of tillage operations (April) and secondly close to the time of harvest (September). The data from these sampling times have been used as a proxy for spring tillage operations (April) and autumn tillage operations (September). The optimum moisture content for tillage is calculated using Equation 4.4 (Muller *et al.*, 2003). Comparisons between soil textures and land management can be made through differences in the optimum moisture content for tillage and *in field* measured moisture contents at the sampling time (Figure 4.44).

Optimum or below moisture content	(green)
Above Optimum moisture content	(red)

	Sandy silt loam		Clay Loam		Clay	
	April	Sept	April	Sept	April	Sept
Organic	**34.90** *44.83*	**34.18** *44.83*	**13.24** *31.41*	**29.50** *31.41*	**40.78** *33.17*	**48.62** *33.17*
Conventional	**34.44** *45.52*	**35.34** *45.52*	**12.38** *28.91*	**31.55** *28.91*	**39.53** *32.97*	**44.62** *32.97*

Figure 4.44: Average measured soil moisture conditions (%) shown in bold and the optimum moisture content for tillage shown in italic for organic and conventional management and soil texture. Not significantly different (p> 0.05).

There is no difference between organic and conventional management or between spring and autumn operations for sandy silt loam or clay. Sandy silt loam always exhibited workability at the sampling time whereas clay was never workable in this study. The samples were taken in March and September when the clay soil had higher water content. The only difference between organic and conventional management was shown in clay loam during the autumn sampling times. This showed that tillage on the conventional land is more likely to cause structural damage.

4.3.10.4 Workability Index (Boekel, 1963)

Table 4.25 shows that all of the values for workability index were less than 1, and hence would indicate poor soil workability at the time of soil sampling. There was a difference within tillage regimes where for both organic and conventional management the plough tillage regime has the highest workability index. There was no overall difference between organic and conventional management for workability. Thomasson (1987) provides information for each soil textural class (based on UK soil textural classification). He suggests that for a sandy silty loam an average field capacity (0.05 bars) would be 35.0 % and the lower plastic limit would be 32.0 % providing a workability index of 1.09. The sandy silt loam values for both field capacity and lower plastic limits are higher than these values. The sandy silt loam has a high SOC level which helps to increase the amount of water held by a soil and hence would move the plastic limit to a higher level (Marshall and Holmes, 1988).

Table 4.25: Soil workability index (LPL and Field capacity) for sandy silt loam (Aberdeen) with average SOC for organic 35.44 g kg^{-1} and conventional 37.21 g kg^{-1}. Different letters show significant differences ($p < 0.05$).

Management	Tillage Regime	Field capacity (%)	Lower plastic limit (%)	Workability index
Organic	Plough and undersow	49.11	36.74	0.75^{a}
Organic	Plough	48.48	40.25	0.83^{b}
Organic	Reduced tillage (disc)	48.63	37.45	0.77^{a}
Organic	Reduced tillage (rotavator)	50.14	36.26	0.72^{a}
Conventional	Plough	50.23	40.25	0.80^{b}
Conventional	Reduced tillage (disc)	51.42	36.34	0.71^{a}
Conventional	Reduced tillage (rotavator)	49.58	36.76	0.74^{a}
Average from Thomasson (1987)		35.00	32.00	1.09

Table 4.26 shows that all of the values for workability index were greater than 1, and hence would indicate good soil workability. There was a difference within tillage regimes with opposite trends being shown for organic and conventional. The highest workability index in the organic management was the organic plough with the lowest for minimum tillage. This trend was reversed for the conventional management with

minimum tillage having the highest workability index. There was a slightly higher workability index for the organic compared to the conventional management but it is not significantly different. Thomasson (1987) provides information for each soil textural class (based on UK soil textural classification). He suggests that for clay loam an average field capacity (0.05 bars) would be 43.3 % and the lower plastic limit would be 32.00 % providing a workability index of 1.35. The clay loam values for field capacity were lower and plastic limits were higher (with the exception of the conventional plough which is closest to this average). This difference in field capacity is because the samples had a higher bulk density (1.31g cm^{-3}) and hence lower porosity than the averages from Thomasson (1987).

Table 4.26: Soil workability index (LPL and Field capacity) for clay loam (East Grinstead) with average SOC for organic 16.24 g kg^{-1} and conventional 10.05 g kg^{-1}. Different letters show significant differences ($p < 0.05$).

Management	Tillage regime	Field capacity (%)	Lower plastic limit (%)	Workability index
Organic	Plough	34.66	48.07	1.39[a]
Organic	Minimum tillage	35.16	40.16	1.14[b]
Conventional	Plough	30.91	33.26	1.08[b]
Conventional	Minimum tillage	33.34	45.49	1.36[a]
Average from Thomasson (1987)		43.30	32.00	1.35

Table 4.27 shows that all of the values for workability index were greater than 1, and hence would indicate good soil workability. There was a difference within tillage regimes especially in the conventional management. The highest workability index in the organic management was the organic plough with the lowest for direct drill. This trend was reversed for the conventional management with direct drill having the highest workability index. There was a slightly higher workability index for the organic compared to the conventional management but it is not significantly different. Thomasson (1987) provides information for each soil textural class (based on UK soil textural classification). He suggests that for clay an average field capacity (0.05 bars) would be 48.0 % and the lower plastic limit would be 45.0 % providing a workability index of 1.06. The clay values for field capacity were lower and plastic limits were higher; this could be due to compaction within core samples which would have reduced the field capacity. Whereas, higher than the average percentage clay was found in the

samples measured which would require more moisture for the soil to behave in a plastic manner.

Table 4.27: Soil workability index (LPL and Field capacity) for clay (Huntingdon) with average SOC for organic 25.00 g kg^{-1} and conventional 25.00 g kg^{-1}. Different letters show significant differences ($p < 0.05$).

Management	Tillage Regime	Field capacity (%)	Lower plastic limit (%)	Workability index
Organic	Plough	34.62	52.02	1.50^{a}
Organic	Reduced tillage (disc)	37.29	47.91	1.28^{b}
Organic	Direct drill	38.65	47.41	1.23^{b}
Conventional	Plough	35.01	41.26	1.18^{b}
Conventional	Reduced tillage (disc)	36.65	42.65	1.16^{b}
Conventional	Direct drill	38.26	51.80	1.35^{a}
Average from Thomasson (1987)		48.00	45.00	1.06

4.3.10.5 Comparative summary

There was no in available work days difference between organic and conventional management (Thomasson, 1987). This was due to the model not having a high enough resolution to determine between two different land management systems. This model would be useful particularly to determine the effects of changing climatic conditions with increasing precipitation reducing the number of available work days. This would influence the crops grown (spring or winter) and the types of tillage regimes (reduced tillage or ploughed). Variations in optimum moisture content for tillage (Muller *et al*., 2003) are small between organic and conventional management. There are differences that can be seen due to soil texture (spatial distance could be contributing due to climatic differences). Only clay loam shows that for the organically managed soil there is a positive benefit for autumn operations compared to the conventionally managed soil; this was the soil which had been managed organically for the longest period of time. This would be expected as sandy silt loams are typically more workable compared to clay soils. The nature and mineralogy of the clay soil means that the effect of changing management (organic) was not detected during this study because the land was only managed organically for eight years. Variations in workability index (Boekel, 1963) are governed more by soil texture than soil management (organic or conventional). There was no overall trend for organic and conventional managed to have a higher workability index. Changes in tillage regimes do alter the workability index; but not always in the same direction across every soil type. For example, in the sandy silt loam soil, workability index is greatest under ploughed treatments, whereas in the clay loam conventionally managed minimum tillage and organically managed ploughed treatments have the highest workability index values.

4.3.11 Yield

4.3.11.1 Aberdeen (Sandy silt loam)

Table 4.28 shows yield data for 2009 and 2010; two different cereal crops were grown firstly spring barley and secondly spring oats. Hence the yield between the two years cannot be compared. Comparisons will be drawn according to management and tillage regime. The yields for ploughed treatments were up to 13 % lower for the organically managed land compared to conventionally managed land. This corresponds with research by Mäder *et al.* (2007) who found on average yield was 23 % lower on organic farms which can be attributed to lower availability of nutrients.

For the cropping year 2009, the organically managed land (3.99 t) has a lower average yield compared to the conventionally managed land (5.86 t). The ploughed treatments in both organic and conventional have the highest yield. The lowest yields were from the reduced tillage treatments especially in the organically managed land. The difference between tillage treatments on the conventionally managed land is reduced; this is due to more readily available nitrogen early season due to the fertiliser input, as well as some weed control (herbicides) reducing the ryegrass. The organic treatment of ploughing and undersowing was aimed at helping build fertility through N fixation; which should boost yield in the subsequent years. However, it appears to have no effect in the short-term.

In 2010, the organically managed land (2.54 t) has a lower average yield compared to the conventionally managed land (5.36 t). The highest yields were in the ploughed treatments both for organic and conventional management. The lowest yield was for the organic reduced tillage treatments. The plough and undersown treatment did not provide a boost in yield through N fixation; this is due to poor establishment of the clover during 2009 which reduced the amount of N carryover.

Table 4.28: The effect of tillage treatment, management and sampling timings on crop yield (t) in Aberdeen. Different letters are significantly different ($p < 0.05$). No comparisons can be made between the two cropping seasons.

Year	Organic				Conventional		
	Plough	Plough and undersow	Reduced tillage (disc)	Reduced tillage (rotavator)	Plough	Reduced tillage (disc)	Reduced tillage (rotavator)
2009 Spring Barley	5.66^{a}	5.85^{a}	3.77^{b}	2.54^{c}	6.54^{e}	5.17^{f}	5.95^{f}
2010 Spring Oats	4.23^{a}	3.09^{b}	1.07^{c}	2.34^{d}	6.65^{e}	5.17^{f}	4.28^{g}

Figure 4.45 shows the different tillage treatments for both the organic and conventional fields during crop growth. There were several weed issues in the organic field namely charlock, which is a persistent weed and can remain dormant for up to 10 years. There was also a problem with ryegrass which was more prevalent in the reduced tillage rotavator plots compared to reduced tillage and disc and ploughed plots. There was no issue of ryegrass in the conventional plots; this is due to a combination of factors firstly the field was top-dressed with fertiliser soon after sowing ensuring a fast growth of barley. Secondly, an herbicide (Pennant and Optica) was applied which would have had an effect in reducing the ryegrass problem.

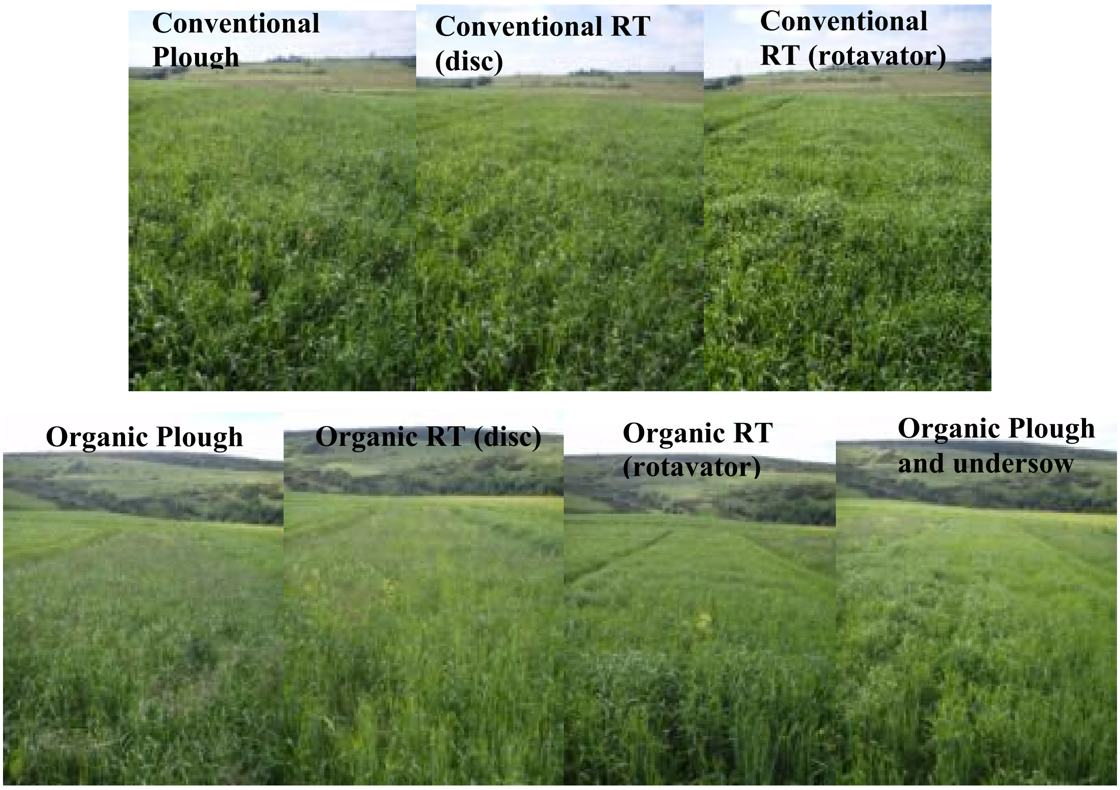


Figure 4.45: Photographs of each of the tillage treatments in 2009 on both organic and conventional land during crop growth at the Aberdeen site. RT = reduced tillage (Photographs with permission of Walker, 2011).

4.3.11.2 East Grinstead (Clay loam)

Table 4.29 shows the yield data for 2009 and 2010; it was not possible to compare yields between the two years because different crops were grown. It was also not possible to compare between organic and conventional management as there was a difference in spring and winter cereals being grown. Planting times can make a significant difference to yields with winter cereals usually having a higher yield than spring ones (Nix, 2010). However, organic farmers tend to favour spring cereals to help reduce competition of the crop with weeds (Vakali *et al.*, 2011). There was an issue with weeds; namely thistles which were prevalent in the organic fields although additional topping was performed to help reduce their numbers. There was no issue of weeds in the conventional field this was due to application of herbicides (Optica).

For the 2009 crop, the highest yields for both organic and conventionally managed land were from the ploughed treatments. The lowest yields were from the minimum treatment which reduced yields by up to 11 % compared to the organically managed ploughed treatment. This could be due to the novel Ecodyn equipment which did not produce a good seed bed and hence establishment of the crop was poor. Also cereals require high N during spring and Berner *et al.* (2008) determined that minimum tillage systems release N through mineralisation later than ploughing, which can reduce plant growth. In 2010, the highest yields were in the ploughed treatments both for organic and conventional management. For the conventionally managed ploughed treatment, the yield was 43 % higher compared to conventionally managed minimum tillage treatment. The lowest yield was for the organic minimum tillage treatment; this could be related to later availability of N, compaction and the weed issues.

Table 4.29: Tillage treatment, management and sampling timings for yield (t) in East Grinstead. Different letters are significantly different ($p < 0.05$). It is not possible to calculate a yearly mean as spring wheat was grown in the organic field and winter wheat was grown in the conventional field.

Year	Organic (Spring wheat)		Conventional (Winter wheat)	
	Plough	Minimum Tillage	Plough	Minimum Tillage
2009	4.5^{a}	4.0^{a}	8.35^{b}	4.75^{c}
2010	4.26^{a}	3.4^{a}	7.50^{b}	5.21^{c}

4.3.11.3 Huntingdon (Clay)

Table 4.30 shows the yield data for 2009. The highest yields for both organically and conventionally managed land were from the ploughed treatments. Changing tillage regime to reduced tillage (disc) reduces yield by 25 % and 16 % for organically and conventionally managed land respectively. This corresponds to the research by Mäder *et al.* (2007); however there were issues establishing the conventional crop as the first wheat failed. This was due to compaction as the soil texture is clay (Evesham series). There was an issue of black grass on both the organic and conventional land; however it was controlled through the use of herbicides (Pennant) on the conventional land. The lowest yields were from the reduced tillage treatments; this could be related to a lower release of N (Berner *et al.*, 2008) and compaction issues. Tillage intensity did not seem to have an impact on weed presence on the organic or conventionally managed land for a clay soil.

Table 4.30: Tillage treatment, management and sampling timings for yield (t) in Huntingdon. Different letters are significantly different ($p < 0.05$). It is not possible to calculate a yearly mean as different crops were grown in organic and conventionally managed land.

Year	Organic - Spring wheat			Conventional – Winter wheat		
	Plough	Reduced tillage (disc)	Direct drill	Plough	Reduced tillage (disc)	Direct drill
2009	4.26[a]	3.16[b]	1.66[c]	7.26[d]	6.11[e]	6.60[e]

4.3.11.4 Comparative Summary

Overall, whilst for two out of the three sites, it was not possible to compare the two different management systems; it was possible to compare tillage regimes. At Aberdeen, where the same crops were grown in both the organically and conventionally managed land, the yields were lower by 13 % on organically managed land. There was a universal trend across all three soil textures; that as tillage intensity increases yield also increases. Therefore, reducing tillage (minimum tillage / direct drill / reduced tillage disc) can lower the yield by up to 43 % depending upon soil type and land management (organic or conventional).

4.4 Summary of Results and Discussion

The results summarised in Table 4.31 show that a number of significant effects in soil properties could be determined due to management (organic / conventional), tillage regime (reduced tillage / plough), time, and soil texture. This research aimed to address the finding from the field scale study (Chapter 3), that there were no significant differences in soil properties due to organic farming in arable fields. This was further explored through the interactions of tillage regimes with soil properties on organic and conventionally managed land for three soil textures over time. The soil properties which were measured indicate overall soil physical health and its ease of workability (plastic limit, shear strength, bulk density, field capacity, total porosity, pH, Total C:N and workability index). The other soil properties which were measured align with ecosystem services (Costanza *et al.*, 1997): namely the sequestration of SOC and water regulation / disturbance regulation (water holding capacity and infiltration rate). These ideas will be further developed in the integrated discussion (Chapter 6).

The results from the plot scale study (Chapter 4) will be compared with the field scale study (Chapter 3). In the field scale study there was no significant difference between organically and conventionally managed arable land for any of the properties measured. The properties measured had the resolution to show differences due to soil texture and land management. Therefore, it was thought that a range of tillage practices could be masking any effect in the arable fields due to conventional / organic management. In the field scale study, there were some issues over proximity of sampled fields as ideally matched pairs would have been in immediately adjacent fields to ensure climatic and soil variation were minimised. However, this was not possible for either the fields in the field scale or plot scale studies. The distance between fields, in the plot scale study, with the exception of East Grinstead (1500 m apart), was lower than the field study (average 995 m apart). Therefore, when the farms were matched according to topsoil texture; differences between land management (organic and conventional) were shown. The differences shown in Table 4.31 reveal interactions between land management (conventional or organic), tillage intensity (plough or reduced tillage) and duration of the study (two year) all of which vary with soil texture. Therefore, it would be possible to reject the null hypothesis established earlier that 'organic farming does not influence soil properties on arable fields or tillage regimes, time and texture over time.'

Overall, there was no trend to suggest that organically managed land has a higher SOC content. There are variations in soil texture, the sandy silt loam shows conventionally managed land had a higher SOC content (44.82 g kg^{-1}) whereas the clay loam shows organically managed land had a higher SOC content (15.29 g kg^{-1}) and the clay shows no significant difference. This can also be related to the length of time each of the farms have been managed organically, there was no significant difference on clay soils where the land has been managed organically for the shortest period of time (eight years). The farm which was managed organically for the longest period of time (fifty years) was the clay loam and here a significant difference for SOC in favour of organic management is found. This was because management factors which are thought to differentiate between organic and conventionally managed land are frequent applications of FYM and grass leys in arable rotations (Armstrong Brown, 2000). These practices help to encourage a build up of SOC. In this short duration study, depending on the soil texture, reduced tillage improved SOC content by 5 % compared to traditional plough. This could be due to a reduction in disturbance of topsoil in reduced tillage which can lower mineralisation of SOC allowing it to build up. It is important to note that whilst differences in SOC can be identified in the short-term; the overall balance of SOC is affected by complex interactions between current and past land use and management.

Whilst, it was not possible to compare organically managed and conventionally managed land in terms of yield for all of the sites; it was possible in Aberdeen (sandy silt loam) where the same crops were grown. Organically managed land had a significantly lower yield between 32 – 52 % depending on crop type compared to conventionally managed land, which agrees with research by Mäder *et al.* (2007). It was possible to see an effect due to tillage regimes, which is uniform across all sites (soil textures) and management (organic and conventional), reduced tillage lowers yield in the short-term by up to 27 %. This agrees with the findings of Carter (1994) who determined that the benefits of reduced tillage systems are not felt in the short-term.

Generally, the following soil properties: plastic limit, bulk density, field capacity, total porosity, pH and total C:N were not significantly different between organically and conventionally managed soils. However, there were exceptions to this, which can be attributed to different soil textures. Soil physical properties are difficult to alter in the short-term as most are related to inherent soil textural properties and whilst the organic management was medium to long term, there was no overall difference. The clay loam soil field capacity was higher under organically managed soil. This, therefore, has implications for the soil workability, whereby the clay loam soil exhibited improved workability for organically managed soils. No differences in workability between organically and conventionally managed soils were shown in the other soil textures. Improving workability of soil under organic management in the clay loam is important due to changing climatic conditions such as wetter winters (Cooper *et al.*, 1997) which would potentially reduce the number of work days. There were no significant differences between these properties for tillage regimes or changes over time in this short duration study. This is because changes in soil structure can take years to improve (Carter, 1994) and this was a short duration (two year) study.

Overall, the following soil properties: shear strength, aggregate stability and maximum water holding capacity were significantly different between organically and conventionally managed soils. These effects vary with soil texture. The shear strength is higher for organically managed soils in both the sandy silt loam (64.44 kPa) and clay loam (87.71 kPa) and there was no significant difference for the clay soil. This is beneficial especially for improving soil workability during times when vehicle access is required to the land as this would help prevent compaction. However, there may be an issue during seedbed establishment as higher shear strengths can reduce the ease of penetration of roots which could decrease crop yields. Tillage regime has a significant effect on soil shear strength; reducing tillage intensity increases the shear strength by up to 29 % depending upon soil texture. This is due to the formation of a good soil structure which is not disturbed as in traditional ploughing.

The aggregate stability was higher for organically managed soils in sandy silt loam (46.00 %) showing a lower value in the clay soil (47.95 %) and no significant difference in the clay loam soil. This would have implications on potential soil erosion especially in the sandy silt loam where higher aggregate stability could reduce the likelihood of soil surface capping and improve workability and infiltration rates. The reduced tillage regime can improve aggregate stability by up to 8 % depending on soil texture; due to a reduction in disturbance (through tillage) allowing a build up of SOC and increasing microbial activity binding the aggregates (Tisdale and Oades, 1982). The clay soils showed the highest aggregate stability compared to the sandy silt loam as would be expected. There was an overall increase in aggregate stability with time for both sandy silt loam and clay soils but there is no significant difference for clay loam soil. The maximum water holding capacity is significantly higher for organically managed soils across all three soil textures. There was also an improvement which can be attributed to reduced tillage systems. There was no detectable difference in total porosity, as the soil cores taken were large enough to account for improvements in macroporosity. It is thought that improvements to soil structure and formation of continuous pores, particularly macropores, are felt under organic management. This is due to increasing grass / clover leys in the rotation and the benefits are twofold; to increase fertility and improve the structure and porosity of soils.

The infiltration rates were higher for organically managed soils compared to conventionally managed soils for both the sandy silt loam (10.32 mm hr^{-1}) and clay loam (3.02 mm hr^{-1}). There was no significant difference between land management for the clay soil. This would suggest that heavier (clay soils) are less likely to show differences between land management. The higher infiltration rates for organically managed land correlate with improvements in maximum water holding capacity. This is important with the recent changes in rainfall patterns with more extreme storm events; as organically managed fields would have the opportunity to both infiltrate water quicker but also to store more water. This would therefore reduce runoff and potentially flooding which would be beneficial to farmers and society. This result, in conjunction with the findings in the field scale study show that organically managed grassland has an improved infiltration rate compared to conventionally managed grassland. This has implications for runoff and flooding at the catchment scale which is developed further in the catchment modelling (Chapter 5).

There were differences in infiltration rates which could be attributed to soil texture, with the sandy silt loam having the highest infiltration rate compared to the other two textures. This can be related to the higher proportion of SOC (due to differences in climatic conditions in Aberdeen, Towers *et al*., 2006) and the natural more porous texture and structure of sandy silt loams compared to the other two soil textures. There were also differences that could be attributed to tillage regime, with the ploughed system having the highest infiltration rates up to 41 % higher depending upon soil texture. This disagrees with research by Abid and Lal (2008b) who found that reducing tillage intensity improved infiltration rates due to improvements in pore continuity. It is thought that in this two year study, the effects of pore continuity and higher numbers of macropores were not shown in the different tillage regimes. Therefore ploughing which disturbs soil structure and reduces compaction is more influential on infiltration rates in the short-term.

Table 4.31: Descriptive summary of the main findings for each property measured in terms of management, time, tillage treatment and soil texture.

KEY: SSL = sandy silt loam, CL = clay loam, C = clay, RT = reduced tillage and PL = plough, ↑ = increased, N.S. = not significant

Property	Management (Org/ Con)	Time (over the cropping season)	Tillage Treatment	Soil Texture
SOC	**No universal trend** SSL ↑ Con 44.82 g kg^{-1} CL ↑ Org 15.29 g kg^{-1} C N.S.	SSL and CL ↑ over time CL N.S.	RT ↑ (up to 5%)	↑ SSL 40.96 g kg^{-1} C 17.47 g kg^{-1} CL 11.21 g kg^{-1}
Field Capacity	**No universal trend** SSL N.S. CL ↑ Org C N.S.	N.S.	N.S	N / A
Maximum Water Holding Capacity	**Organic is higher** SSL ↑ Org 58.51 % CL ↑ Org 44.77 % C↑ Org 56.61 %	N.S.	RT ↑	N / A
Aggregate Stability	**No universal trend** SSL ↑ Org 46.00% C ↑ Con 68.72 % CL N.S.	SSL and C ↑ over time CL opposite trend	RT ↑ (up to 8 %)	↑ C 57.45 % CL 53.25 % SSL 40.94 %
Plastic Limit	**No universal trend** SSL N.S C and CL N.S.	CL ↑ over time SSL and C opposite trend	RT ↑ C and CL PL ↑ SSL	↑ C 401.54 g kg^{-1} CL 399.85 g kg^{-1} SSL 257.65 g kg^{-1}
Shear Strength	**No universal trend** SSL ↑ Org 64.44 kPa C ↑ Org 83.71 kPa CL N.S.	Cyclic ↑ following harvest and reducing post tillage	RT ↑ (up to 29 %)	↑ CL 103.66 kPa C 88.22 kPa SSL 55.45 kPa
Bulk Density	**No universal trend** SSL N.S CL ↑ Con 1.32 g cm^{-3} C N.S.	↑ over time	N.S.	N.S.

Property	Management (Org/ Con)	Time (over the cropping season)	Tillage Treatment	Soil Texture
Total Porosity	**No universal trend** SSL N.S CL ↑ Org C N.S.	N.S.	N.S.	N.S.
pH	**No universal trend** SSL ↑ Con 6.44 CL ↑ Con 6.75 C N.S.	No trend	No trend	↑ C 6.61 CL 6.59 SSL 6.19
Total C:N Ratio	**No universal trend** SSL ↑ Con 13.83 C and CL N.S.	SSL and C ↑ overtime C N.S.	No trend	↑ SSL 13.31 CL 10.22 C 9.43
Infiltration Rate	**No universal trend** SSL ↑ Org 10.32 mm hr^{-1} CL ↑ Org 3.02 mm hr^{-1} C N.S.	↑ post tillage	↑ PL (up to 41 %)	↑ SSL 8.94 mm hr^{-1} C 1.7 mm hr^{-1} CL 3.5 mm hr^{-1}
Workability (Mueller / Boekel)	**No universal trend** CL ↑ Org	Not applicable	N.S.	**Reverse trend with Boekel** ↑ workability SSL CL C – not workable
Yield (cereal)	**Con is always higher** SSL ↑ Con 5.88 t Not applicable for CL and C	Not applicable	**Ploughed is always higher** ↑ Con PL 7.38 t	Not applicable

4.5 Conclusions

In contrast to the field scale study, the plot scale study was able to detect differences between organically and conventionally managed arable land. This was due to better control of topsoil textures (ensuring similarity) on both organically and conventionally managed soils. The main conclusions which can be drawn from the plot scale study are as follows:

- Organic management can have a benefit in arable fields for a number of soil physical propertied. Differences in soil properties vary with soil texture and any differences are not always in the same direction. There was a spatial climatic effect of soil texture on soil properties especially for SOC. Therefore care was taken when comparing between different soil textures to account for any abnormalities in soil properties due to spatial differences.
    - For soil physical and hydrological properties (maximum water holding capacity, aggregate stability, shear strength, infiltration rate) organically managed soil has an improved soil quality. There was no significant difference for bulk density, field capacity, plastic limit or total porosity which could be due to the short duration of the study.
    - For soil chemical properties (pH, total C:N ratio and SOC) there was no overall trend to show that organically managed land improves soil quality. SOC presented a cyclic trend over the cropping season which was present in both organic and conventionally managed land.
    - For soil workability and crop yield there was no overall significant benefit from managing the land organically for all three soil textures. For example, in East Grinstead (clay loam) there was an improvement in workability during autumn for the organically managed soil; this was the only soil where a difference between management was found and this can be attributed to the length of time the land was managed organically (50 years). In Aberdeen (the only site with the same crop in both organic and conventional management), crop yields were reduced for organically managed land corresponding with Mäder *et al.* (2007).
- Tillage regimes, whether reduced or traditionally ploughed, make a difference to soil quality. The difference was not always in the same direction for each of the soil properties measured.

    - There was a benefit for reduced tillage for: SOC, maximum water holding capacity, plastic limits and shear strength. However, the level of improvement varies with soil texture.
    - There was a benefit for ploughed treatments for: yield and infiltration rates. However, it is important to note that the heavier (clay) the soil texture the less likely the tillage regime makes a significant difference. Also there was an implication due to the duration of this research, that the benefits of reduced tillage are not felt in the short-term.
- Infiltration rates on organically managed were higher or equal to conventionally managed arable land. This could be related to the significant improvement in maximum water holding capacity for organically managed soils. Pores are likely to become more continuous and connected providing a better soil structure which would improve infiltration rates. This has implications for flood prevention; whereby if prior to a rainstorm fields were held at field capacity, there would be increased storage for water under organic management. Higher infiltration rates would also help to reduce runoff rates and this is modelled in further detail in Chapter 5.

5 Catchment modelling of organic farming and flood mitigation

5.1 Background

The incidence of flooding worldwide has increased considerably (Figure 5.1) and it has the potential to cause wide scale damage affecting a large number of people. In the UK, the flood events tend to be smaller scale, due to size of the rivers, but they are still devastating to the communities affected (Wheater, 2006). Currently, five million people in the UK live in 'at risk' areas, and it is expected to rise within both increasing population and larger number of homes built in areas at risk from flooding. In recent years, the number of flood events has dramatically increased with significant floods recorded in 1998, 2000, 2004, 2005, 2007, 2009 and 2010.

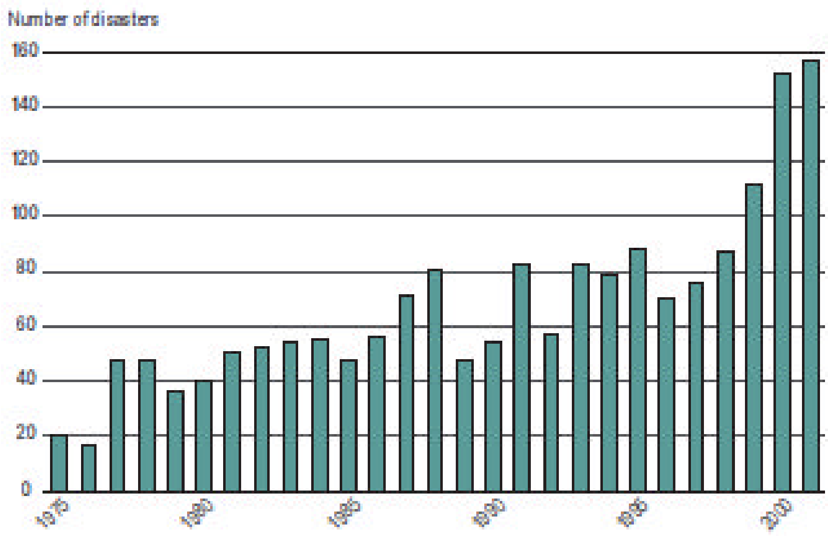


Figure 5.1: Number of flood related disasters worldwide from 1975-2001 (Source: Centre for research on epidemiology of disasters, CRED, 2002 University of Louvain, Belgium).

In 2007, June was one of the wettest months with some areas of the UK receiving an entire month's precipitation in 24 hours (Figure 5.2). The flooding was widespread over several counties and damaged thousands of homes, with 600 people being displaced in Oxfordshire alone (Environment Agency (EA), 2007). It is estimated by the Association of British Insurers that the total insurance damage bill for the 2007 floods was £3 billion. In January 2005, Carlisle received 164 mm of precipitation (in excess of one month's worth) in 24 hours which caused devastation to 2000 properties and over £450 million worth of damage. These flash floods are difficult to predict and the damage can be very widespread not only to individual properties but to infrastructure and services as well (Wheater, 2006).

Figure 5.2: Flooding in an Oxfordshire street (Courtesy of A. Davies, 2007).

In the UK, changing climate to wetter winters and drier summers combined with land use change, are thought to be the major contributors to increased flooding (Godwin and Dresser, 2003). Land management change due to economic pressures, such as differing cropping patterns, increasing untimely soil cultivation and heavier machine especially in arable land, can be detrimental to soil structure. Holman *et al.* (2002) reviewed the condition of UK soils and revealed many were suffering from substantial degradation. In grassland, changes in grazing patterns such as maintaining stock on land over the winter, increasing stock density and increasing weight of stock can also lead to damage of soil structure (Hathaway-Jenkins *et al*, 2011).

The local scale effects of land management practice are complex and depend on soil type, land use, location and timing of access to land by machinery and animals (Wheater, 2006). If the land management practices are over a sufficient spatial extent; a significant change in the peak runoff and catchment hydrology can occur. The effects of environmental change due to more subtle agricultural practices, such as improved grassland management practices including conversion to organic management, remain unquantifiable at present. Any potential improvements due to changing practices that might prevent local scale effects on soil degradation and 'muddy' floods from agricultural land; could be used to decrease runoff generation and downstream flood risk. It is important to use a suitable model to see the impacts of land use and management at the catchment scale. This chapter is fulfilling objectives three and four outlined in the introduction (Chapter 1). It aims to investigate how changing land management to organic management at the catchment scale can influence peak runoff rates and flood frequency. It will quantify the effects on flood return periods both economically through the use of insurance replacement costs and environmentally through an ecosystems approach.

This chapter will address this issue by applying the USDA SCS model to hypothetical scenarios involving different land use and management. The modelled scenarios were formed from actual measured data from the field studies outlined in Chapter 4. Finally, the potential costs to the farmer of changing land management techniques and the advantages to wider society will be outlined through cost benefit analysis.

5.2 Runoff Estimation

5.2.1 Introduction

5.2.1.1 Pilot Study

It was shown in Chapter 3 that both land use (arable/ grassland) and management (organic/ conventional) have a significant effect on the infiltration rate. This information is shown in Figure 5.3; the predicted runoff was calculated assuming that if the rainfall does not infiltrate then it will generate runoff.

Runoff = Total Rainfall – Infiltration **Equation 5.1**

When comparing the *infield* measured infiltration rate with the potential amount of runoff for a 1 year return period storm 20 mm hr^{-1} (Nerc, 1975); there is potential for a reduction in runoff under organically managed grass land by 500 m^3 ha^{-1} compared to conventionally managed grass land (Figure 5.3).

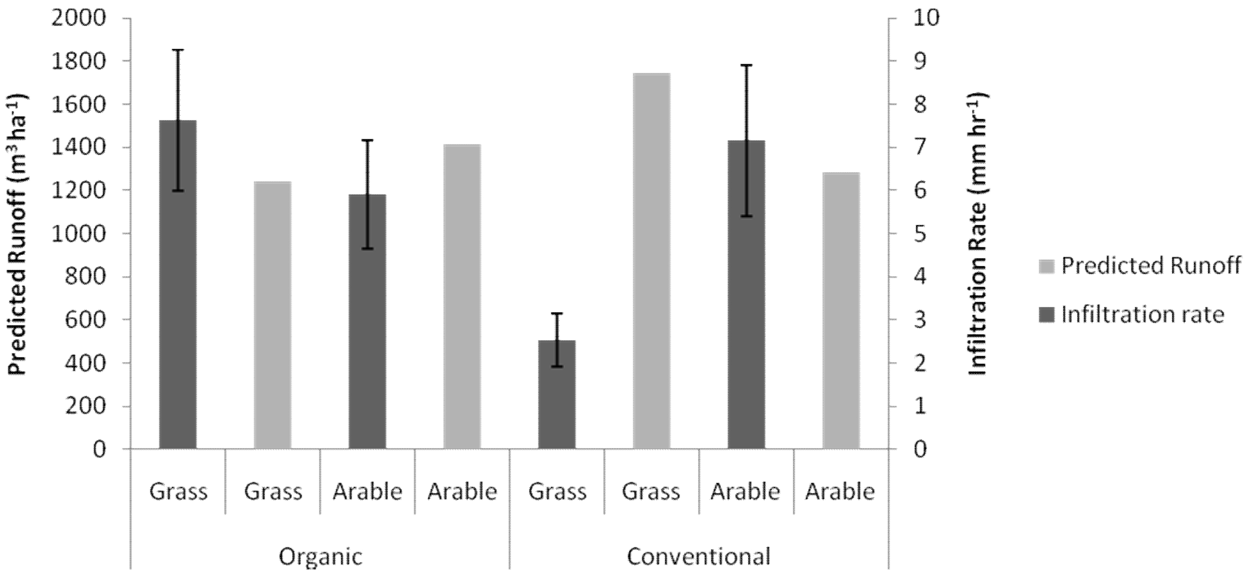


Figure 5.3: A comparison of the mean infiltration rates between organic and conventional management for grass and arable land use. Also shown are the LSD values for infiltration rates at 0.95 and the predicted runoff from 20 mm hr^{-1} rainfall event (1 year return period) (Nerc, 1975).

Cooper *et al.* (1997) suggest that the UK climate is likely to experience wetter winters and warmer summers. Figure 5.3 shows the relationship between infiltration and predicted runoff; increasing precipitation upon poorly structured soils could reduce infiltration rates and increase predicted runoff. The effects of different land use and management are also shown, where higher infiltration rates are shown under organic grass management compared to conventional management. Hence, there could be a major impact upon the amount of runoff and flood generation downstream especially with changing land use management and climatic conditions. However, this crude attempt does not account for previous conditions in the catchment, evapotranspiration or land use. Therefore, in order to investigate this in more detail several alternative methods will be reviewed before highlighting the model which is most appropriate.

5.2.1.2 Possible Models

There have been many different attempts to derive empirical models of the rainfall runoff relationship (Beven, 2001). There are well in excess of 100 different models being used worldwide to determine this relationship. O'Connell *et al.* (2007) propose a five step procedure to model changes in land use and management. The first step addresses this issue of deciding on a suitable model and the next steps are as follows:

1. Select an appropriate model
2. Calibrate the model and run simulations of the catchment prior to change
3. Alter the parameters to reflect the change
4. Estimate the effect of change on runoff
5. Estimate the uncertainty bounds (validity) and state the level of reliability

Therefore, following this five stage procedure some alternative models will be discussed before highlighting the model used for analysis of land use change. Only four different models are shown as these are models which have previously been used in the UK and were found to be valid for the UK environment.

The **ADAS method** (1983) was developed initially as a simple handbook for drain flow calculations. ADAS adapted these calculations using subjective assumptions to predict peak flood flows from natural catchments. It is calculated through Equation 5.2.

$$\mathbf{Q_0 = S_T \times F \times A} \qquad \textbf{Equation 5.2}$$

(Where Q_0 = peak flood flow, S_T = soil type factor, F = catchment characteristics, A =area ha)

This model requires the input of length and slope data from the catchment which is integrated through a nomograph (show numerical relationships between three coplanar variables) and other data tables. This method is satisfactory for predicting surface runoff from small agricultural catchments (not bigger than 30 ha). Comparisons of different runoff models by Godwin and Dresser (2003) revealed that the ADAS method can significantly underestimate the peak runoff. Therefore, due to the catchment size being greater than 30 ha and the issues of underestimation of runoff this method was not used in this investigation.

The **HOST** classification is described by Boorman *et al.* (1995), this classifies UK soils into 29 different classes. These classes are based upon differences in soil physical properties which are correlated with hydrological variables at the catchment scale for base flow index (BFI) and standard percentage runoff (SPR). Holman *et al.* (2003) estimated how soil degradation would affect HOST classification and more specifically the SPR. From the data in the field scale study (Chapter 3) it is possible to see that this model can predict the effects of soil degradation showing an increase in SPR and possible change to the HOST classification. However, this model requires an experienced soil surveyor in the field to classify the soil and determine degradation, which was not available. This model also was deemed not to give enough detailed data on specific land use management which can lead to differences in soil structure. Hence, this model was not used as it does not have the resolution to highlight differences between organic and conventional management.

The Soil and Water Assessment Tool **(SWAT)** was developed in the USA by Arnold *et al*. (1998) it incorporates hydrology, sedimentation, soil temperature, crop growth, nutrients, pesticides and agricultural management. It uses routing algorithms to consider attenuation of flow within a catchment. It was developed to quantify the impact of land management practices in large, complex watersheds. According to Gassman *et al.* (2007) this model is very informative and has been proven to be robust both in the USA and throughout Europe (with a slight adaptation to the model). However, this model requires very detailed information; such as weather, hydrology, soil temperature and properties and plant growth, nutrients, and is not suitable for hypothetical catchments where this data is not available.

The Catchment Resources and Soil Hydrology (**CRASH**) model (Maréchal and Holman, 2005) is a UK based, daily, catchment-scale, rainfall-runoff model. This model links together HOST and rainfall data allowing derivation of infiltration and excess surface runoff. The benefit of this model is that it is specifically developed and calibrated for UK soil based on the soil surveys of England and Wales. The model is still being developed and tested. It was not used in this research as it requires too much detailed data regarding stream flow which is not available for the hypothetical scenarios presented in this chapter.

The United States Department for Agriculture Soil Conservation Service (USDA SCS) Method for runoff estimation was chosen and run for this investigation. More details about this model can be found in the methodology section. The model was run according to 'typical' conditions found in the field scale and plot scale studies. Several different land cover options and soil management methods were explored and the results are presented for a catchment similar in characteristics to the Parrett Catchment in Dorset and Somerset as reported in Godwin and Dresser (2003). This model was chosen because data were available and it has been used successfully in the UK both by Hess *et al.* (2010) and Godwin and Dresser (2003), who found that it was accurate to within 2.5 % for the Parrett Catchment.

5.2.1.3 Rainfall and runoff relationship to potential flooding

There is a need to improve water storage capacity on some of the land within catchments; to help reduce water runoff. This may not be able to be over the whole catchment, as some areas could have been permanently degraded by surface sealing through urbanisation. The major area that can be improved is agricultural land which can be improved through changes in soil management practices. Holman *et al*. (2002) identified a number of UK agricultural fields as suffering from structurally damaged soils with unnaturally low infiltration capacities which significantly increased the chance of overland flow and flood potential. Schwab *et al.* (1996) suggested that there were three major ways to alleviate these problems on agricultural land:

1. Soil should not remain saturated at peak rainfall event times
2. Reduce soil surface caps and subsoil pans to increase the amount of infiltration
3. Increase the amount of surface depressional storage

As rainfall patterns change through climatic factors affecting intensity, duration and frequency the outputs from hydrological modelling are valuable. They can help to determine the effect of organic farming and other improved soil management processes at the landscape and catchment levels in helping to alleviate the flood risk.

5.2.2 Methodology

During the *infield* infiltration measurements differences were detected between organic and conventional grass and arable land uses, hence the SCS model was initially used for a catchment comprising totally of grass land and then one comprising totally of arable land before modelling other hypothetical catchments. Firstly, this section contains an introduction to the SCS model followed by the model parameters and data inputs for the scenarios chosen.

5.2.2.1 Background to Soil Conservation Service (SCS) Model

The USDA SCS Curve number (CN) method was developed for uniform rainfall and it is limited in accuracy to watersheds of less than 800 ha with slopes greater than 0.5° (USDA, 1973). This model relates antecedent rainfall (Table 5.1), drainage status and optimum soil moisture conditions to predict runoff within the catchment. It incorporates land use and hydrologic soil group (Table 5.2) through chosen N factors; where N = 100 there is no infiltration and all the rainfall runs off. Where there is infiltration the N factor is reduced depending upon whether the land use is fallow, arable, grass or woodland (typically N factors of 90 to 60) although values as low as 25 represent ideal infiltration conditions in woodland (Godwin and Dresser, 2003).

Table 5.1: Antecedent rainfall conditions and curve numbers (for Ia (initial abstraction) = 0.2S (maximum potential difference between rainfall and runoff) (USDA, 1973).

		5-Day Antecedent Rainfall (mm)	
Condition	**General Description**	**Dormant Season**	**Growing Season**
I	Optimum soil condition from about lower plastic limit to wilting point	< 13	< 36
II	Average Value for annual floods	13-28	36-53
III	Heavy rainfall or light rainfall and low temperatures within 5 days prior to the given storm	> 28	>53

Table 5.2: Hydrologic soil group description and infiltration rate (Godwin and Dresser 2003).

Soil Group	Description	Final Infiltration Rate (mm hr^{-1})
A	*Lowest Runoff Potential* – includes deep sands with very little silt and clay, also deep rapidly permeable loess.	8-12
B	*Moderately Low Runoff Potential* – mostly sandy soils less deep than A, and loess less deep or less aggregated than A, but the group as a whole has above-average infiltration after thorough wetting.	4-8
C	*Moderately High Runoff Potential* – comprises shallow soils and soils containing considerable clay and colloids, though less than those of group D. The group has below-average infiltration after pre-saturation.	1-4
D	*Highest Runoff Potential* – includes mostly clays of high swelling percent, but the group also includes some shallow soils, nearly impermeable sub-horizons near the surface.	0-1

In this case antecedent rainfall condition II (I = 0.2S) was used for each of the different scenarios and soil hydrological cover complexes as this is the average value for the annual floods. Therefore Table 5.3 was used for determining the N curve values.

Table 5.3: Runoff Curve (N) numbers for hydrological soil-cover complexes for antecedent rainfall condition II and I = 0.2S (Adapted from USDA, 1973).

			Hydrological Soil Group			
Land use	**Treatment**	**Condition**	**A**	**B**	**C**	**D**
Fallow	-	-	77	86	91	94
Row Crops	Straight Row	Good	72	81	88	91
Row Crops	Straight Row	Poor	67	78	85	89
Rotation Meadow	-	Good	66	77	85	89
Rotation Meadow	-	Poor	58	72	81	85
Pasture	-	Good	68	79	86	89
Pasture	-	Poor	49	69	79	84
Woodland		Good	25	55	70	77

From the *infield* measurements of infiltration rates, the soil group within the SCS model were determined using Table 5.2 and are given in Table 5.4.

Table 5.4: Infiltration rates and SCS soil group for each land use management combination.

Land use and Management	Infiltration Rate (mm hr^{-1})	SCS Soil Group
Organic Arable	5.9	B
Organic Grass	7.6	B
Conventional Arable	7.1	B
Conventional Grass	2.5	C

The relationship between runoff and rainfall is shown below in relation to their N curve number (Figure 5.4).

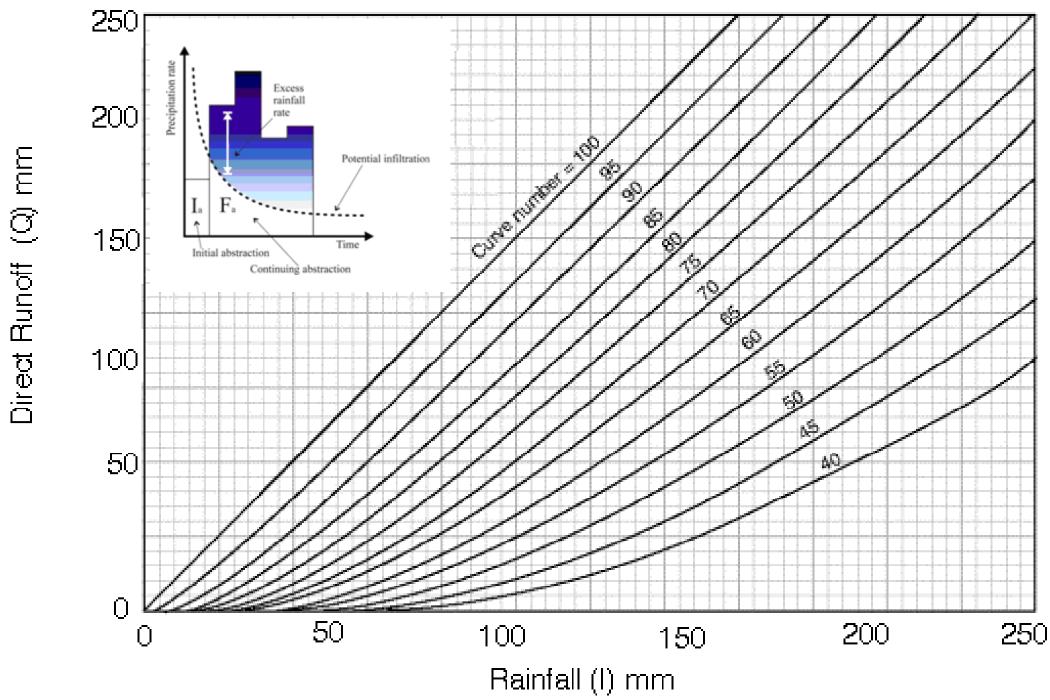


Figure 5.4: Relationship between rainfall and runoff depth by curve numbers (Godwin and Dresser, 2003).

The model requires the input of rainfall data for different return periods. It was decided to use the model for the rainfall data in the Midlands, South and South West England as given in Table 5.5 from Smith and Trafford (1976). It was also decided that the model would be run for short duration rainfall events; as this is most likely to cause minor floods and small scale events where changing land management may have a significant effect.

Table 5.5: Rainfall rates based on three different regions Midlands (Dry), South (Intermediate) and South West (Wet) adapted from Smith and Trafford (1976).

	Rainfall mm hr^{-1}		
Return Period	Dry	Medium	Wet
1 Year	33	45	64
2 Year	43	52	73
10 Year	56	66	87

5.2.2.2 Method of implementation of SCS Model

Step 1: Determine the catchment characteristics such as slope, size and land use.

Step 2: Choose the antecedent conditions (I, II, III) Table 5.1 and soil hydrological group (A, B, C, D) Table 5.2 and Table 5.4.

Step 3: Determine the runoff curve number (N) Table 5.3

Step 4: These inputs are combined through the following equation for the runoff rate (q):

$$q = q_u A Q \qquad \textbf{Equation 5.3}$$

Where q_u = unit peak flow rate ($m^3 s^{-1} ha^{-1} mm^{-1}$)

A = area of infiltration

Q = direct surface runoff

$$Q = \frac{(I - 0.2S)^2}{I + 0.8S} \qquad \textbf{Equation 5.4}$$

Where Q = direct surface runoff

I = storm rainfall

S = maximum potential difference between rainfall and runoff

$$I = 0.2\,S \qquad \textbf{Equation 5.5}$$

$$S = (25400 / N) - 254 \qquad \textbf{Equation 5.6}$$

The model also requires the calculation of the time of concentration (T_c) which is given by the following equation:

$$T_c = L^{0.8}\,[(1000 / N) - 9]^{0.7} / [4407\,(0.01)^{0.5}] \qquad \textbf{Equation 5.7}$$

Where: L = length of catchment and N = N curve number

$$I_a\text{: P Ratio} = I_a / P \qquad \textbf{Equation 5.8}$$

Where: I_a = initial abstraction and P = rainfall

Step 5: These two values are combined using Figure 5.5 to calculate the value for peak discharge (q_u) for the catchment and it is then converted in $m^3 s^{-1} ha^{-1}$.

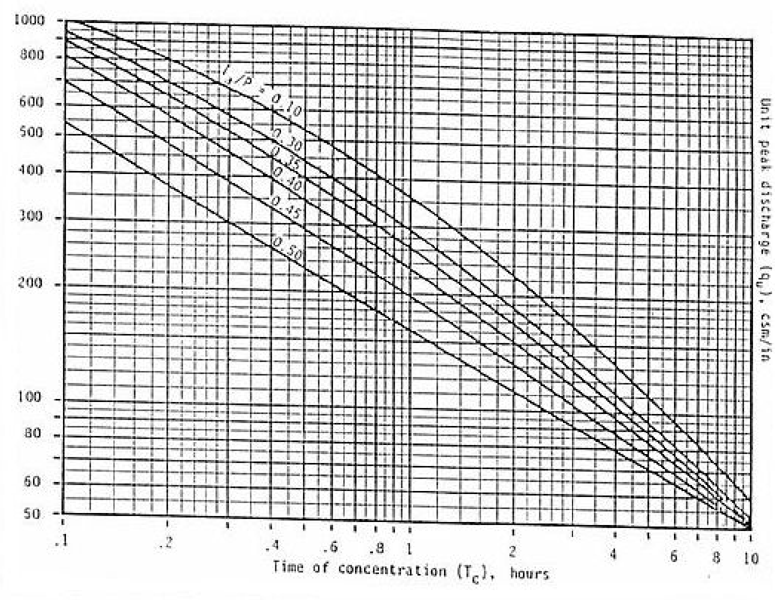


Figure 5.5: Unit peak discharge (q_u) for SCS Type II rainfall distribution (USDA, 1973).

5.2.2.3 Limitations of the Model

This is a simple conceptual method which is well supported by empirical data in the USA where it was developed. Therefore, the results should be interpreted with care when using it in the UK and bounded by the conditions and inputs to the model, shown in Table 5.6 for this study. The model allows for good management and poor management of soil conditions through changing the hydrological soil group. It is important to define these terms for better interpretation of data. According to Hess *et al.* (2010) ***poor management*** practices is defined as 'poor soil structure leading to enhanced runoff generation plus evidence of practices which increase runoff transmission; e.g. downslope tramlines, fine seed beds, large sloping fields, compaction caused by intensive livestock trampling or use of heavy machinery during wet conditions'. Hess *et al.* (2010) also define ***good management*** practices as 'good soil structure plus limited activities to reduce runoff transmission from the field e.g. contour ploughing.' However, this can be very difficult in the UK due to unfavourable topographical conditions and hence is seldom adopted in practice.

This model is difficult to validate in the field where more complex interactions in the factors which control runoff rates cannot be held constant so that solely the effects of land use can be measured (Hess *et al.*, 2010). This is a common problem with most of the modelling tools available (O'Connell *et al.*, 2007). Hess *et al.* (2010) stressed that this does not mean that there is no effect due to land management; or that effects shown in peak runoff at the catchment scale are incorrect.

5.2.2.4 Inputs to the Model

The following different land use scenarios using both poor and good management practice were then evaluated and the results presented.

1. Grassland only – highlighting further the differences between organic and conventional grassland (Figure 5.6)
2. Arable only – highlighting differences between organic and conventional management and tillage regimes (through measured soil conditions) (Figure 5.7)
3. Scenarios based on current landscape compositions for an organic landscape and conventional landscape (Norton *et al*., 2009) (Figure 5.8)
4. Future scenarios based upon an organic landscape and conventional landscape with all land in production either arable or grassland with the grassland being either organic or improved conventional grass land (Figure 5.9)

The size of the catchment (chosen as 550 ha), the total maximum rainfall (calculated for each of the values in Table 5.5) and antecedent moisture contents (average value for annual floods 13-28 mm) remained the same throughout the different scenarios. The hydrological conditions of the soil were adjusted from the conditions found in the 32 paired sites of field scale study (Chapter 3) that were measured to simulate degraded and improved soil conditions. Initially, catchment with 100 % grassland was explored to determine any changes between 100 % organic or conventional grassland using arable land as a comparison. All of the parameters required for the model are given in Table 5.6.

Table 5.6: Inputs and sources of data for SCS CN modelling.

Model Input Requirements	Source
Catchment characteristics – slope, size	0.5 ° slope, 550 ha (typical values Godwin and Dresser, 2003)
Antecedent rainfall conditions	Condition II (average value for annual floods)
Hydrological soil conditions	Group B and C depending on *in field* infiltration rates and Table 5.4
Rainfall Depth (mm)	Data from Smith and Trafford (1976) shown in Table 5.5
N curve number	Data in Table 5.3 based upon the land use and percentage of land use within the catchment
Direct Runoff (Q) (mm)	Figure 5.4 and rainfall depth and N curve number
Time to Concentration (T_c) (sec)	Catchment size and N curve number
Maximum potential difference between rainfall and runoff (S)	Equation 5.7 combining rainfall data and Direct Runoff (Q)
Initial Abstraction (I_a)	Equation 5.8
Unit peak discharge (qu)	Initial abstraction and time to concentration given in Figure 5.5

According to the Environment Agency (EA), the way in which land is used and managed can affect the extent and frequency of flooding at a local scale; which in turn can propagate downstream and contribute to flooding at the catchment scale (EA, 2009). Therefore, two different current landscape scenarios were explored:

1. Conventionally dominated landscape with 60% arable land, 25% grassland and 15% fallow land set-a-side (bare)
2. Organically dominated landscape with 45% arable land, 40% grassland and 15% fallow land set-a-side (bare)

The composition of the landscapes 1 and 2 above resulted from studies by Norton *et al.* (2009) following a survey of organic and conventional landscapes, where it was found that organic farms had a significantly higher proportion of grassland compared to a conventional landscape and this was reflected in the choice of land cover for each of the two scenarios. Set-a-side was included at 15 % of the total catchment, however, it should be noted that organic farming is now exempt from set-a-side rules.

A further two landscapes were also included in the modelling exercise. These was based upon a future projection where there is a need to increase the amount of land for crop production (both food and bio fuels); hence there is no fallow land.

a) Alternative landscape future scenario with 45 % organic arable land and 55 % organic grassland
b) Alternative landscape future scenario with 60 % organic arable land and 40 % organic grassland.

The results from using the model indicated that the total amount of projected runoff was the same for each scenario; hence only one alternative landscape is presented. For this scenario and soil condition both good and poor management practice effects for runoff were calculated to allow comparisons with the current conditions. The full calculations for each modelled scenario are shown in Appendix E.

5.3 Results and Discussion

5.3.1 Grassland Catchment Modelling

This section compares the differences between organic grass and conventional grass management. As shown in Figure 5.6, the total peak runoff for organic grass is always lower than conventional grass. For example, for the 1 in 1 year return period for the driest climatic region, the organic grass runoff rate is substantially lower (90 %) than conventional grass; reduced from 0.14 to 0.01 $m^3 s^{-1}$. The trend is the same regardless of the regional climatic situation whether dry, intermediate or wet. However, the reduction in runoff rate between organic and conventional grassland becomes larger with wetter climatic conditions.

The flood return period is also known as a recurrence interval and is an estimate of the interval of time between flood events of a certain intensity or size. It is a statistical measurement denoting the average recurrence interval over an extended period of time, and is usually required for risk management (FHRC, 2010). The graphs in Figure 5.6 help to determine the effects of changing land management on flood return periods. For example, if there was a 1 in 10 year storm in a dry climatic condition, then the conventional grassland would generate 0.75 $m^3 s^{-1}$ runoff. However, if this is converted into organic grassland this would reduce to 0.25 $m^3 s^{-1}$. This is a reduction in total runoff of 66 % which results in a much less severe equivalent return period of 1 in 1.5 year had the grass remained in conventional management. This is the same trend which occurs for the climatic conditions with a reduction in runoff in a 1 in 10 year return period shown in Table 5.7.

Table 5.7: The effect of changing practices from conventional grassland to organic grassland on flood return period. The values reflect the change from 1 in 10 year flood when managed organically.

Climatic Condition	Good Practices	Poor Practices
Dry	1 in 1.5	1 in 2
Intermediate	1 in 1	1in 1
Wet	1 in 1	1 in 1

This is supported by the work of Hess *et al* (2010) who modelled catchments in England and Wales based on the Environment Agency catchment sensitive farming areas. Hess *et al* (2010) found that the greatest relative reduction in runoff (up to 40% depending on land cover and soil class) can be achieved through the improvement of degraded permeable soils under managed grassland in drier regions.

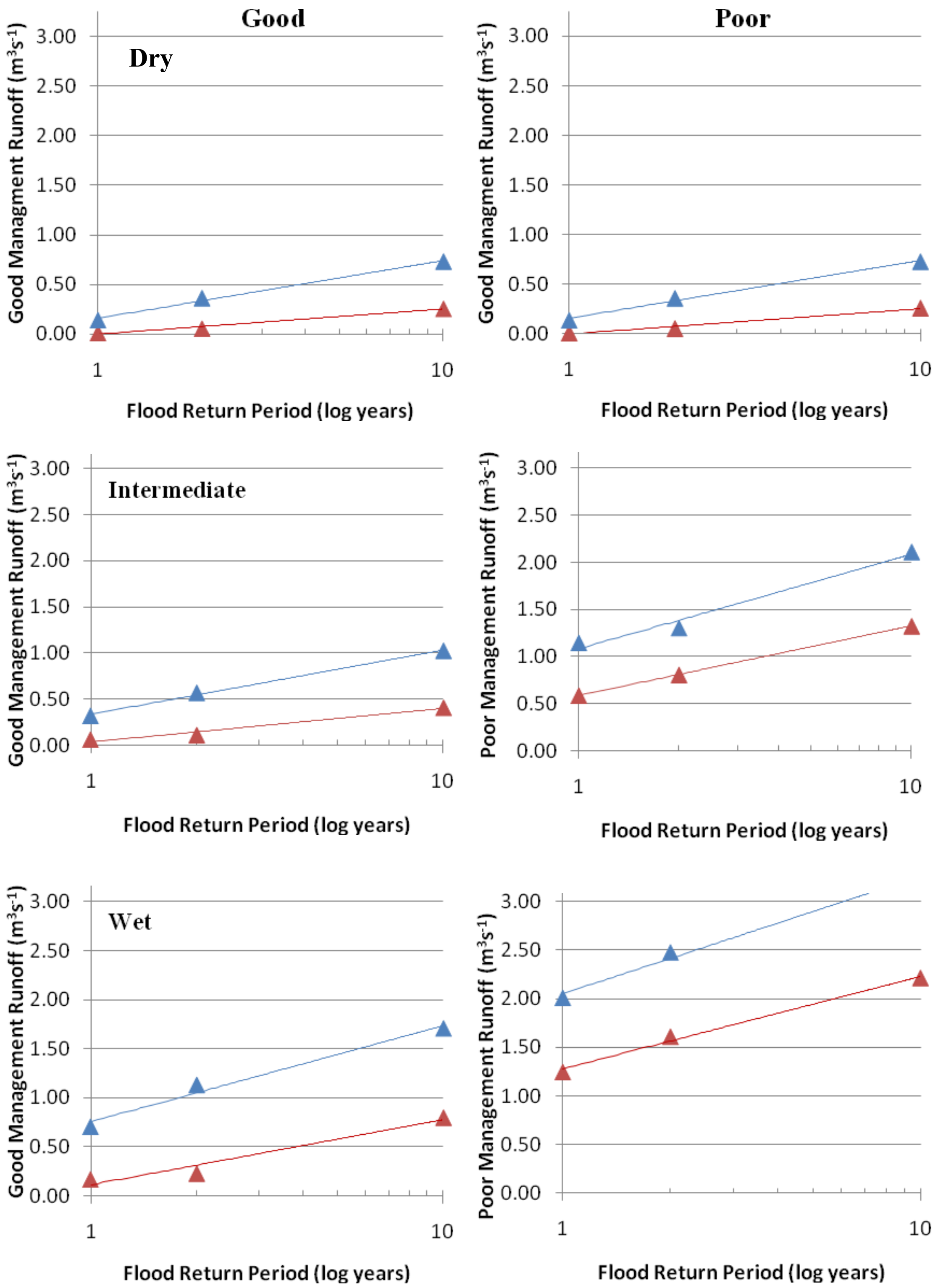


Figure 5.6: Flood return period and runoff rate for organic and conventional grass land use in the three different climatic regions for good (left) and poor (right) management in a 550 ha and 0.5° catchment. (Blue triangle represents conventional grass and red triangle represents organic grass).

5.3.2 Arable Catchment Modelling

In the arable only modelled scenario (Figure 5.7), the arable land use has a higher runoff rate compared to the grassland (Figure 5.6); with the exception of the wettest climatic conditions where arable has a lower runoff rate. However, when looking at only the grassland values in the model; it shows the same significant difference between organically managed and conventionally managed grass as determined through the *infield* measurements (field scale - Chapter 3). In the modelled scenario this was not the case, with the arable runoff being higher than organic grassland but not as high as the conventional grassland. Arable and organic grass are different due to the nature of cover which typically have relative N numbers of arable 81 and grass 79 for good soil conditions. The model inputs also deem that arable land has a higher runoff due to planting row crops where there are areas of bare soil where the infiltration would be reduced (Mishra and Singh, 2003). The model does not have a high enough resolution to pick out differences between the different tillage regimes (plot scale - Chapter 4), but it is able to show the differences between organic and conventional management.

Table 5.8: The effect of changing practices from conventional arable to organic arable on flood return period. The values reflect the change from 1 in 10 year flood when managed organically.

Climatic Condition	Good Practices	Poor Practices
Dry	1 in 3.5	1 in 5.5
Intermediate	1 in 2.5	1 in3.5
Wet	1 in 1.5	1 in 3.5

When taking the organic 1 in 10 year flood and converting this into the equivalent flood for conventional management; it is possible to see a reduction in flood return period (Table 5.8). This highlights a reduction in flood severity. This means that the more destructive floods such as the 1 in 10 year flood are reduced due to less runoff; and events which previously were more disruptive would no longer be classified as flooding. It is possible to see that climatic conditions also affect the reduction of flood return period; with the wetter climates exhibiting the greatest difference in flood return period. Poor practices in both organic and conventional arable do not reduce the flood return period as much as good practices.

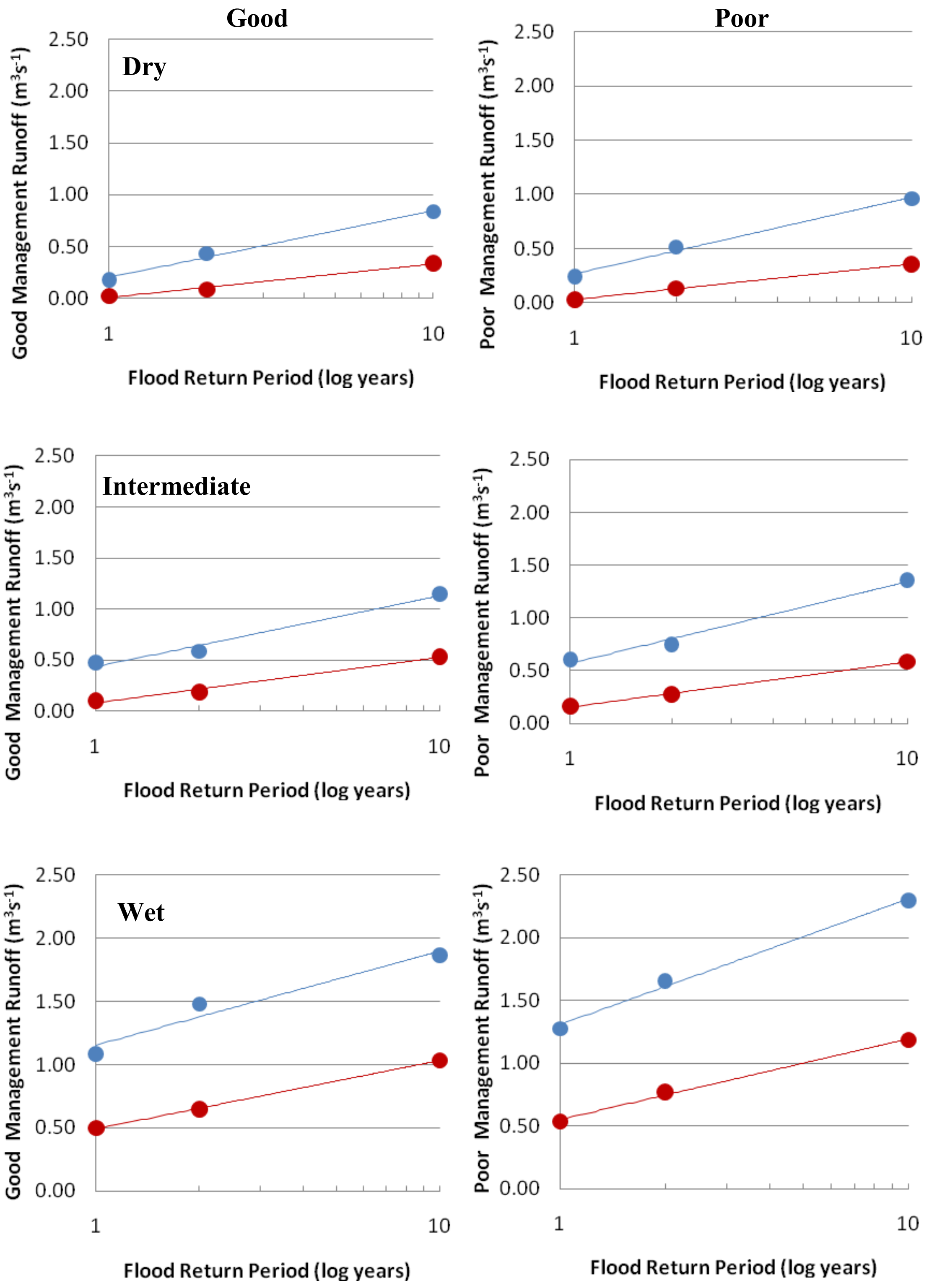


Figure 5.7: Flood return period and runoff rate for organic and conventional arable land use in the three different climatic regions for good (left) and poor (right) management in a 550 ha and 0.5° catchment. (Blue circle represents conventional arable and red circle represents organic arable).

5.3.3 Current situation

Table 5.9 shows the current situation for runoff in the catchment. Where the conventionally dominated landscape (60 % arable / 25 % grass / 15 % fallow) has the greater amount of runoff under good and poor soil management practices; compared to the organic landscape (45 % arable / 40 % grass / 15 % fallow) for the three climatic regions respectively. It should be noted, that the differences in total runoff between organically and conventionally dominated landscapes are not as great as when a totally grassland catchment is modelled.

From Table 5.9, it is possible to see that under poor management practices there is less difference in reducing runoff between organic and conventional dominated landscapes. This is a similar trend across all different climatic conditions and rainfall return periods; therefore one case will be used as an example to further highlight this issue. Using, the intermediate climatic conditions and 1 in 2 year rainfall event (Table 5.9- highlighted in blue) as an example; under good management there is a difference of 0.23 m^3s^{-1} compared to under poor management where there is a difference of 0.20 m^3s^{-1}. In this example, under good management practices, runoff decreases by up to 37 % if the landscape is organically dominated with a higher percentage of grassland. This highlights the importance for good soil management on grassland and prevention of overstocking which can lead to soil structural damage by trafficking and poaching. This could be explained through a reduction in livestock units between conventional (1.3) and organic (1.1) farms (Sutherland *et al.*, 2011).

Table 5.9: The total runoff for the conventional and organic dominated scenarios based upon rainfall return period for *current* hydrological soil conditions (based upon the values determined by *in situ* infiltration rates) for the a) dry b) intermediate and c) wet climatic regions. (% reduction in runoff = (poor practice – good practice) / poor practice).

Landscape	Rainfall Return Period (yrs)	Good Practice Runoff ($m^3 s^{-1}$)	Poor Practice Runoff ($m^3 s^{-1}$)	Runoff ratio good / poor	Reduction in runoff (%)
DRY					
Conventional	1	0.15	0.29	0.51	49.00
Organic	1	0.06	0.19	0.32	68.00
Conventional	2	0.39	0.63	0.62	38.00
Organic	2	0.27	0.51	0.53	47.00
Conventional	10	0.81	1.06	0.76	24.00
Organic	10	0.52	0.89	0.58	42.00
INTERMEDIATE					
Conventional	1	0.34	0.59	0.57	43.00
Organic	1	0.16	0.43	0.37	63.00
Conventional	2	0.64	0.92	0.69	31.00
Organic	2	0.41	0.72	0.55	45.00
Conventional	10	1.09	1.47	0.74	26.00
Organic	10	0.76	1.14	0.66	34.00
WET					
Conventional	1	1.06	1.33	0.79	21.00
Organic	1	0.75	1.18	0.64	36.00
Conventional	2	1.37	1.81	0.76	24.00
Organic	2	1.03	1.43	0.72	28.00
Conventional	10	1.87	2.49	0.75	25.00
Organic	10	1.40	2.00	0.70	30.00

Figure 5.8 utilises the data from Table 5.9; it shows the effect of organically and conventionally dominated landscapes on total runoff. It is clear the conventionally dominated landscapes have a greater amount of total runoff compared to organically dominated landscapes. This trend is the same across all three climatic conditions with the total amount of runoff increasing as the climate becomes wetter and the difference between the two landscapes is greater.

When taking the organic 1 in 10 year flood and converting this into the equivalent flood for conventional management; it is possible to see a reduction in flood return period (Table 5.10). This highlights a reduction in flood severity but may increase flood frequency of less destructive floods. It is possible to see that climatic conditions also affect the reduction of flood return period; with the wetter climates exhibiting the greatest difference in flood return period. Poor practices in both organic and conventional reduce the flood return period less than good practices.

Table 5.10: The effect of changing practices from conventionally dominated to organically dominated on flood return period. The values reflect the change from 1 in 10 year flood when managed organically.

Climatic Condition	Good Practices	Poor Practices
Dry	1 in 3.5	1 in 5.5
Intermediate	1 in 2.5	1 in 3.5
Wet	1 in 1.5	1 in 3.5

Overall, in the current situation there is a positive benefit from the organically dominated landscape compared with the conventionally dominated landscape. This is due to the increased proportion of grassland and fallow land (55 % compared to 40 % in the conventionally dominated landscape), which improve the amount of infiltration in the organically dominated landscape. It could be argued that this is due to the rotation opposed to organic management; however the author believes that organic management and the involvement of the more grass within the rotation are crucial to organic farm principles. However, a conventional farm can follow organic practices increasing the amount of grass in the rotation. However, in Norton *et al.* (2009) landscape analysis showed that organic management consistently provided more grassland within the rotation than conventional management. There is always less runoff when good soil management practices are followed; which can reduce runoff by 63 % in an organically dominated landscape in dry climatic conditions.

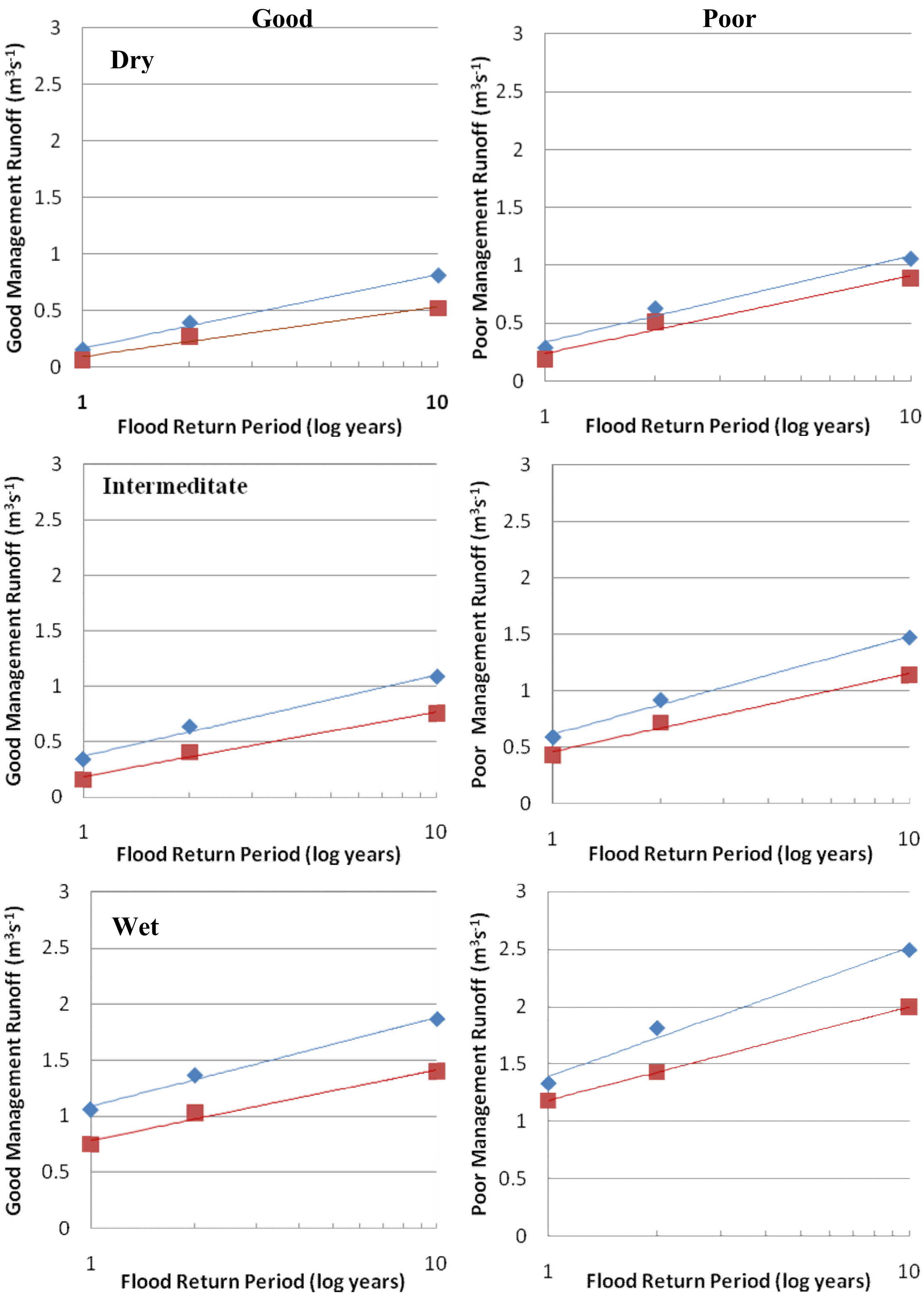


Figure 5.8: Flood return period and runoff rate for organic and conventional dominated scenarios in the three different climatic regions for good (left) and poor (right) management in a 550 ha and 0.5° catchment. (Blue represents conventionally dominated and red represents organically dominated).

5.3.4 Future Scenarios

According to Food and Farming Foresight (2011), there are five key challenges which need to be met by 2030:

1. Manage demand and supply sustainably
2. Stability in food supplies
3. Global access to food
4. Production with climate change mitigation
5. Preserving ecosystem service and biodiversity

The global population is expected to rise to 8 billion by 2030; this will increase the demand for food creating competition for land, water and energy whilst need to account for changes in climatic conditions (Foresight, 2011). It is a widely held view that more land will be required for both livestock and arable (cereal) production; hence in the modelled scenarios fallow land was removed due to pressures to use the land for production. A third set of scenarios were modelled where the 15 % fallow (bare) soil was converted to (A) 45 % organic arable land and 55 % organic grassland and (B) 60 % organic arable land and 40 % organic grassland. These were thought to be more realistic future landscape based upon Foresight (2011).

For the alternative future scenarios, there are benefits in terms of increased infiltration and less runoff production across all three different climatic conditions (dry, intermediate and wet). The data in Table 5.11 shows the results of these predictions and indicate that there is little difference between the two future land use scenarios. The data in Table 5.11 also show a reduction in runoff between good and poor practices which is greatest under wet climatic conditions. The results of the model for the future scenarios again reveal the importance of following good soil management practices as runoff significantly increases as the quality of the soil management decreases.

As there was little difference in runoff generated between the two future scenarios modelled, only one scenario (scenario B) was chosen and compared against the current conventionally and organically dominated landscapes (Figure 5.9).

Table 5.11: The total runoff for future scenarios A (45 % arable and 55 % grassland) and B (60 % arable, 40 % grassland) based upon the 1 in 2 year rainstorm for three climatic conditions.

Scenario A	Good Practice runoff ($m^3 s^{-1}$)	Poor Practice runoff ($m^3 s^{-1}$)	Runoff ratio good / poor	Reduction in runoff (%)
Dry	0.00	0.01	0.17	83.00
	0.02	0.05	0.39	61.00
	0.08	0.19	0.40	60.00
Intermediate	0.02	0.07	0.34	66.00
	0.04	0.13	0.34	66.00
	0.16	0.35	0.46	54.00
Wet	0.15	0.33	0.47	53.00
	0.25	0.48	0.52	48.00
	0.55	0.81	0.68	32.00
Scenario B				
Dry	0.01	0.05	0.13	87.00
	0.05	0.1	0.29	71.00
	0.07	0.19	0.37	63.00
Intermediate	0.02	0.06	0.31	69.00
	0.04	0.12	0.29	71.00
	0.14	0.35	0.41	59.00
Wet	0.14	0.31	0.45	55.00
	0.23	0.47	0.49	51.00
	0.49	0.78	0.63	27.00

The effect of converting fallow land to either arable or grassland shows that there is a reduction in the amount of runoff improving the conditions in the catchment. Overall, there is a reduction in the return periods from both the conventionally and organically dominated landscapes to the future scenario for each of the climatic regions. This is substantial and results in reducing the severity of runoff. For example, a 1 in 10 year rainfall event becomes equivalent to rainfall return periods of less than 1 in 1 year for either of the conventional or organically dominated landscape in the intermediate and wet climatic conditions.

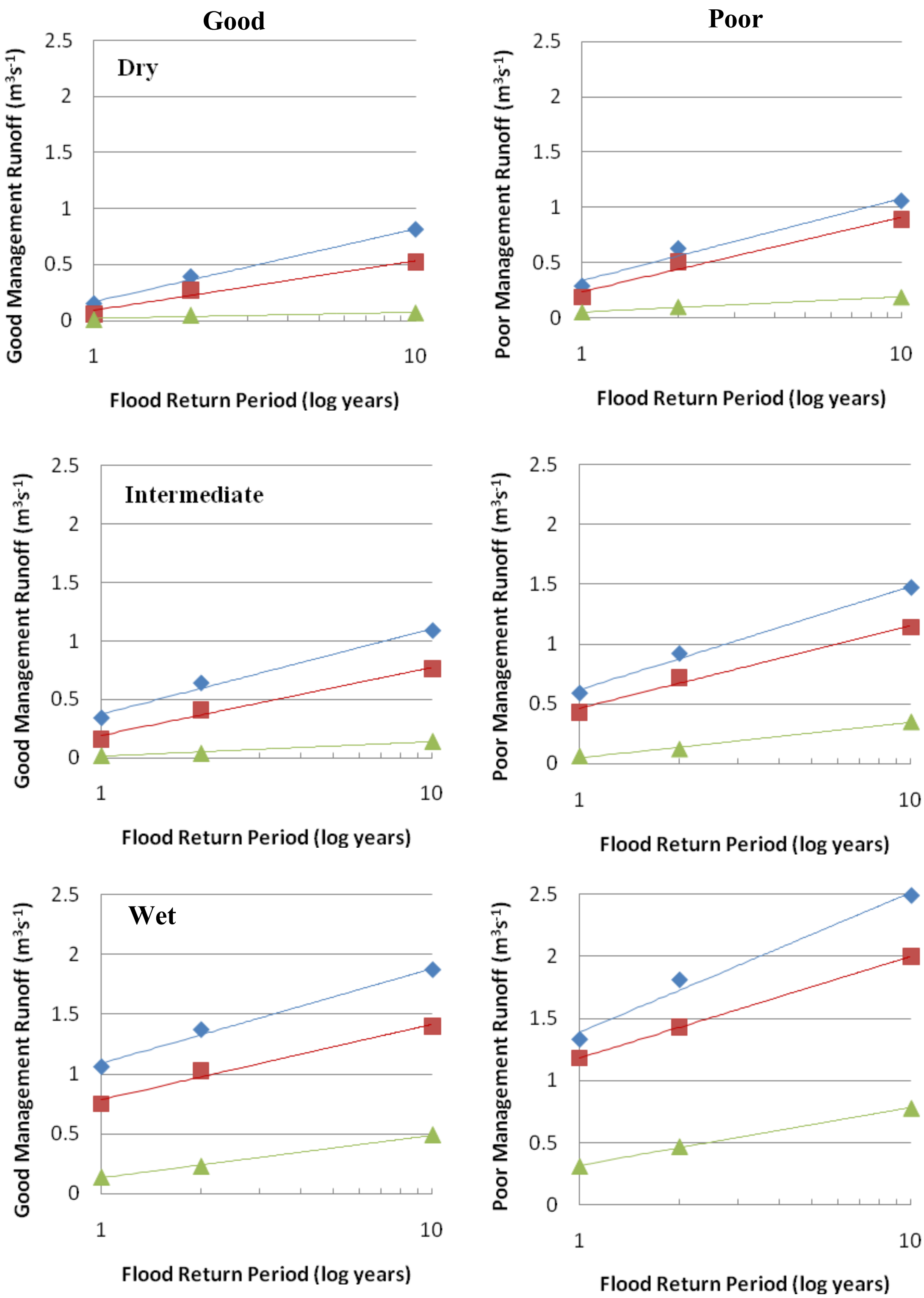


Figure 5.9: Flood return period and runoff rate for good (left) and poor (right) management practices in organic, conventional and future scenarios in the three different climatic regions for a 550 ha and 0.5° catchment. (Blue diamond represents current conventional dominated, red square represents current organic dominated and green triangle represents future scenario with no fallow land).

5.3.5 Summary of results and discussion

From the data presented in each section; it is possible to see that the amount of runoff is influenced by how well the soil is managed and also by the composition of the landscape (the total amount of land under grass or arable land use). When comparing the different scenarios modelled; it is possible to rank the order of the highest to the lowest amount of runoff; which applies similarly across all climatic conditions (Figure 5.10).

Current landscapes (organic and conventional) > total arable (conventional) > total arable (organic) > total grassland (conventional) > total grassland (organic) > future scenario (conversion of fallow to grassland or arable)

Figure 5.10: The ranked order of the different scenarios from the highest generated runoff to the lowest amount of generated runoff.

The overall move from conventional grass to organic grass would reduce runoff such that the 1 in 10 year flood return period reduces in severity to approximately 1 year in 2, based upon model predictions using the USDA SCS runoff curve. The move from conventionally dominated landscape (60 % arable / 25 % grass / 15 % fallow) to an organically dominated landscape (45 % arable / 40 % grass / 15 % fallow) would reduce runoff as follows:

- For dry climatic conditions – the 1 in 10 year return period would reduce to 1 in 3.5
- For intermediate conditions – the 1 in 10 year return period would reduce to 1 in 2.5
- For wet climatic conditions – the 1 in 10 year return period would reduce to 1 in 1.5

For the future scenario (where the fallow land was converted to either arable or grassland) this is further reduced as follows:

- For dry climatic conditions it becomes the 1 in 1 year return period
- For the intermediate it becomes less than 1 in 1 year return period
- For the wet conditions it becomes less than 1 in 1 year return period.

This shows that in the future following good soil management practices; regardless of whether the landscape is organically or conventionally dominated, it is beneficial for reducing runoff. This is partially due to the inputs to the model where arable row crops reduce infiltration rates (which were supported by in field measurements – plot scale Chapter 4), but also due to the reduction in fallow land which within the model has a lower infiltration rate (Table 5.3). As previously highlighted, the model was developed in the USA and so some slight differences compared with actual measurements in the field would be expected due to differences in soil properties. Within the current landscape scenarios; organic landscapes under good soil management have the lowest amount of runoff across all three climatic regions. This is due to a higher proportion of organic or well managed grassland which improves infiltration rates as shown empirically in the field scale study.

5.4 Costs to the farmer and benefits to society

The modelling undertaken in the previous section has shown that through conversion to organic farming there is a benefit to society through the reduction of surface runoff. This is one of the ecosystem benefits outlined by Costanza *et al.* (1997) and in the introduction (Chapter 1), which are provided by farming practices in both organic and conventional systems. Farming practices provide a wide range of ecosystem services which have not been covered in this research but the recommendations need to be balanced with other services such as carbon sequestration. Increasing the amount of organic land or well managed grassland in the landscape could be costly to the farmer and the next section outlines the theoretical costs of a farm converting to organic agriculture. Then the societal benefits of reduced flooding are analysed through a cost benefit analysis (presenting three different options), before highlighting the cost savings due to the reduction in flood damage from converting to organic management principles (not necessarily certified).

5.4.1 Economic impacts for the farmer

There can be many costs associated with changing farm systems (to organic) or to changing land use (increasing well managed grassland in rotations). Increasing the amount of well managed grassland; could be related to decreasing the overall stocking density which could prove costly to the farmer due to a reduction in income. However, this is difficult to quantify as it varies depending on the size of the enterprise, the current system operating in the farm and the current health of the farm. These issues also influence the costs which can be associated with converting to organic farming. These are described by Lampkin *et al.* (2009) and the main conversion costs are as follows:

- Output reduction – through increasing fertility building legumes in the rotation or mistakes
- New investments – changing livestock to organic, improving fencing
- Information and experience gathering – directly through advisory literature
- Variable cost reductions – reseeding grassland, withdrawal of prohibited inputs
- Fixed cost increases – labour use (10-20 % higher), certification (up to £450 per farm per year)
- Lack of access to premium prices during two year conversion – this can cost between £200 – 500 ha^{-1} and cost of market development
- Eligibility for single payment and other benefits

According to the organic farm handbook (Lampkin *et al.*, 2009) there are two main methods for adopting organic agriculture: staged and single step. There are risks associated with both methods. Staged farm approach usually provides a buffer against opportunity costs in the first few years of conversion as some of the farm remains farmed conventionally (maintaining yield and knowledge of prices). The whole farm approach is seen as more risky by farmers as any errors are detrimental over time; especially after a large outlay to converting through certification and possible investment in new machinery (Morris *et al.*, 2010a). However, whilst being more risky support through the Organic Entry Level Scheme (OELS) for the first five years provides a buffer to organic farmers. This is typically £60 per ha per year, with an additional payment of £175 per ha per year in the first two years (Lampkin *et al.*, 2009). Therefore, it is important to look at the whole farm margins over a period of a few years to determine the true benefit to the farmer of conversion compared with remaining conventional (Table 5.12). There appears to be a benefit in both cropping (arable only) and mixed farming for organic farmers, this is related to a reduction of synthetic fertilisers and pesticides as well as a price premium. However, if the price premium was removed; this may no longer be the case as organic farming internalises many of the costs associated with producing food.

Table 5.12: Comparison of net farm income (average 2005/2006 and 2006/2007) between organic and conventional farms (Lampkin *et al.*, 2009).

Farm Type	£ / farm	£ ha^{-1}
Cropping		
Organic	45,344	271
Conventional	23,089	151
Mixed		
Organic	20,095	184
Conventional	18,076	154

5.4.2 Ecosystem's Approach to flood prevention

If all farms within a neighbourhood collectively manage the grass fields with organic or less intensive conventional management there could be a reduction of runoff in the sub catchment, agreeing with the findings of Hess *et al*. (2010). This effect needs further study at the sub catchment level as Morris *et al.* (2010) report 'there is little hydrological evidence to verify this [benefit], it is generally felt that policies that encourage retention of water in the landscape can contribute to flood risk mitigation especially for smaller, more frequent events.'

This research helps to provide some data for Defra's 'Making Space for Water' and current land use policy, as it suggests that rural management in upstream areas of catchments can ameliorate runoff and reduce the incidence of localised flooding. Defra (2006a) suggested that cultivation practices such as minimum tillage could help to reduce runoff. However, the resolution of the **SCS-CN** model was not able to identify differences in runoff due to changing tillage practices (plot scale study - Chapter 4).

Defra indicates that the benefits of controlling runoff from agricultural soils could be captured into cross-compliance and the single farm payment scheme. Table 5.13 presents two options for changing catchment management through increasing grassland or increasing organic farming and their economic, environmental costs and benefits. It shows that whilst there is no immediate expenditure if continuing with the current management (baseline), there could be hidden costs associated with flood protection and flood damage repairs. There is likely to be an increased cost associated with improving flood defences due to a reduction in water retentive capacity because of surface sealing and compaction.

The cost of implementing Option 1 is likely to be lower than Option 2; especially for the individual farmer (as outlined previously). The options would provide the same ecosystem services of improved water retention, higher infiltration rates and reducing runoff. However, it was shown in the research presented in the field scale, plot scale and catchment scale studies that organic land has a higher infiltration rate compared with conventional land. The associated cost to convert to certified organic status is higher (due to certification and improving demand for organic produce) than increasing grass land within rotations. Whilst this research supports payments for changing catchment management by farmers, it is felt that as the research presented is hypothetical it would be beneficial to study the effects for a real catchment. This would allow detailed costing for conversion to organic agriculture and flood damage costs to be linked through actual data for a specific catchment.

Table 5.13: The effect of changing catchment management on economic, social and environment aspects (based on AST EA) using ecosystems approach (Environment Agency, 2002).

Option	Baseline	Option 1	Option 2
Description	No Change	Increase the amount of grassland in the landscape through incentives (countryside stewardship scheme paid £179 ha^{-1} yr^{-1})	Increase the number of organic farms and farms practising BMPs
Technical Issues	None	Reluctance for change / cost to farmers of establishment of crops	Limited number of certifying bodies, monitoring issues, access to information for farmers
Assumptions and uncertainties	None	Farmers will be willing to convert more land into grassland and there are no economic barriers or demand to grow crops on the land.	Farmers will be willing to convert to organic – accepting initial investments and potential loss of earning.
Approach to Adapt	None	Staged approach tackling high risk flood areas first.	Staged approach (partial conversion of farm) tackling high risk flood areas or fields first.
Comparative costs of adoption	£	££	£££
ECONOMIC	May need more flood defences; as natural soil buffers and soil water storage is decreased due to compaction, surface sealing and land use change.	Need to sow at least three perennial grass species will cost £71 ha^{-1} establishment costs and restrict grazing density (to 1.1 LSU).	Conversion costs are variable, some covered by OELS but only for the first 5 years of conversion.
ENVIRONMENTAL	No changes.	It will decrease leaching, create an SOC sink. It will also improve infiltration rates reducing runoff rates and preventing soil erosion.	It will improve soil quality; organic land infiltrates more water and could have the potential to reduce runoff rates and prevent soil erosion.
SOCIAL	Implications of increasing flooding and the issues on livelihoods of people at risk.	Increased amount of permanent grassland in the landscape is very aesthetically pleasing.	Major changes to farming systems and need to change farmers approach. Need to change public perception to purchase organic farm.

5.4.3 Effect of changing land management on flood damage repair cost

As shown previously in Section 5.3 there is a benefit in terms of reducing flood intensity by converting to organic farming. Hence, the impact different land uses, such as residential or agricultural, is important. The shape and size of the catchment as well as the proximity to rivers influence the likelihood of flooding to occur. Therefore, a hypothetical catchment of 550 ha which consists of both agricultural land and some residential properties will be considered. Hess and Morris (1986) investigated the occurrence of winter flooding due to catchment size. They found that smaller catchments (below 25 km^2) had 60% of flood events happening between October and March compared to 80 % in larger catchments. The catchment size in this hypothetical scenario is small and so there is more risk of summer flooding which is more damaging particularly to agricultural land. The shape and topography of the catchment will also have an impact on the extent of flooding and flood depth; however this cannot be estimated from this hypothetical data.

Firstly, the effects of a reduction in flood intensity for agricultural land will be discussed. When determining the cost of flood damage to agricultural land both loss to output (such as crop yield or livestock units) and cost of remedial work need to be considered. The timing and duration of the flood are also highly significant. Summer flooding lasting a few weeks is more damaging than winter flooding, due to the crop growth stage and inaccessibility of the land for working. Data in the FHRC (2010) is based upon flood frequency rather than flood return period (severity); therefore typical gross margins for land use (based upon crop type) will be used to give a value to agricultural land. As the modelling and research in the field and plot scale studies have looked at cropped fields (mainly cereals) and grassland fields these two examples will be highlighted. The typical wheat financial gross margins for good field drainage conditions are £300-350 ha^{-1} and the typical gross margins for good conditions grassland with high stocking density (1.7-2.0 LSU) is £1200 – 1400 ha^{-1} (FHRC, 2010). For example, if there was the 1 in 10 year return period more land is likely to be flooded and for a longer period compared to a 1 in 2 year return period. This would reduce the gross margin due to crop damage, soil damage (compaction), loss of livestock and remedial work.

Secondly, the effects of a reduction in flood intensity for residential properties will be discussed. As shown in section 5.3, when converting to organic management there is a reduction in return period from the 1 in 10 depending upon climatic conditions. Figure 5.10, shows the cost of flood damage per residential property up to the 1 in 25 year return period. There is a relationship between flood damage and return period; the damage augments with increasing flood return period until saturation point is reached. In Figure 5.11, the saturation point is reached at the 1 in 25 year return period. If further points are plotted onto the graph such as the 1 in 50 year return period – there is a slight increase before a plateau is reached in the 1 in 100 year return period where no more damage is caused. This research focuses on reducing the 1 in 10 year flood; and Figure 5.11 shows that the relative effects of short duration events are very significant.

Figure 5.11 shows the cost of flood damage from a 1 in 10 year flood event to a residential properties would be £20 592. However, in the current situation, with good management for an organically dominated landscape, this is reduced to £ 9707 (dry climatic conditions), £1350 (intermediate climatic conditions) and £0 (wet climatic conditions). This provides a substantial saving in flood damage costs through altering land use (increasing grassland within the rotation) and management (organic or conventional).

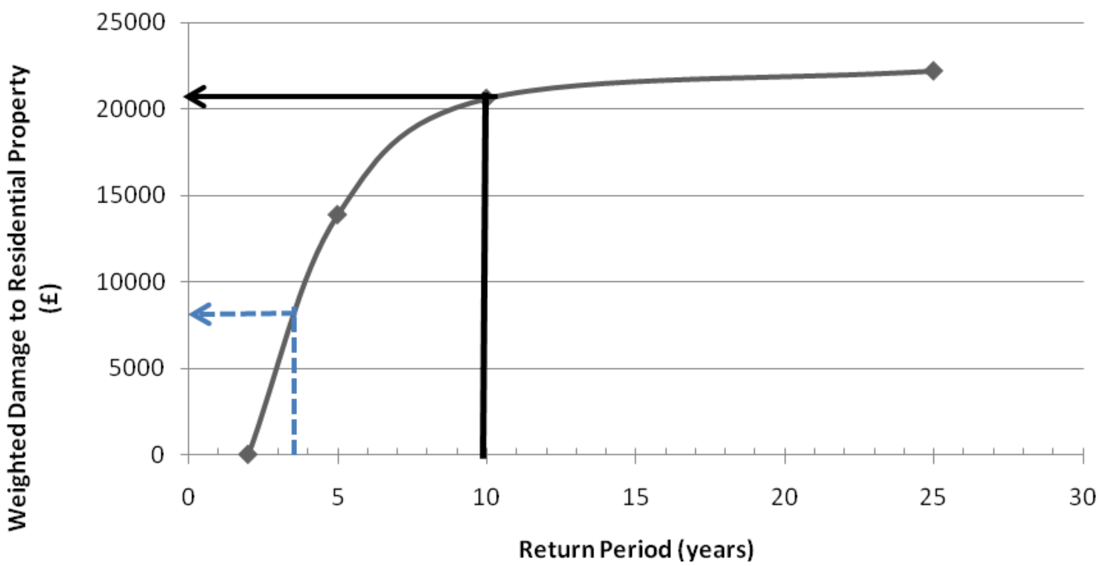


Figure 5.11: Cost of damage due to flooding to a four bedroom residential property (FHRC, 2010). Black arrow shows the cost of the 1 in 10 year return period, blue dashed arrow shows the reduction of costs when converting to organic agriculture dry conditions.

Overall, this research has shown that for each of the different climatic conditions modelled a positive benefit is felt by society through reduction of flood severity. This is particularly beneficial in terms of reducing flood damage costs to residential properties; as in dry climatic conditions converting to organic management can decrease the damage by 50 %. It is particularly important in wet climatic areas, where there are already higher levels of precipitation, as this reduces the costs of damage to residential properties by 100 %. It is thought that there would also be a benefit to agricultural land, as a reduction in the generation of runoff should provide savings in flood damage repairs. However, it is not possible to quantify these potential savings.

5.5 Conclusions

The main conclusions which can be drawn from the modelling and the cost benefit analysis are as follows:

- SCS model, despite its limitations, provides useful catchment scale comparisons for both good and poor soil management.
    - If all grassland is organically managed runoff is substantially reduced by 60 – 70 % and in turn reduced the effective return period from the 1 in 10 to 1 in 1.5 years, 1 in 1 and 1 in 1 for dry, intermediate and wet climatic conditions respectively
    - Organically dominated landscapes (45 % arable / 40 % grass / 15 % fallow) reduce runoff compared to conventional dominated landscapes (60 % arable / 25 % grass / 15 % fallow) by 29, 33, 47 % for the three climatic zones (dry, intermediate and wet).
    - Moving from conventional to organic management reduces the effective return period from the 1 in 10 year to the 1 in 3.5, 1 in 2.5 and 1 in 1.5 year return periods for the dry, intermediate and wet climatic regions respectively.
    - Converting the fallow land (arable or grassland) gives very similar overall effects and reduces the runoff by 44, 60, 85 % for the three climatic zones (dry, intermediate and wet).

    - It also reduces the effective return period for the 1 in 10 to 1 in 2, 1 in 1.25 and 1 in 2 year return periods for the three climatic regions (dry, intermediate and wet).

- For the hypothetical catchment, there would be a saving of £20 592 in flood damages (per residential property) in wet climatic conditions if land is converted to organic agriculture with good management practices. There are also potential savings for both dry and intermediate climatic conditions of £13 659 and £ 19 242 respectively. There would also be a benefit for agricultural land which was not able to be quantified.
- There is a benefit for flood reduction when converting to organic management or through better management of grassland. However, this is for a hypothetical catchment and the benefit would vary according to catchment characteristics such as shape and size. It was not possible to validate this model with *in field* measurements of runoff so care should be taken when extrapolating these findings to larger scales.

6 Integrated Discussion

This chapter will integrate the principal findings relating to soil physical quality, workability and soil hydrology from the field scale (Chapter 3), the plot scale (Chapter 4) and modelled catchment (Chapter 5). Firstly, a few caveats relating to the research should be described to prevent over interpretation of the data. This research compared organic and conventional farming systems whereby organic was separated from conventional by its certification which met EU regulations. It is very difficult, especially in the case of the field scale study, to distinguish the systems by different soil management and tillage regimes as a range of practices were occurring over both systems. This research was predominantly focused on lowland areas of the UK with farms covering the midlands, south west, south east and one in Scotland. This resulted in considering a range of climatic variations. However, any variations in soil properties determined seem to hold true in all areas. The farm types were similar, small mixed rotational farms. Larger monocultures and intensive systems were excluded from this study; this is a more usual conventional arable farming system in the east. Therefore, practices which were occurring on both organic and conventional farms could have been more similar rather than being at different extremes in the management spectrum. Previous land use and starting conditions of these fields could have a significant effect upon any differences; this was minimised in the plot scale study as all sites were previously leys. The infiltration measurements, which also formed the basis of the inputs to the **SCS-CN** runoff modelling, were collected in field using a Decagon tension infiltrometer which has a small surface area. Hence, care should be taken when interpreting these results and the output from the **SCS-CN** runoff modelling.

Whilst there has been much research, comparing organic and conventional farming for soil properties, yield and farm economics (Stolze *et al*., 2000). In the UK, there has been little new research about the effects of organic farming on soil properties in the last 10 years. The focus has shifted towards the effects of climatic change partially due to an increase in flooding in recent years. This has been blamed upon poor agricultural practices reducing soil functionality leading to compaction and decreasing the water holding capacity of soils. The idea of a functioning soil combines sustainability (ability to produce food without being detrimental to the environment or natural resources, such as soil) and the specific abilities of soil. Soil has many key functions (Defra, 2009a) but this research has focused on four factors which can be altered through changing management (organic or conventional):

- Storing carbon (monitoring soil carbon content)
- Storing, filtering and transforming nutrients substances and water
- Biomass production (crop yield)
- Provision of ecosystem services (benefit to humans from natural ecosystems – for example water storage on agricultural land to reduce flooding)

The two main threats which affect agricultural soils are decreasing SOC content and increasing soil compaction. These two components are central to both soil health and soil functioning. By 2030, Defra set a target that England's soils will be managed sustainably and degradation threats tackled successfully (Defra, 2009a). This research addressed these two degradation threats and aimed to look at the effects of organic farming at different scales (plot, field and modelled catchment) with different land uses (arable and grassland) and tillage intensity (reduced tillage and ploughing). Firstly, the effects of organic farming on SOC will be discussed, before highlighting the implications for soil health and soil functions at different scales. Then the potential benefits to ecosystems services will be considered and the economic consequences for changing land management.

6.1 Soil Organic Carbon

This research has shown that organic farming has no detectable advantage for increasing SOC compared to conventional farming; with the exception of the organically managed clay loam soil in the plot scale study. The field scale study (Chapter 3) showed there was no significant difference between organic (46.67 g kg^{-1}) and conventionally (48.85 g kg^{-1}) managed land across a range of soil textures and two land uses (grass and arable). This lack of difference was attributed to a range of soil management practices and number of years under organic management (between 0-50 years) which could have masked any differences. There was a difference attributed to land use where grassland (52.48 g kg^{-1}) (both organic and conventional) had a higher SOC content compared to arable land (38.72 g kg^{-1}). The plot scale study (Chapter 4) showed that there was a significant difference between organic and conventionally managed arable land which was dependent upon soil texture. The organically managed land was certified organic for eight, twenty and fifty years, for clay, sandy silt loam and clay loam soils respectively. For the sandy silt loam conventionally managed land (44.82 g kg^{-1}) had a higher SOC content whereas for the clay loam organically managed land (11.73 g kg^{-1}) had a higher SOC content and the clay showed no significant difference. This could be due to the length of time the different systems had been managed organically; increasing time that the land had been managed organically appears to improve the SOC content. The trend for differences between plough and reduced tillage was universal across all three soil textures; reducing the tillage intensity increased the amount of SOC by up to 5 % compared to traditional ploughing. This is due to a reduction in SOC turnover due to less aeration of the soil which helps SOC to build up. Hence, the benefits of changing tillage system (towards reduction in number of passes and depth) can be felt in the short term within this two year plot scale study.

Therefore, this research concludes that there is no significant improvement in SOC due to organic management at the field scale. However, at the plot scale, differences are apparent depending upon soil texture and the length of time under organic management. This could be related to the amount of SOC inputs which need to be added periodically in a continued manner; if no further SOC is added, the rate of decline is greater than the initial build up of SOC (Bhogal *et al.*, 2009). Cooper and Melchett (2008) suggest three practices which help to build SOC: reduced tillage, ley periods (grass or clover) and organic amendments. Although organic amendments were not investigated specifically in this research, the influence of these on SOC is considered important. These practices are not specific to either the organic or conventional farming systems; however, they are encapsulated in the principles of organic farming. The effect of these practices on SOC has been confirmed through this research. Where SOC content was greatest under reduced tillage practices and there was a higher SOC content for grassland compared to arable land use. When relating these findings to the catchment scale; Chapter 5 suggests that there is a higher amount of grassland within the organic rotations and organic landscapes (Norton *et al.*, 2009). Therefore, as shown in the field scale study (Chapter 3), there is an increase in SOC for grassland (whether organic or conventional) this could potentially improve the amount of SOC at the catchment scale which may have implications for carbon sequestration.

Gattinger (2010) performed a meta-analysis using 37 peer reviewed journal articles to compare topsoil SOC content in long term trials. They found a benefit for organic farming which had 14.7 $g\,kg^{-1}$ SOC compared to 11.6 $g\,kg^{-1}$ SOC for conventional farming. Cooper and Melchett (2008) also found that in the long term organic farms had a higher SOC content compared to conventional farms. Therefore, it is suggested that there is a potential to sequester atmospheric carbon in the soil, helping to combat climatic change through the reduction of greenhouse gases (Smith *et al.*, 2011). However, it is difficult to know where to draw the boundaries of the system; whether at the farm gate or to include transportation and manufacturing relating to fertiliser production. Hence, comparisons between organic and conventionally managed land on SOC and potential sequestration for climate change mitigation are difficult. As this research showed that the amount of SOC depended upon length of time the land has been organically managed, soil texture and tillage intensity; it is not possible to draw firm conclusions about potential carbon sequestration effects due to organic or conventional systems.

SOC is a soil property which exhibits interactions with the other properties measured to help maintain productivity and sustainable soil functions; such as reducing compaction and increasing soil water holding capacity and workability. Therefore, from the results of the SOC analysis in the field scale study (Chapter 3); it would be thought that there would be little impact upon the other soil physical properties measured for soil health and ecosystem services under arable land use. However, this was not the case for the plot scale study (Chapter 4) where differences were anticipated especially in the clay loam.

6.2 Soil physical and chemical properties to maintain soil functions

This research shows that organic farming does not have a detectable benefit or a detrimental effect on soil physical health and sustainability of soil functioning compared to conventional farming. However, it does show that organic farming has a smaller number of fields (2 fields) with nutrients, herbicides and pesticides present in soil water quality compared to conventional farming (13 fields). However, the levels recorded were less than the current thresholds that are considered detrimental to the environment for both organic and conventional agricultural management systems. The soil indicator properties for soil physical and chemical health were able to show the impacts of different soil textures, land uses and tillage regime however they did not always attribute any changes to management (organic or conventional) on soil functioning. The soil physical properties (aggregate stability, plastic limit, shear strength, bulk density and total porosity) were chosen to be indicators of soil strength and resistance to compactability. Each of these properties are affected by SOC, increasing amounts should improve the overall soil physical quality. The soil chemical properties (total C: N ratio, pH, total NPK, agrochemicals) were chosen to indicate the effects on productivity (nutrient availability) and agricultural pollution (runoff / leaching of nutrients).

Each of the measured soil properties (indicators) will now be discussed with reference to their effects at the plot and field scale and the implications for soil functions. It is important to note that the impacts of organic and conventional farming on the different properties are complicated by interactions and variations in both space and time (Liebig and Doran, 1999). Any implications for climatic change will also be highlighted.

6.2.1 Soil physical functions

Overall, there was no clear benefit in terms of improving soil physical functioning when managing the land organically. There were no significant differences attributed to organic land management for plastic limit, bulk density, total porosity, or workability. However, there were some significant differences between organically and conventionally managed land for aggregate stability and shear strength. All of these properties are dependent upon the clay content and the amount of SOC; therefore differences were found between different soil textures for each of the soil properties measured.

The field scale study (Chapter 3) showed there were some significant differences which could be attributed to land use (grass or arable). For example, grass had a higher plastic limit (311.00 g kg^{-1}) compared to arable land (281.50 g kg^{-1}); this is expected as there was an increase in the amount of SOC helps to bind the soil together. However, there were no differences which could be attributed to reducing tillage intensity for plastic limit, bulk density, total porosity or workability. This is related to the short duration of this study; where any benefits in these soil physical properties were not found in after two years. The plot scale study (Chapter 4) showed there was no significant difference between organic and conventionally managed arable land for bulk density and total porosity. However, bulk density and total porosity were not measured on the grassland fields. The plot scale study (Chapter 4) showed that the differences in workability of arable land depended upon soil texture rather than management system, increasing clay content reduced workability compared to sandy silt loam. There was no significant difference between organic and conventionally managed arable land for workability in the field scale study (Chapter 3), which could be attributed to a mixture of soil textures.

Aggregate stability and shear strength will now be discussed in more detail and their impact on soil functions in a changing climate. The field scale study (Chapter 3) showed that there was no significant difference between organic and conventional management for aggregate stability. Although there was a trend for the organically managed land (51.18 %) to have a slightly higher aggregate stability compared to conventionally managed land (49.40 %). Land use had a significant effect on aggregate stability with grass having a higher value compared to arable land. This is expected as grassland has a higher SOC content which helps to bind the soil together (Tisdall and Oades, 1982).

Aggregate stability can often show the impact of changes in land use and management before a change SOC is observed (Haynes and Swift, 1991). The plot scale study (Chapter 4) showed that there was no overall trend and results were mixed dependent upon soil texture. The sandy silt loam exhibited improved aggregate stability under organic management (46.00 %), the clay had a higher stability under conventional management (68.72 %) and the clay loam showed no difference. Therefore, land management whether organic or conventional seem to make a significant difference on lighter textured soils. However, the heavier textured clay soil exhibited no significant difference between management types (organic or conventional) because there was no difference in the amount of clay or SOC content. Aggregate stability was significantly affected by tillage intensity; reducing tillage increased the stability of the soil by 8 % depending on soil texture. As aggregate stability is governed by the clay and SOC content; higher clay contents seems to be more important than changing land management and its induced SOC content changes. Stolze *et al* (2000) reviewed comparative studies for aggregate stability and overall deemed there was no significant difference. This research has shown that there can be a significant difference in aggregate stability due to land management change (organic and conventional); however differences vary according to soil texture (clay content).

Aggregate stability is important for helping to prevent soil erosion and resisting the impact of raindrops. This helps to prevent surface sealing and crust formation which restricts crop growth and water infiltrating (USDA, 1996). At the landscape scale, as previously highlighted, organic farms tend to have a higher proportion of land within grassland use due to their crop rotation. The field scale study (Chapter 3) shows that grassland use has a higher aggregate stability which would help to prevent soil erosion and surface sealing. There was no difference between organic and conventional grassland, so it is argued that increasing the amount of grassland within the catchment either organic or conventional would have a benefit for aggregate stability. This would help maintain and improve soil functions especially through the regulation of water movement in soils. Climate change particularly in the UK, associated with increasing Green House Gas (GHG) emissions, are making extreme rainfall events and flooding more common (Min *et al.*, 2011). Hence, improvements in aggregates stability and prevention of soil surface sealing through increasing grassland in the catchment would help to improve water infiltration and storage.

There was a benefit in terms of increasing shear strength when managing arable land organically. Soil shear strength is important for contrasting two reasons: seedbed preparation and vehicle access. Low shear strength during seedbed preparation enables seeding to emergence and to produce a good crop. Whereas higher shear strengths would enable good vehicle access with reduced amount of soil compaction (Benjamin and Cruse, 1987). Higher shear strengths also help reduce likelihood of soil erosion and surface sealing; thus improving infiltration rates and preventing surface runoff of water. This is particularly significant in changing climatic conditions whereby rainfall is more intense; as there is potential to infiltrate more water and prevent excessive overland flow and flooding. The field scale study (Chapter 3) showed that there was no significant difference between organic (52.11 kPa) and conventional management (55.24 kPa); this is regardless of land use. Grassland (55.97 kPa) had a significantly higher shear strength compared to arable (48.24 kPa). This is expected as there was an increase in the amount of SOC helps to bind the soil together improving its strength.

The plot scale study (Chapter 4) for arable land only, showed that organic management increases shear strength on loamy soils (clay and sandy silt) but there is no difference in the clay soil. This research showed that reducing tillage intensity (from traditional ploughing to reduced tillage) increases the shear strength of the soil by up to 29 % depending on soil texture. This could be due to improvements in soil structure; as the reduced tillage soil has not be disturbed whereas the ploughed soil is loosen which would lower the shear strength. If this is scaled up to the landscape, where an organically managed landscape has a higher proportion of grassland as shown in the catchment modelling (Chapter 5) the benefits are two-fold. This is because there is higher shear strength on both organic grassland and organic arable land which would reduce soil erosion and surface sealing allowing more infiltration and less runoff.

Therefore, whilst the majority of these physical properties measured showed no significant difference between organic and conventional management, shear strength and aggregate stability reveal an overall benefit especially on organically managed arable land for soil functions. This does vary with soil texture (heavier textured soils showing fewer differences), length of time managed organically (increasing longevity of management increases difference) and climatic conditions based on geographical location of sampling.

6.2.2 Soil chemical functions

Overall, there was no benefit for improving soil chemical functioning shown in this study; equally there was no detrimental effect. The field scale study (Chapter 3) showed that organically managed land indicated fewer pesticide and herbicides residues in soil water with only two fields showing trace levels. This reduction in pesticides and herbicides would help to prevent agricultural pollution through leaching; although none of the recorded levels were above the No Observed Effects Concentration (NOEC). The field scale study (Chapter 3) shows that there were no significant differences between organic and conventionally managed land for nutrients (total P, K). However, conventionally managed arable land had a significantly higher total N content (30.56 g kg^{-1}) compared to the other land uses and management. These differences are due to the timing of sampling in spring, post applications of fertilisers for many of the conventional farms.

The plot scale study (Chapter 4) showed that there was no significant difference between organically and conventionally managed land for total C:N ratio or pH. There was a variation with soil texture; where only the sandy silt loam showed a significant difference where conventionally managed land was higher than organic land for both total C:N 13.83 (conventional), 13.03 (organic) and pH 6.44 (conventional), 6.06 (organic). This higher C:N ratio on the conventional managed land is consistent with a greater SOC compared to the organic managed land. Usually, higher levels of C:N ratio are related to lower bulk densities and increased water holding capacity which would aid resistance to compaction (Martins *et al.*, 2011). This study however did not confirm this relationship. There were no significant differences which could be attributed to land use (arable or grassland) or changing tillage intensity (ploughed to reduced tillage). Therefore, this research fails to find any benefit for farming organically on soil chemical functioning which is comforting as the aim of the safeguards and regulations in conventional agriculture are to prevent this.

6.3 Ecosystem services – water storage and infiltration

This research primarily looked at a reduction in flooding through water regulation by soil as a means to provide public goods (ecosystem service). Ecosystems and their services need to be managed in the face of environmental and climatic change. These changes include increasing intense rainfall during winter and summer months which can contribute to flooding. Therefore, the effect of changing land management (organic or conventional) on soil properties (namely infiltration rates and water holding capacity) is very important for ecosystem services.

Soil surface management in both arable and grassland makes a difference to soil structure tilth, infiltration and runoff. Overall, there is an improvement in infiltration rates due to organic land management for both arable and grassland. From the research presented at the field scale (Chapter 3) and plot scale (Chapter 4), it is possible to see that organically managed land consistently has a higher rate of infiltration compared to conventionally managed land. The amount of infiltration does vary with soil texture and soil series (in relation to the clay content). In the field scale study (Chapter 3), clay soils (9.89 mm hr^{-1}) and sandy loam soils (7.52 mm hr^{-1}) had the highest rates of infiltration compared to the other soil textures. This is due to the shrink well nature of the clay soils and the sampling time (during crop growth). The field scale study (Chapter 3), did not find any difference between organic arable, organic grassland and conventional arable fields that all had higher levels of infiltration than conventional grassland (2.53 mm hr^{-1}) regardless of the soil texture. This is due to soil degradation in the conventional grassland; which was determined by HOST interpretations in the field. There was a higher stocking density on conventional grass land (1.3 LSU) than organic grass land (1.1 LSU) which could be contributing to this degradation of soil structure and reducing infiltration rates.

The plot scale study (Chapter 4), showed a consistent difference between arable fields with organic infiltration rate being higher than conventional infiltration rate. The amount of infiltration did vary with soil texture; with no significant difference between management found in the clay soil but both the sandy silt loam (47 % higher) and the clay loam (68 % higher) showed an improvement under organic management. Tillage intensity (ploughing or reduced tillage) and sampling timing (post harvest or post tillage) contributed to significant differences within each management type. Ploughed tillage treatments increased the amount of infiltration by up to 5 % compared to reduced tillage. This is because the benefit of reduced tillage is not felt in the first few years as increase the continuity of pore structures especially macropores which influence the amount of infiltration have not developed (Carter, 1994). Hence, due to increasing soil strength and structural changes the reduced tillage soil may be more compact compared to the ploughed soil.

In the catchment modelling (Chapter 5), the effects of these differences in infiltration rates were converted into runoff and scaled up for a hypothetical catchment. It is important to note that whilst it was not possible to validate this model through infield measurements of runoff rates, the model was based upon measured infiltration data presented in the field and plot studies (Chapters 3 and 4). Irrespective of the three different climatic conditions modelled, organically dominated landscapes (45 % arable / 40 % grassland / 15 % fallow) always decreased runoff in comparison to conventionally dominated landscapes (60 % arable / 25 % grassland / 15 % fallow). This has implications for cost savings through reduced flood likelihood especially in wet climatic regions where the most significant reductions in runoff (up to 47 %) were seen. In wet climatic regions, there is a reduction from the 1 in 10 year return period to the 1 in 1.5 return period; which is a huge reduction in flood severity and would reduce damage costs to a residential property and agriculture land substantially. Flood damage costs to residential properties were reduced by 33 %, 47 % and 100 % for dry, intermediate and wet respectively. This would also prevent loss of productive agricultural land saving £300 ha^{-1} for arable land and £1200 ha^{-1} for grassland. Therefore, organic farming can provide increased infiltration rates and reduced runoff rates which would help mitigate against flooding.

6.4 Economics of flood prevention

It has widely been acknowledged that agriculture plays a key part in diffuse pollution and flooding (Merrington *et al.*, 2002). As this research has shown, changing land management system can influence the amount of flooding and runoff at all scales measured. However, as shown at Aberdeen (sandy silt loam) in the plot scale study, organic farming produces a lower yield in comparison to conventional farming. For the sandy silty loam soil where there was spring oats grown on both land management systems; yield was reduced by up to 2 % on organically managed land. Whilst this is not a large reduction in yield, values can vary according to soil texture and climatic conditions. Therefore, farmers in high risk areas for runoff and flooding need to be encouraged to manage fields with typically organic practices. This includes reducing livestock density on grassland and increasing grassland leys within arable rotations. As farmers will be providing a public good (reduction in flooding) they cannot be expected to internalise all the costs of conversion such as reduced yields. However, as existing agri-environmental schemes and CAP are due another reform in 2013 which would potentially reduce funding; the financial support needs to come from other sources (EC, 2010). Hence, flood insurance companies (who would benefit through reducing floods) could make allowances for farmers providing this ecosystem service through reducing conversion costs and barriers to conversion for the farmers.

This study was not biased towards organic farming and investigated the effects for typical small mixed rotational farms. The main finding was that infiltration rates for organically managed land was always equal to or greater than conventionally managed land. On grassland (field scale) this is thought to be due to a reduction in stocking density or other management factors which were not tested. On arable land improved infiltration rates are thought to be due to an improvement in maximum water holding capacity. Therefore, organic farming or practices inherent within this farming system such as a reduced stocking density, increased amount of grassland in the rotation and higher incorporation of organic amendments can provide ecosystem service benefits through the reduction of flooding at the catchment scale. Hence measures should be recommended to encourage conventional farms to address these issues with greater vigour.

7 Conclusions

This research has reviewed existing data; highlighting research gaps regarding the differences between organic and conventional agriculture on soil properties and hydrology. The main conclusions from each study (plot scale, field scale and catchment scale modelling) have been shown in Chapters 3, 4 and 5 and integrated in Chapter 6. This chapter presents overall conclusions from the research and highlights advice on best soil management practices for flood prevention. Finally, suggestions for further research are offered.

7.1 Overall Conclusions

The main conclusions which can be drawn are as follows:

1. There is little direct benefit on soil physical and chemical condition for organic farming practices but equally there is no detrimental effect. Any differences depend upon the sampling resolution, whether at the plot, field or catchment scale. The results from the field scale study show that there were no significant differences between organic and conventional management for any of the soil physical properties measured (Soil Organic Carbon (SOC), shear strength, field capacity, aggregate stability and Atterberg Limits). There were fewer traces of indentified pesticides and herbicides in organic fields compared to conventional fields. The pesticide and herbicide levels recorded were less than the current thresholds that are considered detrimental to the environment for both agricultural management systems.

   The results from the plot scale study show that organically managed land had higher (shear strength, aggregate stability) depending upon soil texture. SOC was higher in organically managed land only in the clay loam soil which had been managed organically for the longest time period (50 years). There was a seasonal change in SOC which was cyclic with the same trends being present across all three soil textures. There were no significant differences for soil pH or total C:N ratio between organically and conventionally managed land. For the other soil properties, the effects of organic farming may cause increases or decreases in the property value dependent on soil texture.

Therefore, it can be concluded that the variability found in this research between organic and conventional agriculture agrees with the comparative literature (Stolze *et al.*, 2000). Any differences between organic and conventional management on soil physical properties were predominately influenced by:

- length of time the land had been managed organically (longer time since conversion increased likelihood of a significant difference between alternative management)
- soil texture (increasing amount of clay or heavier textured soils reduced the likelihood of a significant difference between alternative management)
- land use (grassland improved soil physical properties compared to arable land)

These differences are related to the complex interactions between previous land use, current cropping cycle and tillage regime.

2. Tillage regime whether reduced or traditionally ploughed makes a difference to soil quality. The differences were similar in both organically and conventionally managed land. The effects of tillage regime may cause improvements or decreases in the soil properties measured which is dependent on soil texture. However, the benefits of reduced tillage are not felt in the short-term (Carter, 1994); so may not have shown in this two year duration study.
    - There is a benefit for reduced tillage for: SOC, maximum water holding capacity, plastic limits and shear strength. However, the level of improvement varies with soil texture
    - There is a benefit for ploughed treatments for: yield and infiltration rates. However, it is important to note that the heavier (clay) the soil texture the less likely the tillage regime is to make a significant difference

3. For small mixed rotational farming systems organically managed land always has a higher infiltration rate compared to conventionally managed land. The results from the field scale study, show that there was evidence to support the suggestion that infiltration rates are greater on organically managed grassland (7.62 mm hr^{-1}) than conventional grassland (2.53 mm hr^{-1}) across all soil textures. This is probably due

to lower stocking densities (1.3 Livestock Units (LSU) compared to 1.1 LSU, Sutherland *et al.*, 2011). However, no difference was determined between organic and conventional arable land.

The results from the plot scale study, show that organically managed arable land had a greater infiltration rate compared to conventionally managed arable land; the extent of the variation depended upon soil texture. This significant difference was for the sandy silt loam and clay loam; however there was no significant difference for the clay soil. The lack of difference most likely due to the length of time under organic managed (which is eight years for the clay – the shortest in the plot scale study). The difference between organically and conventionally managed land is probably due to an increase in grass leys within organic management which would help improve soil structure and continuity of pores. This is shown through an increase in maximum water holding capacity of organically managed soils of up to 6 % compared to conventionally managed soils. There was also a difference due to tillage regime where ploughing had a higher infiltration rate up to 41 % compared to reduced tillage with the magnitude of the difference depending on soil texture. This is because any benefit in infiltration rates from reduced tillage on soil pore connectivity would not be felt in a short-duration (two year study).

4. Overall, in the modelled catchment, there is a decreased amount of runoff in organically dominated catchment compared to conventionally dominated catchment across the three different climatic conditions. For example, converting a conventionally dominated catchment (60 % arable / 25 % grass / 15 % fallow) to organically dominated catchment (45 % arable / 40 % grass / 15 % fallow) would reduce flood severity:
    - In dry conditions: the 1 in 10 year to 1 in 5 year and if fallow removed to 1 in 2 year
    - In intermediate conditions: 1 in 10 year to 1 in 3 year and if fallow removed to 1 in 1.25 year
    - In wet conditions: 1 in 10 year to 1 in 3 year and if fallow removed to 1 in 2 year

This helps to reduce the flood return period and the decrease damage to residential property and agricultural land. This could have an economic benefit through substantially reducing flood damage costs to residential properties (by 33 %, 47 % and 100 % for dry, intermediate and wet respectively) and prevent loss of productive agricultural land where the gross profit margins are £300 ha^{-1} for arable land and £1200 ha^{-1} for grassland (FHRC, 2010). The largest saving is found in the wettest climatic conditions where there is greater potential to reduce flood damage on residential properties and agricultural land.

5. This project has looked at soil properties at different scales: field, plot and catchment. This was important in the **RELU** (field scale) study for the biodiversity aspects such as bird populations; however it was not important for individual soil properties. However, soil properties which are altered by management become more important at the landscape scale for potential runoff production. Therefore, differences in organically and conventionally managed land can be attributed to the effect of scale. In the field scale studies, reduced control over spatial distance between organic and conventional fields and soil series matches meant that statistical analysis was more complex. The differences were analysed in a hierarchical nested design for land use and management. However, differences in soil texture produced an unbalanced design so restricted maximum likelihood (REML) was used to improve interpretation of the data. In the plot scale studies, spatial distance between sites was reduced and soil texture was identical on organically and conventionally managed land; therefore repeated measures factorial analysis was used without the difficulties shown in the field scale study. This highlights the importance of incorporating soil texture within the experimental design to enable best statistical analysis and interpretation of the data.

6. The first part of this research (field scale - Chapter 3) was part of a multidisciplinary project; which enabled several disciplines to collectively address a common set of research questions. This process was challenging; as the chosen farms needed to meet the requirements of ecologists, economists, cultural geographers and soil scientists. Often the needs were not complementary; and some of the needs, such as

neighbouring fields by the soil scientists, were compromised. Multidisciplinary research is more time consuming and misunderstanding the terminology between different disciplines can lead to communications difficulties. However, the process can help to provide more holistic solutions to problems facing the environment.

In summary, this research has shown that when comparing organic and conventional farming at different scales (field, plot and catchment), different climatic conditions and over a range of soil textures; some soil physical properties show a benefit when the land is managed organically. In the initial field scale study, there was no effect due to organic management (except for infiltration rates); however the techniques employed had the resolution to detect differences in land use (grass or arable) and soil textures. This provides confidence in the results of both the field and plot scale studies. The main finding was that organically managed land (both arable at the plot scale, and grassland at the field scale) improved infiltration rates in comparison to conventionally managed land. This can be related to improved soil structure and less degradation in grass land fields and improved maximum water holding capacity in arable fields. This has implications for significantly reducing potential runoff and hence reducing flood severity risk from a 1 in 10 year to typically a 1 in 1.25 to 1 in 5 year event. Although, the reader should be reminded of the main caveat concerning this finding, that the data was obtained using Decagon tension infiltrometer.

7.2 Recommendations for farmers and land owners

The Code of Good Agricultural Practices (CGAP) (Defra, 2009b) also advocates the importance of good soil management to ensure sustainability of farming systems. The recommendations below are in addition to following the advice in CGAP; and mainly aim to help to maintain SOC and prevent its loss from the agricultural system. From the findings presented in the plot, field and modelled catchment scales there was an increase in infiltration rate, hence reducing runoff through managing the land organically. As previously highlighted the main factors (Cooper and Melchett, 2009) which are thought to differentiate between organically and conventionally managed land are:

- Frequent applications of FYM or other organic manures

- Reduced stocking intensity (to 1.1 LSU) and increase rotational grazing on grassland
- Greater inclusion of grass / clover leys and green manures within the arable rotations
- Reduced number of passes, depth, weight and tyre pressures of machinery during field operations

These practices are not inherent organic practices however they are rarely practiced by conventional farms. This research does not recommend converting to no tillage systems as the benefits are not felt in the short-term but reducing the number of passes and depth of operations would provide benefits. It should be noted that there may be increased issues of weed control, such as black grass, particularly in organically managed soils so eliminating tillage completely on these systems would not be practicable. This research would recommend that it is not necessary for the farm to convert to certified organic as there may not be a financial benefit. However inclusion of these typically organic practices on conventional farms could produce beneficial results for improving soil quality, infiltration rates and reducing runoff.

7.3 Recommendations for further research

This research has highlighted some areas which would require scientific research to further knowledge. The **SCS-CN** model whilst a useful tool was based on in field measurements of infiltration. These measurements were taken using a Decagon minidisc tension infiltrometer which only has a small surface diameter (50 mm) even with replicates it is important to state this limitation. Therefore, in order to validate the model findings catchment specific runoff measurements would be advised in addition to infiltration measurements. The hydrological consequences of farming management practices also depend on cultivation patterns at the catchment scale, which may limit the usefulness of considering management changes at the individual field or farm scale (Hess *et al.*, 2010). Therefore, further research into the effects of changing land management at the sub catchment scale on water retention and flood mitigation through 'Catchment Sensitive Farming' initiatives (Environment Agency, 2009) is recommended.

Although this research has focused on soil physical, chemical and hydrological properties; it is important to remember that these can also have an impact by the soil microbial communities. Research into the changes in microbial communities through changing tillage regime, addition of amendments or changing land management have been completed (Cong *et al.*, 2006, Birkhofer *et al.*, 2008); however not in conjunction with soil properties and effects on hydrology (flooding likelihood).

Finally, Thomasson (1987) created a model that is able to predict the number of work days for autumn and spring periods based upon soil series and climatic data. This was updated by Thomasson and Jones (1989) and Rounsevell and Jones (1993). However, this model does not have the resolution to detect differences due to land management (organic or conventional) based on the same soil texture. Further research into the impacts of changing the SOC content on work days would be beneficial to help highlight differences due to land management particularly in a changing climate. Further research into seasonal changes in SOC would help to provide explanations into the cyclic trend which was determined in Chapter 4 (plot scale study).

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Appendix A: Methodology for locating paired farms

This first part of the research was multidisciplinary (shown in Chapter 3). It involved the selection of representative and comparable set of 32 focal farms, arranged as paired organic and conventional farms set in organic-dominated (hot spot) and conventional-dominated (cold spot) landscapes. These were indentified using a 10 by 10 km moving window to locate cold spot (< 2% organic farming with a maximum of two organic farms) and hot spot (> 10 % organic farming with minimum of two organic farms). The results are shown in Figure A.1.

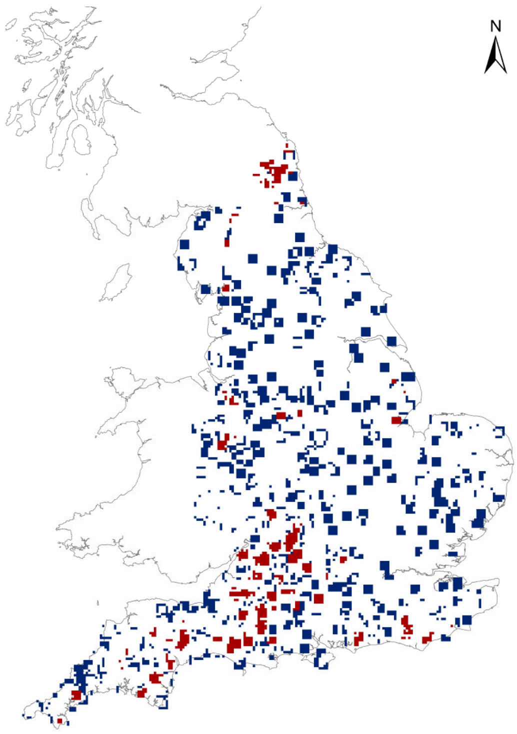

Figure A.1: Location of organic farming in England (Gabriel *et al.*, 2009). Red (hot spot) represents areas with a higher concentration of organic farms and blue (cold spot) represents higher concentrations of conventional farms.

Environmental analysis was also included to account for topography, weather, climate, land cover, soil and hydrology. These were overlaid with the hot and cold spot maps to identify the best matching pairs of organic and conventional farms. The organic farms were located through the Soil Association of growers; they were contacted and a neighbouring conventional farm was approached to participate within the study. For each paired organic and conventional farm criteria had to be met for each member of the multidisciplinary team to complete their part of the study. These were as follows:

- Similar in enterprise type and size
- Similar in soil type
- Close proximity
- Arable and pasture

This was not always possible at each of the 32 paired farms; allowances were made often resulting in not identical soil textures at each farm. Therefore, a further study involving three paired focal farms where the soil texture was identical was established. These organic farms were identified through contacts provided by the Organic Research Centre. The topography, weather and climate, land cover (arable) of the two farms were similar or identical. Five farms were visited, soil samples were collected from both the organic and conventional farm and analysed for soil texture prior to establishing the trials. Two farms were rejected due to differences in soil texture between organic and conventional fields (Table A.1). The farms chosen encompassed a range of soil textures (clay, clay loam and sandy silt loam) and were generally closer in proximity than the fields sampled in the field scale study (Chapter 3).

Table A.1: Topsoil textural classes for the five farms visited prior to establishing the trial.

	Farm A	Farm B	Farm C	Farm D	Farm E
Organic	Clay	Clay loam	Sandy silt loam	Clay	Silt Loam
Conventional	Clay	Clay loam	Sandy silt loam	Clay loam	Sandy Loam

Appendix B: Land Use and Management Statistical Analysis

REML (restricted maximum likelihood) was used as a post-hoc test with hierarchical generalised linear model; using fixed effects as land use (grass vs. arable) nested in fixed effect land management (organic vs. conventional) and soil textural class as a random effect.

This provided estimate tables of parameters from the mean model. From these tables it is possible to determine whether there is a significant difference between a parameter and the reference parameter.

Table B.1: SOC (mg kg^{-1}) estimates of parameters from mean model. The significance is determined at p=0.01 and this is shown by t (60) being greater than 2.

Parameter	S.E.	t (60)	Significance
Organic vs. Conventional	3.18	0.22	NS
Conventional Grass vs. Conventional Arable	3.17	3.21	↑
Organic Grass vs. Organic Arable	3.31	2.22	↑
Soil texture: Clayey	3.15	0.47	NS
Silty	3.01	1.92	NS
Medium	3.16	-1.37	NS
Coarse	3.22	-0.91	NS

Table B.2: SOM (mg kg^{-1}) estimates of parameters from mean model. The significance is determined at p=0.01 and this is shown by t (60) being greater than 2.

Parameter	S.E.	t (60)	Significance
Organic vs. Conventional	5.44	0.55	NS
Conventional vs. Conventional Arable	5.42	3.56	↑
Organic Grass vs. Organic Arable	5.66	1.99	NS
Soil texture: Clayey	5.62	0.62	NS
Silty	5.38	1.90	NS
Medium	5.63	-1.23	NS
Coarse	5.73	-1.18	NS

Table B.3: Field Capacity (%) estimates of parameters from mean model. The significance is determined at p=0.01 and this is shown by t (60) being greater than 2.

Parameter	S.E.	t (60)	Significance
Organic vs. Conventional	2.97	0.58	NS
Conventional Grass vs. Conventional Arable	2.96	2.72	↑
Organic Grass vs. Organic Arable	3.09	1.64	NS
Soil texture: Clayey	3.09	1.15	NS
Silty	2.96	1.00	NS
Medium	3.09	0.01	NS
Coarse	3.15	-2.07	↓

Table B.4: Aggregate stability (%) estimates of parameters from mean model. The significance is determined at p=0.01 and this is shown by t (60) being greater than 2.

Parameter	S.E.	t (60)	Significance
Organic vs. Conventional	5.66	0.64	NS
Conventional Grass vs. Conventional Arable	5.65	4.34	↑
Organic Grass vs. Organic Arable	5.79	4.10	↑
Soil texture: Clayey	3.34	1.25	NS
Silty	3.18	0.02	NS
Medium	3.35	-0.55	NS
Coarse	3.42	-0.71	NS

Table B.5: Plastic Limit (g kg^{-1}) estimates of parameters from mean model. The significance is determined at p=0.01 and this is shown by t (60) being greater than 2.

Parameter	S.E.	t (60)	Significance
Organic vs. Conventional	29.1	1.47	NS
Conventional Grass vs. Conventional Arable	29.0	2.15	↑
Organic Grass vs. Organic Arable	30.3	0.92	NS
Soil texture: Clayey	31.5	1.95	NS
Silty	30.2	0.11	NS
Medium	31.5	-0.27	NS
Coarse	32.1	-1.75	NS

Table B.6: Liquid Limit (g kg^{-1}) estimates of parameters from mean model. The significance is determined at p=0.01 and this is shown by t (60) being greater than 2.

Parameter	S.E.	t (60)	Significance
Organic vs. Conventional	33.2	0.09	NS
Conventional Grass vs. Conventional Arable	33.1	-0.12	NS
Organic Grass vs. Organic Arable	34.7	0.61	NS
Soil texture: Clayey	47.8	1.98	NS
Silty	46.6	0.70	NS
Medium	47.9	-0.62	NS
Coarse	48.5	-2.02	↓

Table B.7: Plasticity Index (g kg^{-1}) estimates of parameters from mean model. The significance is determined at p=0.01 and this is shown by t (60) being greater than 2.

Parameter	S.E.	t (60)	Significance
Organic vs. Conventional	23.2	-1.71	NS
Conventional Grass vs. Conventional Arable	23.1	2.84	↑
Organic Grass vs. Organic Arable	24.1	-0.07	NS
Soil texture: Clayey	20.5	1.08	NS
Silty	19.5	1.26	NS
Medium	20.6	-0.84	NS
Coarse	21.0	-1.40	NS

Table B.8: Total Inorganic N (g kg^{-1}) estimates of parameters from mean model. The significance is determined at p=0.01 and this is shown by t (60) being greater than 2.

Parameter	S.E.	t (60)	Significance
Organic vs. Conventional	4.32	-4.59	↓
Conventional Grass vs. Conventional Arable	4.31	-3.42	↓
Organic Grass vs. Organic Arable	4.39	0.16	NS
Soil texture: Clayey	1.99	-0.61	NS
Silty	1.91	0.94	NS
Medium	1.99	-0.40	NS
Coarse	2.02	0.11	NS

Table B.9: Total K (g kg^{-1}) estimates of parameters from mean model. The significance is determined at p=0.01 and this is shown by t (60) being greater than 2.

Parameter	S.E.	t (60)	Significance
Organic vs. Conventional	339	-0.12	NS
Conventional Grass vs. Conventional Arable	338	0.16	NS
Organic Grass vs. Organic Arable	350	0.12	NS
Soil texture: Clayey	255	1.48	NS
Silty	242	-0.05	NS
Medium	256	-0.09	NS
Coarse	262	-1.32	NS

Table B.10: Total P (g kg^{-1}) estimates of parameters from mean model. The significance is determined at p=0.01 and this is shown by t (60) being greater than 2.

Parameter	S.E.	t (60)	Significance
Organic vs. Conventional	106	-0.72	NS
Conventional Grass vs. Conventional Arable	106	0.73	NS
Organic Grass vs. Organic Arable	109	0.76	NS
Soil texture: Clayey	67.9	-0.59	NS
Silty	64.4	1.54	NS
Medium	68.2	-0.51	NS
Coarse	69.5	-0.35	NS

Appendix C: Tillage regime and Management Statistical Analysis

As shear strength varies with soil moisture content (Ball *et al.*, 1997); correlation matrix were calculated. This was to ensure that no differences could be attributed to initial moisture contents rather than land management or tillage regime.

C.1: Correlation Matrix for Aberdeen between soil moisture content (%) and shear strength (kPa) where significance ($p < 0.05$) is shown by highlighted cell.

Shear Strength / Moisture content	**Moisture Content** Post Harvest	**Moisture Content** Post Tillage	**Moisture Content** Post Harvest
Shear Strength Post Harvest	0.30	0.73	-0.22
Shear Strength Post Tillage	0.24	0.60	-0.28
Shear Strength Post Harvest	0.35	0.78	-0.24

C.2: Correlation Matrix for East Grinstead between soil moisture content (%) and shear strength (kPa) where $p > 0.05$ (no significant differences).

Shear Strength / Moisture content	**Moisture Content** Post Harvest	**Moisture Content** Post Tillage	**Moisture Content** Post Harvest
Shear Strength Post Harvest	0.21	-0.21	0.22
Shear Strength Post Tillage	0.24	-0.11	0.22
Shear Strength Post Harvest	0.11	0.11	0.18

C.3: Correlation Matrix for Huntingdon between soil moisture content (%) and shear strength (kPa) where $p > 0.05$ (no significant differences).

Shear Strength / Moisture content	**Moisture Content** Post Harvest	**Moisture Content** Post Tillage
Shear Strength Post Harvest	0.22	0.11
Shear Strength Post Tillage	0.11	-0.24

Appendix D: Work day model inputs (Thomasson, 1987)

Thomasson's model for workability involves several different steps to incorporate both climate and soil data. These will now be outlined.

- Firstly, soil assessment based upon the England and Wales (1984) soil survey data provides the soil wetness class. For example, the clay soil was Evesham 1 with wetness class IV and the clay loam was Wickham 3 with wetness class II. This method does not allow for differences in soil organic carbon; so it is not possible to compare two different land management regimes.

Table D.1: Soil moisture regime classes and duration of wet states in most years (Thomasson, 1987).

Wetness Class	Duration of Water logging
I	Soil profile is not waterlogged within 700 mm depth for more 30 days
II	Soil profile is waterlogged within 700 mm for 30- 90 days
III	Soil profile is waterlogged within 700 mm for 90-180 days
IV	Soil profile is waterlogged within 700 mm for more than 180 days but not within 400 mm for more than 180 days

- These wetness classes are combined through Table D.2 to provide a soil class (a-d). Soil textural class determines the water capacity of the soil. For example the clay soil has a high water retention capacity whereas the clay loam has a medium water retention capacity.

Table D.2: Soil assessment relating wetness class with retained water capacity to provide soil class (Thomasson, 1987).

Wetness Class	Retained Water Capacity of Topsoil		
	Low	Medium	High
I	a	a	a
II	a/b	a/b	b/c
III	b/c	c/d	c/d
IV	c/d	d	d

- Current rainfall data (yearly) for the years 2008-2010 was collected from the met-office (2010). The current rainfall data was compared against the rainfall data in Smith and Trafford (1976) to provide evapotranspiration rates. Smith and Trafford (1976) provide early, median and late date estimates for the end of field capacity and return to field capacity. The median value was used; interpolation between recorded rainfall and the values in Smith and Trafford (1976) allowed the correct estimation of dates. There was no allowance for different types of machinery or growing different crops.

- The number of workable days was calculated through difference (days) between end of field capacity and the return to field capacity. This was then corrected for soil type and time of operations (spring or autumn) according to Table D.3. For example, for soil *a* in spring 10 days can be added whereas in autumn 20 days can be added.

Table D.3: Integration of soil (soil assessment classification) and climatic components to estimate potential machinery work days in spring and autumn (Thomasson, 1987).

	a	b	c	d
Spring	+10	0	-5	-10
Autumn	+20	0	-20	-30

Appendix E: SCS-CN Calculations

Table E.1: SCS Calculations for Grassland modelling for the three different climatic conditions for the 1 in 1, 1 in 2 and 1 in 10 yea r rainfall events (Smith and Trafford, 1976).

Land use DRY	Antecedent conditions - average value for annual floods	N number Good	Poor	Hydrological Group (based on infiltration measurement)	Rainfall Depth (P) mm	Direct Runoff (Q) mm Good	Poor	Time to concentration hr Good	Poor	Area	Max. potential difference between rainfall and runoff (S) Good	Poor	Initial Abstraction Good	Poor	Ia/P ratio Good	Poor	Unit Peak discharge (qu) $m^3s^{-1}ha^{-1}mm^{-1}$ Good	Poor	Q Good	Poor	q runoff m^3s^{-1} Good	Poor	Ratio Good to poor
Organic Grass	II	69	79	B	33	3	6	1.16	0.88	550	114.12	67.52	22.82	13.50	0.69	0.02	0.0005	0.0019	0.83	4.37	0.01	0.25	0.05
Conventional Grass	II	79	86	C	33	6	11	0.88	0.69	550	67.52	41.35	13.50	8.27	0.41	0.01	0.0011	0.0021	4.37	9.26	0.14	0.58	0.24
Organic Grass	II	69	79	B	43	7	15	1.16	0.88	550	114.1	67.5	22.8	13.5	0.5	0.0	0.0006	0.0019	3.03	8.97	0.06	0.52	0.11
Conventional Grass	II	79	86	C	43	15	24	0.88	0.69	550	67.5	41.3	13.5	8.3	0.3	0.0	0.0013	0.0021	8.97	15.85	0.36	1.00	0.36
Organic Grass	II	69	79	B	56	10	24	1.16	0.88	550	114.1	67.5	22.8	13.5	0.4	0.0	0.0012	0.0019	7.47	16.42	0.26	0.95	0.27
Conventional Grass	II	79	86	C	56	24	35	0.88	0.69	550	67.5	41.3	13.5	8.3	0.2	0.0	0.0015	0.0021	16.42	25.57	0.73	1.61	0.46
Land use INTERMEDIATE	Antecedent conditions - average value for annual floods	N number Good	Poor	Hydrological Group (based on infiltration measurement)	Rainfall Depth (P) mm	Direct Runoff (Q) mm Good	Poor	Time to concentration hr Good	Poor	Area	Max. potential difference between rainfall and runoff (S) Good	Poor	Initial Abstraction Good	Poor	Ia/P ratio Good	Poor	Unit Peak discharge (qu) $m^3s^{-1}ha^{-1}mm^{-1}$ Good	Poor	Q Good	Poor	q runoff m^3s^{-1} Good	Poor	Ratio Good to poor
Organic Grass	II	69	79	B	45	7	15	1.16	0.88	550	114.12	67.52	22.82	13.50	0.51	0.01	0.0007	0.0020	3.61	10.02	0.07	0.59	0.12
Conventional Grass	II	79	86	C	45	15	24	0.88	0.69	550	67.52	41.35	13.50	8.27	0.30	0.01	0.0013	0.0022	10.02	17.28	0.41	1.14	0.36
Organic Grass	II	69	79	B	52	10	24	1.16	0.88	550	114.12	67.52	22.82	13.50	0.44	0.01	0.0008	0.0019	5.94	13.98	0.14	0.81	0.18
Conventional Grass	II	79	86	C	52	15	35	0.88	0.69	550	67.52	41.35	13.50	8.27	0.26	0.00	0.0012	0.0019	13.98	22.08	0.51	1.30	0.39
Organic Grass	II	69	79	B	66	20	29	1.16	0.88	550	114.12	67.52	22.82	13.50	0.35	0.01	0.0012	0.0019	11.85	22.96	0.43	1.33	0.32
Conventional Grass	II	79	86	C	66	29	40	0.88	0.69	550	67.52	41.35	13.50	8.27	0.20	0.00	0.0015	0.0015	22.96	33.64	1.02	2.11	0.49
Land use WET	Antecedent conditions - average value for annual floods	N number Good	Poor	Hydrological Group (based on infiltration measurement)	Rainfall Depth (P) mm	Direct Runoff (Q) mm Good	Poor	Time to concentration hr Good	Poor	Area	Max. potential difference between rainfall and runoff (S) Good	Poor	Initial Abstraction Good	Poor	Ia/P ratio Good	Poor	Unit Peak discharge (qu) $m^3s^{-1}ha^{-1}mm^{-1}$ Good	Poor	Q Good	Poor	q runoff m^3s^{-1} Good	Poor	Ratio Good to poor
Organic Grass	II	69	79	B	64	20	29	1.16	0.88	550	114.12	67.52	22.82	13.50	0.36	0.01	0.0012	0.0019	10.92	21.61	0.40	1.25	0.32
Conventional Grass	II	79	86	C	64	29	40	0.88	0.69	550	67.52	41.35	13.50	8.27	0.21	0.0	0.0015	0.0021	21.61	31.99	0.96	2.01	0.48
Organic Grass	II	69	79	B	73	25	35	1.16	0.88	550	114.12	67.52	22.82	13.50	0.31	0.0	0.0012	0.0019	15.32	27.87	0.53	1.61	0.33
Conventional Grass	II	79	86	C	73	35	55	0.88	0.69	550	67.52	41.35	13.50	8.27	0.18	0.0	0.0016	0.0021	27.87	39.50	1.33	2.48	0.54
Organic Grass	II	69	79	B	87	30	52	1.16	0.88	550	114.12	67.52	22.82	13.50	0.26	0.0	0.0013	0.0019	23.10	38.31	0.88	2.21	0.40
Conventional Grass	II	79	86	C	87	52	70	0.88	0.69	550	67.52	41.35	13.50	8.27	0.16	0.0	0.0015	0.0021	38.31	51.62	1.71	3.24	0.53

Table E.2: SCS Calculations for arable modelling for the three different climatic conditions for the 1 in 1, 1 in 2 and 1 in 10 year rainfal l events (Smith and Trafford, 1976).

Land use	Antecedent conditions - average value for annual floods	N number Good	N number Poor	Hydrological Group (based on infiltration measurement)	Rainfall Depth (P) mm	Direct Runoff (Q) mm Good	Direct Runoff (Q) mm Poor	Time to concentration hr Good	Time to concentration hr Poor	Area	Max. potential difference between rainfall and runoff (S) Good	(S) Poor	Initial Abstraction Good	Initial Abstraction Poor	Ia/P ratio Good	Ia/P ratio Poor	Unit Peak discharge (qu) $m^3s^{-1}ha^{-1}mm^{-1}$ Good	(qu) Poor	Q Good	Q Poor	q runoff m^3s^{-1} Good	q runoff m^3s^{-1} Poor	Ratio Good to poor
Land use DRY																							
Organic Arable	II	67	72	B	33	3	6	1.23	1.07	550	125.10	98.78	25.02	19.76	0.60	0.02	0.0005	0.0019	0.48	1.57	0.02	0.03	0.89
Conventional Arable	II	78	81	C	33	6	11	0.90	0.82	550	71.64	59.58	14.33	11.92	0.36	0.01	0.0011	0.0021	3.86	5.51	0.18	0.24	0.73
Organic Arable	II	67	72	B	43	7	15	1.23	1.07	550	125.10	98.78	25.02	19.76	0.5	0.0	0.0006	0.0019	2.26	4.43	0.08	0.13	0.64
Conventional Arable	II	78	81	C	43	15	24	0.90	0.82	550	71.64	59.58	14.33	11.92	0.3	0.0	0.0013	0.0021	8.20	10.66	0.43	0.51	0.84
Organic Arable	II	67	72	B	56	10	24	1.23	1.07	550	125.10	98.78	25.02	19.76	0.4	0.0	0.0015	0.0019	6.15	9.73	0.34	0.36	0.95
Conventional Arable	II	78	81	C	56	24	35	0.90	0.82	550	71.64	59.58	14.33	11.92	0.2	0.0	0.0015	0.0021	15.33	18.75	0.84	0.96	0.87
Land use INTERMEDIATE																							
Organic Arable	II	67	72	B	45	7	15	1.23	1.07	550	125.10	98.78	25.02	19.76	0.44	0.01	0.0007	0.0020	2.75	5.14	0.10	0.16	0.63
Conventional Arable	II	78	81	C	45	15	24	0.90	0.82	550	71.64	59.58	14.33	11.92	0.26	0.01	0.0013	0.0022	9.19	11.81	0.48	0.61	0.79
Organic Arable	II	67	72	B	52	10	24	1.23	1.07	550	125.10	98.78	25.02	19.76	0.38	0.01	0.0008	0.0019	4.79	7.34	0.19	0.28	0.69
Conventional Arable	II	78	81	C	52	15	35	0.90	0.82	550	71.64	59.58	14.33	11.92	0.23	0.0	0.0012	0.0019	12.98	16.12	0.59	0.75	0.78
Organic Arable	II	67	72	B	66	20	29	1.23	1.07	550	125.10	98.78	25.02	19.76	0.30	0.0	0.0012	0.0019	10.11	14.75	0.54	0.58	0.92
Conventional Arable	II	78	81	C	66	29	40	0.90	0.82	550	71.64	59.58	14.33	11.92	0.18	0.0	0.0015	0.0021	21.65	25.73	1.15	1.36	0.84
Land use WET																							
Organic Arable	II	67	72	B	64	20	29	1.23	1.07	550	125.10	98.78	25.05	19.76	0.31	0.0	0.0012	0.0019	9.26	13.69	0.50	0.54	0.93
Conventional Arable	II	78	81	C	64	29	40	0.90	0.82	550	71.64	59.58	14.33	11.92	0.19	0.0	0.0015	0.0021	20.34	24.29	1.08	1.28	0.85
Organic Arable	II	67	72	B	73	25	35	1.23	1.07	550	125.40	98.78	25.05	19.76	0.27	0.0	0.0012	0.0019	13.30	18.65	0.65	0.77	0.84
Conventional Arable	II	78	81	C	73	35	55	0.90	0.82	550	71.64	59.58	14.33	11.92	0.16	0.0	0.0016	0.0021	26.42	30.92	1.48	1.66	0.89
2Organic Arable	II	67	72	B	87	30	52	1.23	1.07	550	125.10	98.78	25.05	19.76	0.23	0.0	0.0013	0.0019	20.53	27.24	1.03	1.19	0.87
Conventional Arable	II	78	81	C	87	52	70	0.90	0.82	550	71.64	59.58	14.33	11.92	0.14	0.0	0.0015	0.0021	36.60	41.86	1.87	2.30	0.81

Table E.3: SCS Calculations for current landscape modelling for the three different climatic conditions for the 1 in 1, 1 in 2 and 1 in 10 year rainfall events (Smith and Trafford, 1976).

Landscape DRY	Land use	% in catchment	Antecedent conditions for annual flood	N Number Good	N Number Poor	Weighted average N number Good	Weighted average N number Poor	Hydrological group	Rainfall depth (mm)	Direct runoff (Q) Good	Direct runoff (Q) Poor	Time to concentration Good	Time to concentration Poor	Area	Maximum potential difference between rainfall and runoff Good	Maximum potential difference between rainfall and runoff Poor	Initial abstraction Good	Initial abstraction Poor	Ia / P ratio Good	Ia / P ratio Poor	Unit peak discharge (qu) good	Unit peak discharge (qu) poor	Q Good	Q poor	q runoff good	q runoff poor	Ratio good to poor
Conventionally dominated landscape	Arable	0.6	II	78	81	79.45	83	B	33	5	7	0.86	0.77	550	65.70	52.02	13.14	10.40	0.40	0.32	0.0011	0.0014	4.61	6.84	0.15	0.29	1.98
	Grassland	0.25	II	79	86			C	33	5	7																
	Bareland	0.15	II	86	86			B	33	5	7																
Organically dominated landscape	Arable	0.45	II	78	81	75.6	80.95	B	33	3	6.5	0.97	0.82	550	81.98	59.77	16.40	11.95	0.50	0.36	0.0007	0.0012	2.80	5.48	0.06	0.19	3.24
	Grassland	0.4	II	69	79			B	33	3	6.5																
	Bareland	0.15	II	86	86			B	33	3	6.5																
Conventionally dominated landscape	Arable	0.6	II	78	81	79.45	83	B	43	11	18	0.86	0.77	550	65.70	52.02	13.14	10.40	0.31	0.24	0.0014	0.0017	9.33	12.56	0.39	0.63	1.61
	Grassland	0.25	II	79	86			C	43	11	18																
	Bareland	0.15	II	86	86			B	43	11	18																
Organically dominated landscape	Arable	0.45	II	78	81	75.6	80.95	B	43	10	12	0.97	0.82	550	81.98	59.77	16.40	11.95	0.38	0.28	0.0014	0.0016	6.52	10.61	0.27	0.51	1.85
	Grassland	0.4	II	69	79			B	43	10	12																
	Bareland	0.15	II	86	86			B	43	10	12																
Conventionally dominated landscape	Arable	0.6	II	78	81	79.45	83	B	56	22	30	0.86	0.77	550	65.70	52.02	13.14	10.40	0.23	0.19	0.0016	0.0017	16.92	21.30	0.81	1.06	1.30
	Grassland	0.25	II	79	86			C	56	22	30																
	Bareland	0.15	II	86	86			B	56	22	30																
Organically dominated landscape	Arable	0.45	II	78	81	75.6	80.95	B	56	18	25	0.97	0.82	550	81.98	59.77	16.40	11.95	0.29	0.21	0.0013	0.0016	12.90	18.69	0.52	0.89	1.71
	Grassland	0.4	II	69	79			B	56	18	25																
	Bareland	0.15	II	86	86			B	56	18	25																

Landscape MEDIUM	Land use	% in catchment	Antecedent conditions for annual flood	N Number Good	N Number Poor	Weighted average N number Good	Weighted average N number Poor	Hydrological group	Rainfall depth (mm)	Direct runoff (Q) Good	Direct runoff (Q) Poor	Time to concentration Good	Time to concentration Poor	Area	Maximum potential difference between rainfall and runoff Good	Maximum potential difference between rainfall and runoff Poor	Initial abstraction Good	Initial abstraction Poor	Ia / P ratio Good	Ia / P ratio Poor	Unit peak discharge (qu) good	Unit peak discharge (qu) poor	Q Good	Q poor	q runoff good	q runoff poor	Ratio good to poor
Conventionally dominated landscape	Arable	0.6	II	78	81	79.45	83	B	45	15	25	0.86	0.77	550	65.70	52.02	13.14	10.40	0.29	0.23	0.0011	0.0014	10.40	13.82	0.34	0.59	1.77
	Grassland	0.25	II	79	86			C	45	15	25																
	Bareland	0.15	II	86	86			B	45	15	25																
Organically dominated landscape	Arable	0.45	II	78	81	75.6	80.95	B	45	13	24	0.97	0.82	550	81.98	59.77	16.40	11.95	0.36	0.27	0.0007	0.0012	7.40	11.76	0.16	0.43	2.69
	Grassland	0.4	II	69	79			B	45	13	24																
	Bareland	0.15	II	86	86			B	45	13	24																
Conventionally dominated	Arable	0.6	II	78	81	79.45	83	B	52	20	25	0.86	0.77	550	65.70	52.02	13.14	10.40	0.25	0.20	0.0015	0.0017	14.44	18.48	0.64	0.92	1.42

landscape																										
	Grassland	0.25	II	79	86			C	52	20	25															
	Bareland	0.15	II	86	86			B	52	20	25															
Organically dominated landscape	Arable	0.45	II	78	81	75.6	80.95	B	52	12	22	0.97	0.82	550	81.98	59.77	16.40	11.95	0.32	0.23	0.0013	0.0015	10.78	16.07	0.41	0.72	1.75
	Grassland	0.4	II	69	79			B	52	12	22															
	Bareland	0.15	II	86	86			B	52	12	22															
Conventionally dominated landscape	Arable	0.6	II	78	81	79.45	83	B	66	29	35	0.86	0.77	550	65.70	52.02	13.14	10.40	0.20	0.16	0.0015	0.0017	23.57	28.72	1.09	1.47	1.35
	Grassland	0.25	II	79	86			C	66	29	35															
	Bareland	0.15	II	86	86			B	66	29	35															
Organically dominated landscape	Arable	0.45	II	78	81	75.6	80.95	B	66	25	30	0.97	0.82	550	81.98	59.77	16.40	11.95	0.25	0.18	0.0013	0.0015	18.70	25.66	0.76	1.14	1.51
	Grassland	0.4	II	69	79			B	66	25	30															
	Bareland	0.15	II	86	86			B	66	25	30															

Landscape WET	Land use	% in catchment	Antecedent conditions for annual flood	N Number Good	Poor	Weighted average N number Good	Poor	Hydrological group	Rainfall depth (mm)	Direct runoff (Q) Good	Poor	Time to concentration Good	Poor	Area	Maximum potential difference between rainfall and runoff Good	Poor	Initial abstraction Good	Poor	Ia / P ratio Good	Poor	Unit peak discharge (qu) good	poor	Q Good	poor	q runoff good	poor	Ratio good to poor
Conventionally dominated landscape	Arable	0.6	II	78	81	79.45	83	B	64	29	35	0.86	0.77	550	65.70	52.02	13.14	10.40	0.21	0.16	0.0016	0.0016	22.19	27.20	1.06	1.33	1.25
	Grassland	0.25	II	79	86			C	64	29	35																
	Bareland	0.15	II	86	86			B	64	29	35																
Organically dominated landscape	Arable	0.45	II	78	81	75.6	80.95	B	64	25	30	0.97	0.82	550	81.98	59.77	16.40	11.95	0.26	0.19	0.0014	0.0016	17.49	24.22	0.75	1.18	1.57
	Grassland	0.4	II	69	79			B	64	25	30																
	Bareland	0.15	II	86	86			B	64	25	30																
Conventionally dominated landscape	Arable	0.6	II	78	81	79.45	83	B	73	39	46	0.86	0.77	550	65.70	52.02	13.14	10.40	0.18	0.14	0.0016	0.0018	28.54	34.18	1.37	1.81	1.32
	Grassland	0.25	II	79	86			C	73	39	46																
	Bareland	0.15	II	86	86			B	73	39	46																
Organically dominated landscape	Arable	0.45	II	78	81	75.6	80.95	B	73	31	40	0.97	0.82	550	81.98	59.77	16.40	11.95	0.22	0.16	0.0015	0.0015	23.12	30.84	1.03	1.43	1.38
	Grassland	0.4	II	69	79			B	73	31	40																
	Bareland	0.15	II	86	86			B	73	31	40																
Conventionally dominated landscape	Arable	0.6	II	78	81	79.45	83	B	87	52	60	0.86	0.77	550	65.70	52.02	13.14	10.40	0.15	0.12	0.0016	0.0018	39.09	45.61	1.87	2.49	1.33
	Grassland	0.25	II	79	86			C	87	52	60																
	Bareland	0.15	II	86	86			B	87	52	60																
Organically dominated landscape	Arable	0.45	II	78	81	75.6	80.95	B	87	45	55	0.97	0.82	550	81.98	59.77	16.40	11.95	0.19	0.14	0.0014	0.0016	32.67	41.77	1.40	2.00	1.43
	Grassland	0.4	II	69	79			B	87	45	55																
	Bareland	0.15	II	86	86			B	87	45	55																

Table E.4: SCS Calculations for future landscape modelling for the three different climatic conditions for the 1 in 1, 1 in 2 and 1 in 10 year rainfall events (Smith and Trafford, 1976). Only one future scenario is presented as all the calculations were the same.

Landscape DRY	Land use	% in catchment	Antecedent conditions for annual flood	N Number Good	N Number Poor	Weighted average N number Good	Weighted average N number Poor	Hydrological group	Rainfall depth (mm)	Direct runoff (Q) Good	Direct runoff (Q) Poor	Time to concentration Good	Time to concentration Poor	Area	Maximum potential difference between rainfall and runoff Good	Maximum potential difference between rainfall and runoff Poor	Initial abstraction Good	Initial abstraction Poor	Ia / P ratio Good	Ia / P ratio Poor	Unit peak discharge (qu) good	Unit peak discharge (qu) poor	Q Good	Q poor	q runoff good	q runoff poor	Ratio good to poor
Future landscape	Arable	0.45	II	78	81	62.7	68.05	B	33	2	2	1.37	1.19	550	151.10	119.25	30.22	23.85	0.72	0.92	0.0004	0.0007	0.05	0.65	0.01	0.05	0.29
	Grassland	0.55	II	69	79			B	33																		
Future landscape	Arable	0.45	II	78	81	62.7	68.05	B	33	4	5	1.37	1.19	550	151.10	119.25	30.22	23.85	0.55	0.70	0.0004	0.0006	1.00	2.65	0.05	0.1	
	Grassland	0.55	II	69	79			B	33																		
Future landscape	Arable	0.45	II	78	81	62.7	68.05	B	43	5	8	1.37	1.19	550	151.10	119.25	30.22	23.85	0.43	0.54	0.00006	0.0009	3.76	6.83	0.07	0.19	0.37
	Grassland	0.55	II	69	79			B	43																		

Landscape MEDIUM	Land use	% in catchment	Antecedent conditions for annual flood	N Number Good	N Number Poor	Weighted average N number Good	Weighted average N number Poor	Hydrological group	Rainfall depth (mm)	Direct runoff (Q) Good	Direct runoff (Q) Poor	Time to concentration Good	Time to concentration Poor	Area	Maximum potential difference between rainfall and runoff Good	Maximum potential difference between rainfall and runoff Poor	Initial abstraction Good	Initial abstraction Poor	Ia / P ratio Good	Ia / P ratio Poor	Unit peak discharge (qu) good	Unit peak discharge (qu) poor	Q Good	Q poor	q runoff good	q runoff poor	Ratio good to poor
Future landscape	Arable	0.45	II	78	81	62.7	68.05	B	45	4	5	1.37	1.19	550	151.10	119.25	30.22	23.85	0.67	0.53	0.0005	0.0007	1.32	3.19	0.02	0.06	0.31
	Grassland	0.55	II	69	79			B	45																		
Future landscape	Arable	0.45	II	78	81	62.7	68.05	B	45	8	5	1.37	1.19	550	151.10	119.25	30.22	23.85	0.46	0.58	0.0004	0.0008	2.74	5.38	0.04	0.12	0.29
	Grassland	0.55	II	69	79			B	45																		
Future landscape	Arable	0.45	II	78	81	62.7	68.05	B	52	18	10	1.37	1.19	550	151.10	119.25	30.22	23.85	0.36	0.43	0.0007	0.0010	7.80	11.27	0.14	0.35	0.41
	Grassland	0.55	II	69	79			B	52																		

Landscape WET	Land use	% in catchment	Antecedent conditions for annual flood	N Number Good	N Number Poor	Weighted average N number Good	Weighted average N number Poor	Hydrological group	Rainfall depth (mm)	Direct runoff (Q) Good	Direct runoff (Q) Poor	Time to concentration Good	Time to concentration Poor	Area	Maximum potential difference between rainfall and runoff Good	Maximum potential difference between rainfall and runoff Poor	Initial abstraction Good	Initial abstraction Poor	Ia / P ratio Good	Ia / P ratio Poor	Unit peak discharge (qu) good	Unit peak discharge (qu) poor	Q Good	Q poor	q runoff good	q runoff poor	Ratio good to poor
Future landscape	Arable	0.45	II	78	81	62.7	68.05	B	64	10	18	1.37	1.19	550	151.10	119.25	30.22	23.85	0.47	0.37	0.0008	0.0010	6.17	10.11	0.14	0.31	0.45
	Grassland	0.55	II	69	79			B	64																		
Future landscape	Arable	0.45	II	78	81	62.7	68.05	B	64	15	25	1.37	1.19	550	151.10	119.25	30.22	23.85	0.41	0.33	0.0008	0.0011	9.44	14.34	0.23	0.47	0.49
	Grassland	0.55	II	69	79			B	64																		
Future landscape	Arable	0.45	II	78	81	62.7	68.05	B	73	21	30	1.37	1.19	550	151.10	119.25	30.22	23.85	0.35	0.27	0.0010	0.0012	15.51	21.86	0.49	0.78	0.63
	Grassland	0.55	II	69	79			B	73																		

Appendix F Conference and published papers

Hathaway-Jenkins, L.J., Dresser, M., Godwin, R.J., Palmer, R.C., Sakrabani, R. (2008) 'A comparison of the effects of conventional and organic farming practices on soil properties' in the Proceedings of Biannual SAC / SEPA conference Edinburgh 26th-27th March 2008

Hathaway-Jenkins, L.J. Dresser, M., Godwin, R.J., Palmer, R.C., Sakrabani, R. (2008) 'A Comparison of the Effects of Conventional and Organic Farming Practices on Soil Properties in the UK' in the Proceedings of ASABE (American Society of Agricultural and Biological Engineers) Annual International Meeting (Providence, RI, USA) [Paper No. 084591] ASABE, St. Joseph, MI (49085-9659) 29th June – 2nd July 2008

Hathaway-Jenkins, L.J. Dresser, M., Godwin, R.J., Palmer, R.C., Sakrabani, R. (2008) 'A comparison of the effects of conventional and organic farming practices on soil physical and hydraulic properties in the UK,' Eurosoil 2008 [S07.N.04] Technical University of Vienna, Austria, 25th – 29th August 2008

Hathaway-Jenkins, L.J., Godwin, R.J., Hann, M., Sakrabani, R. (2009) 'A comparison of the effects of conventional and organic farming practices on soil physical and hydraulic properties in the UK,' Young Scientists, University of Reading, April 2009

Hathaway-Jenkins, L.J. (2010) 'Agricultural management impacts on soil physical structure and infiltration rates' ORC Organic Producers Conference, Harper Adams, 7th -9th January 2010

Hathaway-Jenkins, L.J., Godwin, R.J., Hann, M., Sakrabani, R. (2010) 'A comparison of the effects of conventional and organic farming practices on soil physical and hydraulic properties in the UK' SAC/SEPA Climate, Water & Soil: Science, Policy & Practice Biennial Conference, Edinburgh 31st March-1st April 2010

Hathaway-Jenkins, LJ., Godwin, RJ., Pearce, B., Sakrabani R. and Whitmore A. (2010) 'Comparing tillage regimes for conventional and organic farming practices on soil physical and hydrological properties' SAC/SEPA Climate, Water & Soil: Science, Policy & Practice Biennial Conference, Edinburgh 31st March-1st April 2010

Hathaway-Jenkins, L.J., Godwin, R.J., Pearce, B., Sakrabani R. and Whitmore A. (2010) 'A comparison between conventional and organic farming practices 1: Soil physical properties,' 19th World Congress on Soil science, Soil solutions for a changing world, Brisbane Australia, 1st-6th August 2010

Hathaway-Jenkins, L.J., Godwin, R.J., Pearce, B., Sakrabani R. and Whitmore A. (2010) 'A comparison between conventional and organic farming practices 2: Soil hydraulic properties,' 19th World Congress on Soil science, Soil solutions for a changing world, Brisbane Australia, 1st-6th August 2010

Sutherland, L., D. Gabriel, L. Hathaway-Jenkins, D. Rigby, U. Schmutz, U. Pascal, R. Godwin, S.M. Sait, R. Sakrabani, W.E. Kunin, T.G. Benton and S. Stagl. (2011 Under review). The 'Neighbourhood Effect': A multidisciplinary assessment of the case for farmer co-ordination in agri-environmental programmes. Submitted to Land Use Policy.

Hathaway-Jenkins, L.J., Sakrabani, R., Pearce, B., Whitmore, A.P. and Godwin, R.J. (2011) **'**A Comparison of Soil and Water Properties in Organic and Conventional Farming Systems in England,' Accepted 16th February 2011 for publishing Soil Use and Management

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A comparison of soil and water properties in organic and conventional farming systems in England

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Abstract

Organic farming and improvements to agricultural sustainability are often seen as synonymous. However, an extensive European review demonstrated that in practice this is not always true. This study aims to compare the status of soil and water properties between separate fields managed in either an organic or a conventional manner. Soil samples were collected from 16 pairs of farms, throughout England, with both arable and grass fields within each pair on similar soil type. Chemical (nutrients, pesticides, herbicides) and physical (aggregate stability, field capacity, shear strength, soil organic matter, infiltration rates) soil properties were measured in four main soil texture classes in organic and conventional fields. The physical soil properties varied significantly between the different classes of texture and land use. The heavier textured soils have significantly higher soil organic carbon (SOC), aggregate stability and shear strength. The coarse-textured soils have significantly lower field capacity moisture contents. The grassland has a significantly higher level of SOC, field capacity moisture content, aggregate stability and soil shear strength. However, there were no significant differences between organic and conventional treatments for any of the soil physical properties measured. There were fewer traces of agrochemicals in the soil water from the organic fields compared with the conventionally managed fields. The conventional arable fields had higher levels of total inorganic nitrogen than the other land uses and treatments. There was evidence to show that infiltration rates were significantly higher on organically managed grassland soils (7.6 mm/h) than conventionally managed grassland (2.5 mm/h) with lower stocking rates. The results suggest that improved grassland management, whether organic or conventional, could reduce predicted runoff by 28%.

Keywords: Organic and conventional agriculture, infiltration rate, aggregate stability, SOC

Introduction

Changing UK policy relating to farming practices has fuelled the debate over the relative merits of organic and conventional management, especially regarding the issues of sustainability, leaching and agricultural pollution. Generally, conventional farming (nonorganic) has inputs of fertilizers, herbicides and pesticides which result in higher yields than organic farming, but is considered by some as non-sustainable because of the high inputs (Byrne, 1997). Organic farming, governed by various sources of legislation, aims to reduce the reliance on external inputs, obtain nutrients from organic sources and promote good soil management techniques but its lower yields require premium prices to secure economic sustainability (Lampkin, 1999). Sustainable management is crucial to the maintenance of soil structure and organic matter (SOM) levels especially if the availability of water and nutrients as well as ease of soil workability is to be maintained (Pulleman *et al*., 2003). Stolze *et al*. (2000) review the literature comparing organic and conventional farms with respect to soil properties, microbiology and nutrient analysis, which was updated by Armstrong Brown *et al*. (2000), Marinari *et al*. (2006), Mulumba & Lal (2008), Pulleman *et al*. (2003) and Parfitt *et al*. (2005). A summary of the main findings is shown in Table 1; different studies found contrasting results to highlight the difficulty in performing comparative studies between different farming techniques

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Table 1 The effect of organic farming on four soil characteristics: whether beneficial (+/++), no change (NC) or a negative affect (−) when compared with conventional farming methods in Europe (adapted from Stolze *et al.*, 2000). Data are the number of studies in each category

Soil properties	++	+	NC	−
Soil organic matter		5	2	
Soil physical structure			4	
Soil erodibility	1	1	2	1
Flood prevention			3	
Soil total	1	6	11	1

across a range of soil types and conditions. Whilst the majority of the results (11) indicate no improvement, five show improvements in SOM and two reductions in soil erodibility in organic systems.

Pulleman *et al.* (2003) compare SOM dynamics on conventional and organic arable farms in the Netherlands. They conclude that although organic methods were economically favourable, the farmer needs to be careful not to destroy the soil structure so that the benefits from increased biological activity are not lost. It is well accepted (Stolze *et al.*, 2000) that the key to long-term success in organic farming is good soil management. There is at present a lack of comparative research into soil physical properties between organic and conventional management in the UK. The exception is the work of Armstrong Brown *et al.* (2000), which compares topsoil properties of 30 paired organic and conventional farms across a range of soil types and management regimes, but their investigation did not include the implications for hydrology or infiltration rate (IR). Pasture and arable farms showed no significant differences in terms of soil physical and chemical properties between organic and conventional farms. The management factors deemed most important for differentiating between conventional and organic systems included frequent farmyard manure applications to land and the inclusion of grass leys in arable rotations.

This project reports a comparison of the effects of organic and conventional farming practises in England on both soil and soil water. The purpose is to provide complementary data for the biodiversity and socioeconomic analysis of the benefits of organic farming in the Rural Economy and Land Use funded 'Impacts of Scale on Organic Farming' project (Hathaway-Jenkins, 2011) and to update the work of Armstrong Brown *et al.* (2000). To investigate this, a null hypothesis was proposed based on the reviews by Stolze *et al.* (2000), Armstrong Brown *et al.* (2000) and Pulleman *et al.* (2003) that 'organic farming does not have a beneficial effect upon soil and water properties'. The properties examined in this study for a range of soil textural groups are soil organic carbon (SOC), soil strength, field capacity, aggregate stability, Atterberg limits, soil water quality (nutrient, pesticides and herbicide levels), soil structure, soil hydrological class (HOST) and IRs.

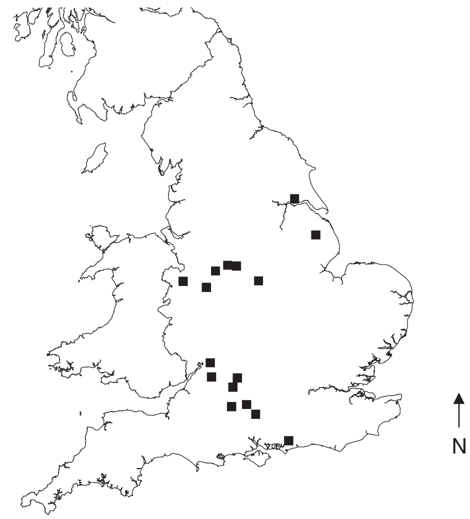

Figure 1 The 16 paired locations comprising of two organic and conventional fields with both grass and arable land uses (after Gabriel *et al.*, 2009).

Materials and methods

Site location

Sixteen sites on mixed (arable and grass rotations) farms were chosen based upon the Defra farm database (for both organic and conventional), which was overlain using GIS with environmental factors such as climate, topography, land use, soil type and hydrological data (similar to Norton *et al.*, 2009). The locations of the 16 sites are shown in Figure 1. Each site comprised a matching pair of organic and conventional fields. At each site both arable (winter wheat) and grass (grass/clover composition) fields were selected. This provided a total of 64 sampling locations. The selection of the sites posed a number of challenges because of the multidisciplinary nature of the project as the sites ideally needed to meet the requirements of ecologists, economists and geographers as well as soil scientists.

At each site three fields were chosen which met the requirements of the multidisciplinary team. The closest matching pairs of organic and conventional fields were determined through in-field soil sampling based upon the NSRI soil database (Landis). The farms were neighbours, but appropriate fields were not always on the adjacent boundary. The distance between the fields is given in Table 2. This shows spatial differences ranging from 25 m to 3 km where 50% of the sampling sites are < 300 m apart. The time period in which the land had been managed organically (not including time in conversion) ranged between 1 and 58 yr. All

Table 2 Details of the 16 paired sites including the distance between organic and conventional fields and land use history for arable (three previous crops) and grass sites

Site	Management	Distance between fields (m)	Managed organically (yr)	Previous crop	Age of grassland	Soil textural group
1	Org	3000	22	RCG	10	Medium
	Con	3000		WW	30	Silty
2	Org	200	6	RCG	20	Silty
	Con	200		SG	10	Clayey
3	Org	300	11	RCG	100	Clayey
	Con	300		WW	70	Coarse
4	Org	100	6	WO	20	Silty
	Con	100		WW	50	Clayey
5	Org	50	11	WCG	11	Clayey
	Con	50		OSR	10	Clayey
6	Org	2000	1	WW	10	Silty
	Con	2000		WW	15	Silty
7	Org	25	3	C	5	Silty
	Con	25		WO	5	Silty
8	Org	100	3	WCG	15	Silty
	Con	100		OSR	4	Silty
9	Org	3000	4	WW	50	Medium
	Con	3000		WB	20	Silty
10	Org	1000	2	WW	7	Medium
	Con	1000		SW	9	Medium
11	Org	1000	7	OSR	25	Medium
	Con	1000		WW	10	Medium
12	Org	2500	12	OSR	2	Silty
	Con	2500		WCG	2	Silty
13	Org	500	4	G	4	Coarse
	Con	500		SB	8	Coarse
14	Org	100	6	M	50	Medium
	Con	100		RCG	40	Medium
15	Org	50	58	WW	30	Coarse
	Con	50		WCG	30	Coarse
16	Org	2000	5	M	10	Medium
	Con	2000		M	12	Coarse

RCG, red clover and grass mix; WW, winter wheat; G, grass; WO, winter oats; WCG, white clover and grass mix; WB, winter barley; SW, spring wheat; OSR, oilseed rape; SB, spring barley; M, maize.

the grassland was grazed and the age of grassland for 68% of the sites was >10 yr. The previous arable crop rotation is also shown in Table 2.

Field sampling and analysis

Soil sampling and within field assessments were carried out in March and April 2007 when soils were at or near to field capacity. This is when seasonal effects of variations in soil moisture content are minimized and soil structural condition is most easily assessed. Sampling occurred after the main dressing of fertilizer on the conventional land. At each site, soil assessment was conducted and samples were collected to measure a suite of physical and agro-chemical parameters. To obtain a representative sample of soil, a 'W' shaped sampling strategy was adopted, avoiding untypical areas (such as severe poaching on grassland and wheelings on arable land), taking 10 samples which were bulked (MAFF, 2000). Samples were obtained from 0 to 200 mm depth. One or more small pits were excavated at each site to determine the soil structure and physical condition of the soil. A shear vane was used to measure shear strength *in situ* based on a grid sampling technique using 30 samples to cover the field.

Ten replicates of IRs were measured using the Decagon mini disc tension infiltrometer (Decagon Services, 2006) in a 'W' sampling strategy on a subset of 16 fields. These covered four soil textures: clay, clay loam, silty clay loam and sandy loam for both arable and grass land. Each replicate was sampled for 30 min at 20 mm tension and the IR was calculated using the method developed by Zhang (1997) and applying the van Genuchten parameters (Carsel & Parrish, 1988).

Laboratory analysis

The soil samples were air dried and homogenized by grinding and sieving (Allen, 1989); the samples were sieved to either 2 mm (to determine SOC and texture) or passed through a 5-mm sieve and retained on a 3.35-mm sieve (to determine aggregate stability). Soil texture was measured using the pipette method (BS 7755). SOC was measured by dichromate digestion (BS 1377-3). Aggregate stability was determined by wet sieving as described by Haynes & Swift (1990). Gravimetric moisture content at field capacity was measured by oven drying at 105 °C until a constant weight was achieved. Atterberg limits were determined as the plastic limit (BS 1377-2) and the liquid limit (BS 1377-2) using a drop cone penetrometer; the arithmetic difference between these two gravimetric moisture contents is the plasticity index (Keen & Coutts, 1928). Soil water sub-samples obtained by centrifugation were analysed for a suite of common pesticides and herbicides (carbonates, dicarboximides, organochlorine, organophosphorus, organonitrogen, synthetic pyrethroids, triazoles) and nutrients (total inorganic nitrogen, total phosphorus, total potassium).

Statistical analysis

Statistical analysis was performed using Statistica (8.0). First, any data that showed deviation from normality were transformed (Box-Cox). Then the 23 variables that characterized the sites were reduced using (i) correlation analysis to reduce the number of correlated variables and (ii) factorial analysis with variamax rotation. This revealed that % clay and % silt had the largest loading in the factor which explained the greatest variation in the data. Thus, the rest of the analyses grouped the data by soil texture as well as land use and management. Four groups of soil texture were formed because of the large variation owing to the spatial differences between the sites, allowing comparisons to be drawn. The soil textural groups were clayey (defined as >35% clay), silty (defined as >50% silt), coarse (defined as >50% sand and <18% clay) and medium (defined as between 18 and 35% clay).

The differences in soil quality between organic and conventional land management were tested using ANOVA, under the assumption that measured variables (SOC, shear strength, field capacity, aggregate stability, Atterberg limits, nutrients and pesticides) were normally distributed and the outliers were identified and removed from the dataset. A general linear model (factorial analysis) was used to determine whether there were significant differences in soil properties between the two treatments (organic and conventional), between two land uses (arable and grass) and between the four soil texture classes. The ANOVA model used was a nested design with land use (fixed effect) nested within treatment (fixed effect) and with soil texture as a random effect. The ANOVA was calculated using both least squares (Statistica 9.0) and restricted maximum likelihood (REML) Genstat (10.1). These results were further interpreted using the Fisher LSD test as this is one of the least conservative *post hoc* tests (Winer *et al*., 1991).

Results

Soil organic carbon

There was no significant difference ($P < 0.05$) in SOC contents of the organic and conventionally managed land (Table 3) in agreement with Gosling & Shepherd (2005). This can be explained by the fact that to have a significant effect on SOC, Bhogal *et al*. (2008) suggest that at least 65 t/ha/yr

Table 3 The mean SOC (g/kg) for each of the soil textures and land uses showing significant differences with different letters where $P < 0.05$. Numbers in brackets are the total number of samples in each category

		Land use and treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean
Soil textural class	Clayey (16)	44.57	3.21	57.33	11.61	49.84	16.29	53.89	18.87	51.41a
	Silty (23)	52.89	11.24	65.47	16.37	46.07	13.64	71.31	20.37	58.94a
	Medium (14)	35.23	2.10	57.67	0.00	32.56	3.94	40.96	9.50	41.61b
	Coarse (11)	31.11	10.44	29.13	9.05	26.39	13.28	64.77	40.84	37.85b
Mean		40.95a		52.40b		38.72a		58.98c		

of fresh organic matter needs to be applied. Currently organic farmers add on average 40 t/ha/yr (Lampkin, 1999). There were significant differences related to land use; grass contained a significantly larger amount of SOC compared to arable land ($P < 0.05$) and soil textural class, while the clayey and silty soils contained more SOC than coarse and medium soils ($P < 0.05$). This is as a result of the way in which clayey soils protect SOC from decomposition (Loveland & Webb, 2003).

Shear strength and field capacity

There were no significant differences in shear strength (Table 4) or field capacity moisture content (Table 5) between organic and conventional fields. There were significant differences between land uses, where soil under grass had a significantly higher shear strength compared to arable. The grass fields generally have higher soil shear strength than the arable fields as a result of the formation of a strong root mat which binds the soil together. The highest strength (93 kPa) occurred in the conventionally managed grassland. The coarse-textured soil had a significantly lower field capacity than the other soils, and the grass fields had a greater field capacity than the arable.

Aggregate stability

There was no significant difference ($P < 0.05$) in the aggregate stability of the soil under organic and conventional management (Table 6); this agrees with the findings of Williams & Petticrew (2009). There were significant differences related to land use, where grass had a significantly greater proportion of stable aggregates compared to arable, and soil textural class whereas the clayey and silty soils were more stable than the coarse- and medium-textured soils. Clayey soil contained most SOC, and both this and the clay help to bind the soil particles, thus improving the stability of the aggregates.

Table 4 The mean shear strength (kPa) for each of the soil texture classes and land uses showing significant differences with different letters where $P < 0.05$. Numbers in brackets are the total number of samples in each category

		Land use and treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean
Soil textural class	Clayey (16)	70.40	10.66	68.03	19.97	54.73	34.60	93.23	11.80	71.60a
	Silty (23)	50.19	26.46	62.50	29.06	41.60	18.94	43.3	7.56	49.40b
	Medium (14)	29.45	6.45	37.30	11.03	47.20	15.70	59.05	5.48	43.25b
	Coarse (11)	42.90	24.39	56.05	3.75	41.15	10.96	61.6	13.62	50.42b
Mean		48.24a		55.97b		46.17a		64.30b		

Table 5 The mean value of field capacity (% mass) for each of the soil texture classes and land uses showing significant differences with different letters where $P < 0.05$. Numbers in brackets are the total number of samples in each category

		Land use and treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean
Soil textural class	Clayey (16)	35.84	4.01	38.03	13.39	31.95	18.25	36.09	3.13	35.48a
	Silty (23)	30.73	3.26	35.81	9.80	30.67	4.79	40.50	11.31	34.43a
	Medium (14)	28.22	1.39	43.35	0.00	27.65	5.07	32.37	5.63	32.90a
	Coarse (11)	22.59	5.02	21.85	5.03	16.67	4.20	29.42	5.09	22.63b
Mean		29.35a		34.76b		26.74a		34.60b		

Table 6 The mean aggregate stability (% mass) for each of the soil texture classes and land uses showing significant differences with different letters where $P < 0.05$. Numbers in brackets are the total number of samples in each category

		Land use and treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean
Soil textural class	Clayey (16)	54.06	18.86	68.19	19.67	48.86	11.67	66.30	6.69	59.35a
	Silty (23)	44.07	16.57	65.33	11.56	36.85	18.13	52.36	17.74	49.65a
	Medium (14)	33.98	8.57	74.61	0.00	27.17	5.79	60.55	9.62	49.08ab
	Coarse (11)	23.92	3.12	45.21	35.28	33.94	26.92	69.11	9.13	43.05b
Mean		39.01a		63.34b		36.71a		62.08b		

Atterberg limits and workability

There were no significant differences ($P < 0.05$) in the plastic limits, liquid limits or plasticity indices of organic and conventionally managed land (Table 7). Soil texture and the amount of SOC are very important for controlling changes in Atterberg limits: higher levels of SOC can cause a shift in plasticity index, extending the friability zone to higher moisture contents (Baver *et al*., 1972). For this reason, REML analysis was performed as it is more sensitive than ANOVA and allows for the variation in soil texture.

The REML analysis showed that the plastic limit of conventional grass is significantly larger than that of conventional arable. This could be partly attributed to the higher clay content but the conventional grass soils also contain more SOC, which could be increasing the plastic limit for these soils because plasticity could be dependent on the polysaccharide gels within SOC (Soane *et al*., 1972). The amount of SOC does not affect the plasticity index but it creates a strong bond with water, increasing the plastic and liquid limits (Brady, 1990). Baver *et al*. (1972) suggest that increasing the SOC in soils would cause a shift in the plasticity index extending the friability zone to fairly high moisture contents.

The plastic limit can be used as a guide to determine the water content at which a soil can be cultivated without causing damage: if the field capacity moisture content is below the plastic limit, there is less risk of soil damage. From this study, it was found that there was no management type (organic or conventional) which made a difference to soil workability which was dependent on soil texture.

Soil water nutrients and pesticides

The soil water in two organic fields contained agrochemicals, but only trace levels. The soil water in 13 conventional fields contained traces of agrochemicals; Table 8 lists the residues present in the conventional fields, their concentrations, the half life values (dt 50) and environmental impacts. The agrochemicals detected in the organic fields were compounds

Table 7 The mean plastic limit (mg/kg) for each of the soil texture classes and land uses showing significant differences with different letters where $P < 0.05$

		Land use and treatment								
		Organic				Conventional				
		Arable (16)		Grass (16)		Arable (16)		Grass (16)		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean
Soil textural class	Clayey (16)	370.00	28.28	350.00	63.70	366.67	35.12	340.00	45.83	356.67a
	Silty (23)	250.00	42.03	334.00	150.43	192.00	104.26	340.00	94.45	279.00b
	Medium (14)	285.00	110.91	380.00	0.00	200.00	49.50	265.00	66.58	285.20b
	Coarse (11)	220.00	50.00	180.00	56.57	206.67	51.32	200.00	52.92	201.67c
Mean		281.25a		311.00b		241.33a		286.25b*		

Numbers in brackets are the total number of samples in each category. *Indicates the significant difference which was shown in REML only.

Table 8 The residues detected in soil water samples and their pesticide group reporting level, half life (dt 50) and environmental factors leaching potential and bioaccumulation potential (adapted from PPDB Footprint report, 2009)

Residue	Group	Recorded value (mg/kg)	dt 50 in soil (days)	NOEC mg/kg (earthworm reproduction)	GUS leaching potential	Bioaccumulation factor
Chlorothalonil (fungicide)	OC	0.30	44 (18–77) Moderately persistent	25.0	1.44 Low leachability	100 Low potential
DDE (metabolite)	OC	5.70	5000 Very persistent	6.1	−2.59 Low leachability	1800 High potential
DDD (metabolite)	OC	0.90	1000 Very persistent	6.1	−3.53 Low leachability	3173 High potential
Flusilazole (pesticide)	T	0.03	300 (63–240) Moderately persistent	8.82	1.93 Transition state	250 Moderatepotential
HCH (insecticide)	OC	0.05	121 Persistent	6.8	2.00 Transition state	1300 High potential
Pendimethaline (herbicide)	ON	0.11	90 (27–186) Moderately persistent	4.0	−0.39 Low leachability	5100 High potential
Trifluralin (herbicide)	OC	0.02	181 (81–375) Persistent	28.98	0.13 Low leachability	5674 High potential

Agro-chemical group: OC, organochlorine; T, triazoles; ON, organonitrate. NOEC is the no observed effect concentration this is based upon the reproductive behaviour of earthworms after 14 days of constant application at the rates above. GUS is the groundwater ubiquity score and is a measure of the mobility of pesticides it does not take into account soil or antecedent condition.

of organochlorine (DDE) and organonitrogen (pendimethaline), with concentrations of 0.3 and 0.02 mg/kg, respectively. These agrochemicals are degraded by the microbial community to form metabolites, and their half lives determine their persistence (Andreu & Pico, 2004). Both are moderately persistent: DDE has a dt 50 of 13 yr and pendimethaline a dt 50 of 90 days. Pendimethaline has bioaccumulated within the soil as a result of subsequent applications prior to the farm converting to organic in 2000. The low concentration of DDE detected can be associated with historical applications and does not pose a threat. None of the residues detected pose a leaching risk; however, all of the residues except chlorothalonil could have an environmental impact through bioaccumulation (PPDB, 2009). All the detected levels are below the 'No Observed Effects Concentration'.

There were no significant differences ($P < 0.05$) in total phosphorus (mean 2176.9 ± SD 970.7 mg/kg) and total potassium (mean 863.6 ± SD 304.3 mg/kg) according to management, land use or soil texture. However, there was a significant difference in total inorganic N (ammonium and nitrate): in the conventional arable soil this was approximately twice that of the grass fields. This is as a result of the application of fertilizer or manure on the conventional arable land and not on the grassland or the organic arable.

Hydrology of soil type (HOST)

UK soils can be classified on the basis of hydrology into 29 classes (Boorman *et al*., 1995). This is based on soil physical properties, which are correlated with catchment scale hydrological variables, the dominant pathways of water movement through the soil and substrate (base flow index, BFI and standard percentage runoff, SPR). BFI is the long-term average proportion of flow that comes from stored sources and SPR is the percentage runoff derived from event data, adjusted to standard rainfall and catchment moisture conditions (Boorman *et al*., 1995). This model allows the level of degradation of soil to be input and hence modifies the HOST class. A physically degraded soil, for example a compacted soil, can lead to a significant change in the amount of runoff for most of the HOST classes. The HOST classification revealed degradation of soil properties within 12 fields; this is indicated by an increase in the SPR of 10% and a decrease in the BFI of 0.1%. Three of the 12 fields were organic arable fields and one was an organic grass field. Overall there were fewer degraded organic than conventional fields, and there were more degraded arable than grassland fields. This highlights the poor soil structure of these fields, which could be the result of untimely cultivations of the arable land or overstocking and hence increased poaching of the grassland.

Infiltration rate

The mean results of the IR studies are given in Figure 2, which shows that the IR under conventional grassland is significantly smaller than that in all other treatments. This difference was found in other studies (Reganold & Palmer, 1995; Oquist *et al*., 2006), which also highlight the issue of variability in infiltration data. The conventional arable land has a higher IR compared to conventional grassland,

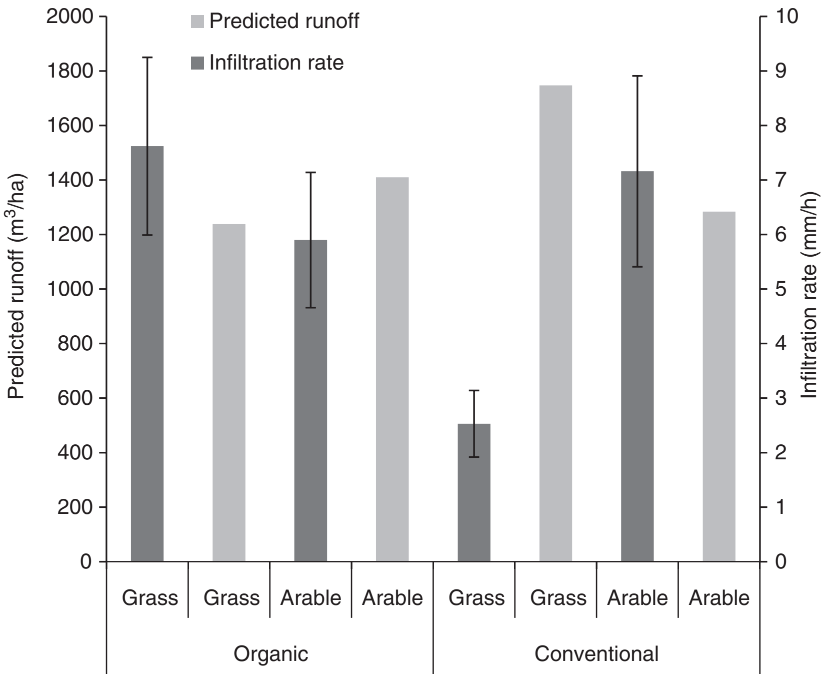

Figure 2 A comparison of the mean infiltration rates between organic and conventional management for grass and arable landuse. Also shown are the LSD values for infiltration rates at $P = 0.95$ and the predicted runoff from a 20 mm/h rainfall event (1 yr return period) (NERC, 1975).

presumably because of the tillage involved in crop establishment. For the organic land management there is no significant difference between the two land uses; this could be related to improvements in structure as a result of the additions of SOC and an overall lower stocking density (where the average organic stocking density was 1.1 livestock units per ha compared to 1.3 livestock units per ha for the conventionally managed grassland, Hathaway-Jenkins, 2011). There were also differences in the soil textural class, where IR in the clay (9.87 mm/h) and sandy loam (7.52 mm/h) soils were significantly greater than in the silty clay loam (4.35 mm/h) and the clay loam (1.47 mm/h) soils. This could be explained by the cracking nature of clay soils and the coarse texture of the sandy loam.

Overall, we conclude that IR is influenced by local conditions such as soil type and structure that occurs regardless of farming practice. This is especially true where the seasonal impacts of cracking, cultivation practices and crop rotation have more of an effect. Figure 2 also shows that the predicted runoff from conventional grassland for a 20-mm/h, 1 yr return period storm (NERC, 1975) is 1800 m^3/ha reducing to 1300 m^3/ha in conventional arable land.

Discussion

The results support the null hypothesis of no overall effect of organic conventional farming practices on soil conditions on mixed farms in England. This gives weight to the findings of Armstrong Brown *et al.* (2000) and Stolze *et al.* (2000) that there is no evidence to show an improvement in soil conditions from organic farming, equally there is no detrimental effect. The fact that the effects of both soil type and cropping (i.e. grassland or arable) are often significant, as might be expected, gives confidence in the data. The data also provide a useful statement on the current relative status of soils under organic and conventional farming, provide baseline soil data to complete the agro-environmental study on the relative effects of organic farming on biodiversity (Gabriel *et al.*, 2009) and support the farm economy studies of the Rural Economy and Land Use project 'Effects of scale in organic agriculture' (Hathaway-Jenkins, 2011).

In an ideal world matched pairs of immediately adjacent organic and conventional fields with the same soil texture and management practice would have been selected. This may result in improved resolution to differentiate between organic and conventional soil management. It was essential, however, that some latitude was shown in field selection to enable the multidisciplinary RELU project to be conducted. The fact that 50% of the fields in this study were <300 m and $<30\%$ were >2 km distant is acceptable given the multidisciplinary nature of this study. To reduce the effect of the distance between organic and conventional fields, a further study is being conducted by Hathaway-Jenkins (2011) on a farm in Aberdeenshire with paired comparisons for a range of soil properties in fields at distances of 500 m.

The most useful finding for organic farmers is that organically managed grassland maintains a higher IR than conventional grassland (Figure 2). Given the recent summer rainfall patterns of more and more extreme storm events, and their effects on runoff and flooding, the reduction in runoff of 28% could be beneficial. However, the benefits would only be accrued through a comprehensive unifying soil and water management plan for each catchment. But if as is thought, the change in IR was owing to slightly lower intensities of grazing, then the same improvements could also result from better soil management on conventional grassland farms.

Conclusions

The analysis of the data shows that whilst it is possible to detect the effects of both soil texture and land use (grassland/arable) on a number of the soil properties, there is no evidence based upon soil organic matter, field capacity, aggregate stability, Atterberg limits/workability and soil shear strength to reject the hypothesis that 'organic farming does not improve soil properties or physical condition'. Hence, in agreement with the results of other studies, there is little direct benefit on the individual soil properties from organic farming practices – equally there is no detrimental effect.

There was evidence to support the suggestion that IRs are greater on organically managed grassland than conventional grassland; such a difference might reduce runoff by up to 28%. This is in general agreement with the results of the HOST analysis which indicates fewer degraded fields under organic management.

Overall, there were fewer traces of pesticides or herbicides in the soil water from the organic fields compared with the conventionally managed fields. The conventional arable fields had higher levels of total inorganic nitrogen than the other land uses and treatments. There are no significant differences in total phosphorus and total potassium for any land use or treatment combinations.

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