Brighton ChaMP for Water
Protecting our precious groundwater

Brighton ChaMP for Water

(Chalk Management Partnership)

Cover Crop Trial

Mark Eastes

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South Downs National Park Authority · Environment Agency · Southern Water · Brighton & Hove City Council · University of Brighton · Natural England · A clear solution for farmers – Catchment Sensitive Farming · The Living Coast – Brighton & Lewes Downs UNESCO World Biosphere Region

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EXECUTIVE SUMMARY

Elevated nitrate concentrations in the Brighton Chalk Block aquifer are a continuing problem with seasonal peaks being observed at Southern Water boreholes during the winter months and general concentrations increasing towards, or exceeding, the Drinking Water Standard. Although diffuse nitrate pollution can arise from a number of sources, both urban and rural, the primary source is attributed to an excess of agriculturally derived fertiliser leaching from farmland, through the soil layer and into the underlying groundwater, which can put the viability of abstraction boreholes at risk. Although post abstraction treatments are available these can be expensive or impractical as nitrate removal plants cost the water industry (and, in turn, the consumer) millions of pounds per year and have only a limited asset life. Brighton ChaMP (Chalk Management Partnership) is a collaborative project which aims to reduce groundwater nitrate concentrations through a catchment management approach by engaging with stakeholders, which includes the farming community, to protect groundwater at source. This study is concerned with one such approach where the use of over winter green cover, or cover crops, were used at two farms located on the South Downs, to determine their efficacy in reducing groundwater nitrate concentrations. Statistical analysis of the results for groundwater nitrate showed all varieties of cover crop mix were effective in reducing nitrate compared to bare fallow ($p = 0.000$; $\alpha = 0.05$) although different mixes were effective at each location, these being the "Complex EFA" mix at Housedean Farm and "Multi Mix" at Mile Oak Farm, suggesting that site specific factors, such as soil texture or geology, also play a role. Furthermore, an associated study showed that the use of cover crops did not lead to an increase in the slug population, allaying fears of possible 'pollution swapping' should more Metaldehyde need to be used whilst attempting to reduce nitrate with cover crops. However, it is suggested that further longer term studies be conducted to evaluate the role of cover crops over successive winters thereby examining their effect on the longer term reduction of nitrate concentrations in groundwater and to better understand any temporal or seasonal effects. It is hoped that the results from this study may help to encourage more farmers to adopt cover cropping schemes as part of their annual agricultural routine to ameliorate the quality of groundwater affected by elevated nitrate from farming practices.

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Chapter 1: Introduction

According to Jones and Robins (1999) the South Downs has the longest standing record of groundwater levels in Europe where these data have been measured and recorded at the Chilgrove House well, situated on the Chichester Chalk Block, since 1836. Since then, the Chalk aquifer as a whole has become one of the most heavily utilised groundwater resources in the UK with the Brighton and Worthing regions obtaining 100% of their water supply from groundwater abstraction. An already formidable task, it is one that is seemingly to become even more of a challenge as the population in the south of England increases, the effects of climate change continue to take effect and the amount of groundwater available for abstraction is reduced (Southern Water, 2018).

To complicate matters further, approximately 85% of the area that comprises the South Downs National Park (SDNP) is farmland, including the Chalk Block aquifer (SDNPA, 2018) and the use of chemical fertiliser to maximise yields has resulted in elevated concentrations of nitrates (NO_3) in the groundwater. Concentrations at excessive levels have been shown to be detrimental to health and for that reason the World Health Organisation imposed a limit of 50mgl^{-1} of nitrate in groundwater abstracted for human consumption, a limit subsequently adopted in the European Commission's Water Framework Directive (WFD) and implemented into UK law in 2003. The WFD is a piece of EU legislation that requires its member states to make plans to protect and improve the water environment, assessing a range of biological and physico-chemical parameters for surface water and quantitative and chemical parameters for groundwater to determine whether the water body has good or potentially good status and to reverse any significant or sustained upward trends in pollutant concentrations. Although treatments are available to the utility companies, such as mechanical/chemical treatments or blending, these are sometimes not possible or financially feasible and the future viability of the abstraction well is put in doubt. Consequently, as a result of the Nitrates Directive, member states of the European Union were required to designate areas used for water abstraction (both surface water and groundwater) as Nitrate Vulnerable Zones (NVZ's) to monitor nitrate concentrations and determine which areas had exceeded the limit, areas likely to exceed it in the future and to identify the likely sources of contamination. The NVZ regulations place mandatory controls on the rate, timing and spreading of nitrogen fertilisers and set a storage requirement for organic manures on designated agricultural land in England and Wales. This became part of a larger 'Catchment Management' operation that not only monitors levels of nitrate but actively attempts to reduce them by engaging with stakeholders such as landowners and farmers and encouraging them to adopt land management practices that can help reduce nitrate pollution, such as reducing the amount of chemical fertiliser used, adjusting the timing of its application or by growing over winter green cover to adsorb any excess nitrate left in the soil to prevent it leaching to the aquifer. Unfortunately, nitrate from fertilisers has already accumulated in groundwater over several decades and will take several more to reduce and the catchment approach helps set a programme of measures to protect and improve the water environment in the river basin district. Without these measures the quality of the water environment would deteriorate with the associated loss of benefits. This catchment based approach aims to bridge the gap between strategic management planning at the river basin district level and any activity at the local water body scale by encouraging groups to work together more effectively to deal with environmental problems locally. These catchment partnerships are groups of organisations with a collective interest in improving the environment of their local area, led by a catchment host organisation, helping to inform the river basin management planning process and implementing suggested measures.

In the South Downs area this has become the responsibility of Brighton ChaMP, or Chalk Management Partnership, a collaborative project which includes the South Downs National Park Authority, Southern Water, the Environment Agency, Brighton & Lewes Downs Biosphere, Natural England, Brighton and Hove City Council and the University of Brighton. This collaboration oversees various catchment management projects, both urban and rural, that aim to protect and improve the quality of the groundwater in this region. One of the measures being considered for a rural application is the use of over winter green cover, or cover crops, where different varieties of plants are grown on agricultural land that would normally remain bare fallow over winter. Leaving the land bare allows any residue nitrate left from fertiliser for the previous crop to leach into the aquifer due to the seasonally higher rainfall. By planting cover crops, nitrate leaching may be effectively reduced by both nitrate absorption by the plant roots and by the foliage intercepting the rainfall thus diminishing the amount of water percolating through the soil. However, a lack of understanding as to their efficacy and cost effectiveness has led to uncertainty among farmers, often limiting their engagement in such schemes.

This uncertainty is generally fuelled by issues concerning the incorporation of a cover crop scheme into the agricultural rotation such as their cost, management and other agronomic concerns including disease carry-over and pest and weed management. The extra cost involved to the farmer is not simply confined to the price of the extra seed as fuel costs, extra pest and weed control and commodity prices (if the cover crop is to be sold as a cash crop) must also be considered. To some extent, in the UK, the financial aspects have tried to be addressed by the introduction of subsidies for agri-environment schemes. To be eligible, the cover crop must be planted on cultivated land that is vulnerable to nitrate leaching or that is identified on the Farm Environment Record as being at risk from soil erosion or surface runoff (Gov.UK, 2018). However, it is also required that the cover crop be planted by mid-September and destroyed, weather permitting, by late January or early February. The cost of destruction, both in time and materials (for example by the application of glyphosate) is another consideration although some cover crops can be grown that are suitable for grazing livestock, potentially providing some extra income, or that can be incorporated into the soil before the planting of the subsequent main crop (often termed 'green manure')(SARE, 2015), thus giving some savings on the application of more chemical fertiliser and perhaps exacerbating the original nitrate problem. Further concerns regarding costs incurred by the purchase of new equipment due to the inclusion of a cover crop in the rotation could, in all likelihood, be overcome by selecting a cover crop scheme that utilises the farms existing kit.

The reasons for planting a cover crop and the options available to the farmer are numerous and will very likely vary from farm to farm, even those in close proximity to one another. Therefore, each cover crop scheme is highly individual and will almost certainly need the time and experience of a professional agronomist to help implement and then 'fine tune' each system suggesting, perhaps, another reason for the hesitancy of some farmers to become involved. However, other benefits from the planting of a cover crop including improved soil health and structure, an increase in biological activity in the soil, possible pest and weed management (depending on the plant variety) and an improvement in wildlife habitat and feeding opportunities may help to persuade farmers of their value, offsetting some of the extra costs, both financial and of time, that may be incurred.

Therefore, this Brighton ChaMP study was implemented to assess the efficacy of cover crops in reducing groundwater nitrate concentrations compared to concentrations found beneath bare fallow by analysing groundwater samples collected from two farms situated on the Brighton Chalk Block aquifer, both having had strips planted with several varieties of cover crop plus one unplanted, bare strip to act as a control. It is hoped that these results may help to encourage farmers to consider the adoption of cover crop schemes in the future.

1.1 Aim

To evaluate the effectiveness of different varieties of cover crop on reducing the amount of nitrate leached through the soil zone and into groundwater and to identify and better understand any other controlling factors.

1.2 Objectives

- Evaluate the efficacy of different cover crop varieties/mixes and their ability to diminish nitrate leaching.
- Quantify nitrate concentrations from beneath cover crops and bare fallow.
- Investigate the relationship between nitrate concentrations from beneath both cover crops and bare fallow and determine if any relationship exists between nitrate concentrations and rainfall using appropriate statistical testing.

1.3 Report Structure

The report is divided into five chapters following on from the Introduction. Chapter Two comprises a literature review which examines the background to the problem of elevated nitrate concentrations in groundwater, a brief consideration of nitrogen fertiliser, its use in agriculture and the use of cover crops in reducing nitrate leaching. It also considers other parameters such as soil, geology and climate which are important factors in understanding the transport and attenuation of nitrate contamination and the viability of the crops. Chapter Three presents the methods used for both field and laboratory work and introduces the statistical methods used to determine normality and critically assess the data. Chapter Four details the results from the laboratory and statistical analyses. Chapter Five presents a discussion and evaluation of the results and considers the limitations encountered while conducting the study and, finally, Chapter Six offers a summary of the key conclusions and some suggestions for further work.

Chapter 2: Literature Review

Chapter One provided a brief introduction to the problems associated with and causes of elevated concentrations of nitrate in groundwater and the potential of cover crops to help remedy the problem. Chapter Two examines these issues in greater detail and also considers other important parameters that affect the transport and attenuation of contaminants such as soil and geology.

2.1 Background to the Problem

According to Southern Water (2018), 70% of their total supply is sourced from groundwater abstraction which, after being pumped to the surface, receives some treatment before being piped to households. The majority of that 70% is abstracted from the Chalk aquifer although in the Brighton and Worthing regions 100% of the water supply is abstracted from the Chalk (Figure 2.1). The amount abstracted is regulated by the Environment Agency (EA) whose role it is to issue licenses for abstraction, if the amount to be abstracted is more than 20m^3/day, in order to help protect the groundwater source and the environment, i.e. the fauna and flora that rely it. However, both Southern Water Services (SWS) and the EA have recognised that pollution from diffuse sources is increasingly a concern as, if the public water supply (PWS) becomes contaminated, the water must be treated, diluted or, in the worst case scenario, the supply closed altogether and an alternative supply found. This inevitably could lead to increased environmental pressures and raised costs to both the utility company and, possibly, the public. Indeed, according to the Environment Agency (2010) the estimated cumulative cost for water treatment as a result of pollution in England and Wales was approximately £1.3 billion per annum.

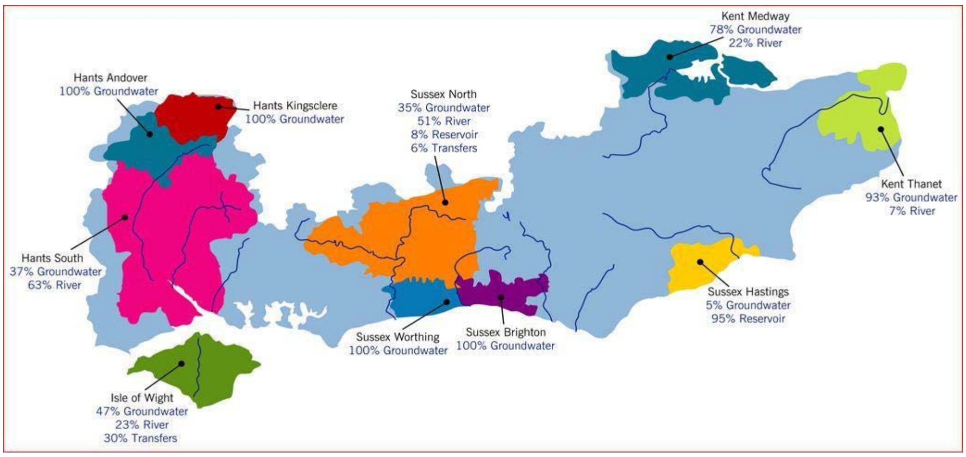

Figure 2.1. Map illustrating the Southern Water region and the apportionment of supply sources for each district (Southern Water, 2018).

In 2007 the Environment Agency stated that approximately 81% of groundwater bodies in England were at risk of failing Water Framework Directive (WFD) objectives due to diffuse pollution, the major contaminant being nitrate which alone was responsible for 60% of these failures.

Elevated nitrate concentrations in surface and groundwater in the UK could be argued to be one of, if not the, largest problem being faced by both the regional water companies as well as bodies involved in environmental regulation, as it is the major cause of surface and groundwater bodies failing to achieve 'good' status (UKWIR, 2004). This is however, a global issue as shown, for example, by studies conducted in China (Gao *et al*., 2012), India (Adhikary *et al.,* 2010), Iran (Akhavan *et al.,* 2010) and the United States (Staver and Brinsfield, 1998) and has therefore led to the World Health Organisation (WHO) to establish an upper limit on nitrate of 50mgl^{-1}, a level which has been adopted by the EU Water Framework Directive (EU, 2000) since 1980 and, subsequently, by both the Environment Agency and the water industry as the prescribed amount at point of use, i.e. the consumer's tap being the point of compliance (DEFRA, 2016). However, this figure is based on health considerations and rarely reflects the natural baseline amount present in groundwater as concentrations this high are almost always caused by diffuse contamination. According to Shand *et al*. (2007), typical median concentrations of nitrate in Chalk groundwater are generally between 5.9 – 9.5 mgl^{-1} Nitrate-N (approximately 26.1 - 42.1 mgl^{-1}) although using historical data the baseline figures are more likely to be less than 1 mgl^{-1} Nitrate-N in upland areas and confined aquifers up to around 3 – 4 mgl^{-1} Nitrate-N (i.e. less than 4.4 mgl^{-1} up to 13.3 – 17.7 mgl^{-1}).

Elevated concentrations of nitrate in groundwater are potentially hazardous to human health causing conditions such as methemoglobinemia, an acute condition where excess nitrate causes the conversion of haemoglobin to methemoglobin thus depleting oxygen levels in the blood. This can be a particular danger to infants, often referred to as blue baby syndrome, if contaminated water is used to mix formula milk (Knobeloch *et al*., 2000). Further health risks have been reported in several studies including those conducted by Forman *et al*. (1985) and Payne (1993) where drinking water containing high levels of nitrate were shown to be responsible for thyroid problems, hypertension and even various forms of cancer. More recently, a Danish study conducted by Schullehner *et al*. (2018) suggested that there was a statistically significant increase in the risk of contracting colorectal cancer if nitrate levels in drinking water exceeded 3.87 mgl^{-1}, far below the drinking water standard of 50 mgl^{-1}. In contrast, several researchers such as Avery (1999) and L'hirondel and L'hirondel (2002) have expressed doubts regarding the significance of nitrate in drinking water contributing to the risk of methemoglobinemia and have suggested that the regulatory level of 50 mgl^{-1} (or 45 mgl^{-1} in the United States) is overly conservative and could be safely raised to 15 – 20 mgl^{-1} Nitrate-N (66.4

– 88.5 mgl^{-1} as NO_3) with no increase in the incidence of methemoglobinemia. However, these problems are more commonly associated with domestic or private wells or wells which service small communities in more rural areas. For example, in the United States it was found that 22% of domestic wells in agricultural areas exceeded the US maximum contaminant level (MCL) of 45 mgl^{-1} and in Romania 20% of 2000 wells tested had nitrate levels greater than 101.8 mgl^{-1} (Ward *et al*., 2005). In England and Wales, the natural baseline water quality for nitrate is approximately between 4.4 and 17.7 mgl^{-1} and although higher concentrations do occur the utility companies, including Southern Water, strictly adhere to the drinking water regulations to ensure that the quality of drinking water supplied does not exceed the drinking water standard for nitrates.

The causes of elevated nitrate in groundwater have been the subject of some debate and largely depend upon the characteristics of the affected area. However, in urban areas the most likely sources are municipal sewerage systems/septic tanks, road run off and historic landfill (Lerner, 2003) whereas in rural areas it is generally accepted to be the intensification of agricultural practices (Limbrick, 2003; Wade *et al*., 2004). Some crossover between the two can and does occur which, according to Edwards and Withers (2008), makes any estimates of rural sources affecting densely populated areas uncertain and difficult to determine. Bearing this in mind, the Brighton area is a case in point with it and the surrounding area having been declared a Nitrate Vulnerable Zone (NVZ) since at least 2008 (Environment Agency, 2016) due to both urban and rural sources of nitrate (figure 2.2). An NVZ is defined as an area of land that drains into waters that are polluted by nitrates. With this designation, changes in farming practices which include the use of over-winter green cover, are required to mitigate the risks of leaching nitrate from agricultural sources. Indeed, according to Mian *et al*. (2010), reduced nitrate concentrations in a catchment of the River Derwent in North Yorkshire were highly likely to be the result of the combined effects of NVZ designation and the introduction of the use of winter cover crops.

Figure 2.2. Map to illustrate the extent of the Sussex Chalk NVZ which includes the Brighton Chalk Block aquifer and the study areas (Environment Agency, 2016).

2.2 Nitrogen, its Compounds and their use in Agriculture

The use of livestock manure and water management in agriculture could, according to Bogaard *et al*. (2013), go back as far as 5900 BCE evidence for which has been suggested by high levels of nitrogen-15 in crop samples which is associated with a high and regular application of manure. Although the reasons behind the efficacy of adding manure to promote crop growth were, most likely, largely unknown to early farmers, a greater understanding of chemistry and biology in the nineteenth century allowed scientists to identify the link between healthy plant growth and nutrients such as nitrogen compounds i.e. nitrate, nitrite and ammonia as well as phosphorus, carbon dioxide and other soil minerals. One of the earliest innovators in this field was the German chemist Justus von Liebig who, in the 1840's, discovered that plants required ammonia to grow. Ammonia is derived from nitrogen and although nitrogen is abundant in the air, very few plants are able to fix it in this form and generally require it in a mineralised form such as nitrate or ammonia from the soil (Strong and Mason, 1999) and, for this reason, many of Liebig's experiments were ineffectual due to the inability of the crops to absorb the nutrients in the nitrogen fertiliser he created (Brock, 2002). Later, in 1918, chemists Fritz Haber and with Carl Bosch invented the Haber process (for which Haber won the Nobel Prize for chemistry) which transformed atmospheric nitrogen gas into ammonia. This process was able to be reproduced on an industrial scale meaning ammonia synthesis could facilitate mass production of nitrogen fertiliser and the intensification of agricultural practices needed to accommodate a rapidly expanding global population.

However, these mineralised forms of nitrogen that are available to plants are also more easily leached from the soil. Nitrate is very easily leached and, if present in waterlogged conditions, can undergo denitrification to form nitrous oxide (N_2O) and nitrogen gas (N_2) (Hazleton and Murphy, 2016), nitrous oxide being a significant greenhouse gas estimated to make up 6% of the greenhouse warming effect (Dalal *et al*., 2003a and 2003b). A simplified version of the nitrogen cycle is shown in Figure 2.3. Total nitrogen in the soil can be measured although much of it will be held in organic matter and is not immediately available for use by plants unless it becomes mineralised to the forms mentioned above and cannot, therefore, be used as a measure for these mineralised forms (Hazleton and Murphy, 2016). Nevertheless, it is an important consideration in agronomy to estimate as accurately as possible the amount of nitrogen fertiliser required by the crops to minimise the amount of mineralised forms of nitrogen left as residue (i.e. unused by the plants) which can contribute to diffuse pollution and contamination of water sources as nitrogen applied in fertiliser is, usually, readily converted to nitrate, especially when the soil is warm and moist (Rayns and Rosenfeld, 2006). This is becoming especially concerning when there is substantial doubt regarding the estimated amount of food production required globally without the use of significant amounts of synthetic fertiliser needed to help meet these demands (Stewart *et al*., 2013).

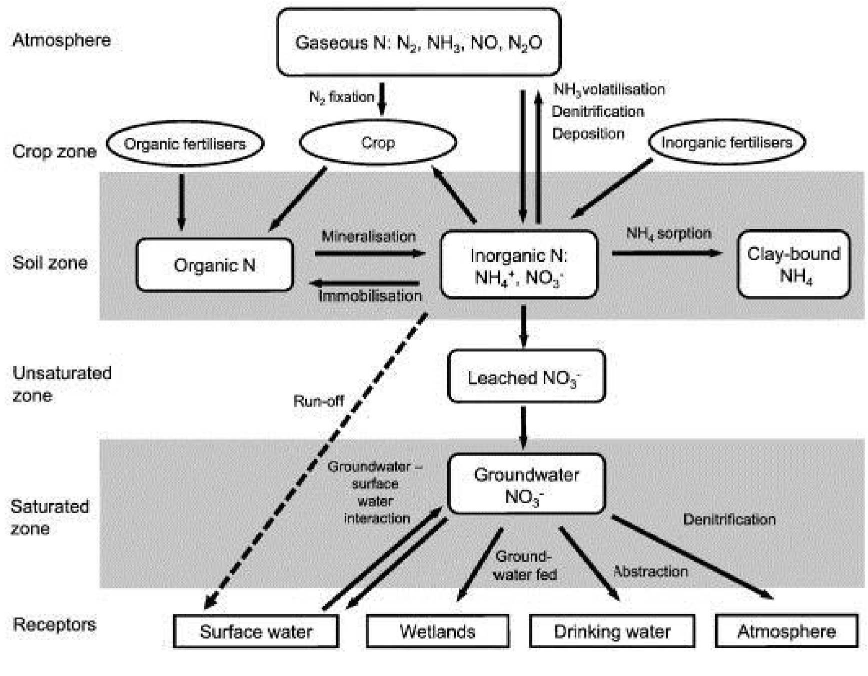

Figure 2.3. Simplified nitrogen cycle highlighting soil processes (Stuart *et al*., 2011).

2.3 The Use of Cover Crops in Reducing Nitrate Leaching

The role of cover crops in controlling the concentration of nitrogen has been considered since at least the 1940's (for example, Karraker *et al*., 1950) although these studies were, more often than not, more concerned with the use of over winter cover crops to conserve nitrogen, which could mineralise to another form for use by the succeeding crop (Meisinger *et al*., 1990). However, through these studies it was also realised that by growing a cover crop not only could it help to conserve nitrogen for the next crop, it also reduced leaching by both absorbing available mineralised nitrogen, such as nitrate, and reducing the amount of rainfall available for percolation (Meisinger *et al*., 1990). A further benefit is the decrement in soil erosion through both plant cover and root attachment suggesting that local geology and soil is another important consideration, with regards to soil erosion, contaminant transport and the choice of potential cover crop variety.

As mentioned previously, the heightened awareness by the EA, utility companies such as Southern Water and other agencies, of the potential problems associated with agriculturally derived increases in concentrations of nitrate, the use of over winter cover crops as a potential method to reduce them would appear useful as this helps to address the problem at source rather than relying on engineering or post abstraction treatment solutions. However, although farmers may be aware of the apparent environmental benefits from planting cover crops, maintaining their profitability must also be a priority and many of the more recent studies have attempted to address this issue.

Several of the early studies concentrated on the use of legumes or grasses/cereals, especially as the former were already well known for supplying nitrogen to succeeding crops (Meisinger *et al*., 1990). As studies and agronomic practices developed, the wider use of brassicas as cover crops has also become more widespread. Several studies including Meisinger *et al*. (1991) and Isse *et al*. (1999) have shown that rye, forage radish and canola have far more potential to scavenge residual nitrate than legume cover crops.

Different studies have, naturally, come to different conclusions regarding the efficacy of different crop types. Premrov *et al*. (2012, 2014a and 2014b) concentrated on the use of mustard over-winter green cover in Southern Ireland and found that there were significant reductions in nitrate in the groundwater under the mustard crop when compared to the control with no cover. An earlier study conducted by Richards *et al.* (1996) which used nine sites around England to compare six cover crop varieties (and natural regeneration) found that phacelia was the overall most efficient cover crop for nitrogen uptake, although it was noted that there was considerable variation between the sites, once again alluding to the role of climate and geology/soil. Shah *et al*. (2017) whose two study areas were both in Southern England, concluded that different selections of species to provide a mixture of cover crops was essential to ensure the establishment of good over winter green cover that was suitable for a variety of weather conditions and soil types. White *et al.* (2014) highlight the importance of establishing areas on a farm scale, including controls with no cover, to evaluate the efficacy of different cover crop mixtures to achieve maximum benefits that are 'tailor made' for specific farms.

Table 2.1 outlines some of the typical species of grasses/cereals, brassicas and legumes that are commonly used as cover crops together with some considerations on their suitability and limitations.

In addition to an increasing variety of crops for selection, other agronomic factors must also be considered such as the most appropriate and beneficial time to plant the cover crop, the tillage/cultivation methods used to treat and seed the area and climate and soil as discussed by Dabney *et al*. (2001). Most authors agree that in order to achieve the best results (especially with regard to nitrogen uptake and root growth to stabilise soil) the earlier the sowing the better especially in areas with mild winters (Premrov *et al*. 2014). According to Staver and Brinsfield (1998) the cover crop efficacy in reducing soil nitrate levels was greatly diminished if cover crop planting was delayed by 30 days and, as a response, in subsequent years the cover crops were planted as soon as possible following the harvest to maximise both the extent and establishment of the vegetation. With regards to tillage practices (e.g. reduced tillage and conventional ploughing) and their effects on nitrate losses from the soil several studies have produced contradictory results. For example, Premrov *et al*. (2014) could find no significant effect on mean nitrate concentrations due to tillage practices over the course of their three-year study although earlier studies conducted by Goss *et al*. (1993) and Riley (1998) both produced evidence to the contrary. Furthermore, Ratsep *et al*. (1994) showed that nitrate leaching can be increased by autumn ploughing although where studies have included natural regeneration (of green over winter cover) under reduced tillage, greatly reduced nitrate concentrations were achieved suggesting that autumn tillage of farmland to stimulate natural regeneration, as opposed to ploughing, was potentially an economically viable method to limit nitrate leaching (Premrov *et al*., 2014).

Table 2.1. Examples of the typical cover crop varieties highlighting some of the properties that should be considered when selecting an appropriate mix. (AHDB, 2015).

	Brassicas	Legumes	Grasses and cereals
Example species	Mustards, radishes, turnips	Vetch, clovers	Oats, rye, rye-grass
Benefits	Brassicas can grow rapidly in the autumn. There is a good understanding of brassica agronomy (from oilseed rape experience) and establishment systems tend to fit with farm equipment.	Legumes fix nitrogen, which can benefit following crops and raise fertility; the amount of nitrogen fixed depends on species, growth and temperature but is likely to be small with an overwinter cover crop.	Cereals and grasses can deliver good early ground cover (important where erosion is a concern) as well as other benefits, including vigorous rooting.
Characteristics	While there are many types and growth habits, autumn-sown brassicas often provide good ground cover and deep rooting. This can mitigate leaching risks and improve soil structure. Some have trap crop and biofumigant activity.	In addition to nitrogen fixing, like most cover crops, legume roots can help to improve soil structure; rooting will vary depending on species, field conditions and cover crop duration.	For autumn sowing, these species can establish quickly and some types offer a wider range of sowing timings than brassicas or legumes.
Sowing	They are often late summer-sown or early autumn-sown at similar timings to oilseed rape. Field conditions and variety should guide specific sowing dates.	Legumes tend to be slower growing than brassicas and, for autumn use, often need to be sown earlier (late July–August) to aid growth and promote nitrogen fixation.	Sowing times vary with species and may range from July through to September.
Considerations	Good autumn establishment is critical to maximise growth, particularly where soil structure or nitrogen capture are key objectives. Think about potential rotational conflicts, eg clubroot, where vegetable brassicas or oilseed rape are grown in the rotation.	Consider management around the sowing and establishment of small-seeded legumes (used alone or in mixtures). There are also potential rotational conflicts, especially where other pulses and legumes are grown in the rotation.	Management tends to be similar to autumn cereals and grasses. They may act as a green bridge for cereal pests and diseases.

2.4 Brief Overview of Soil and Geology of the Study Area

2.4.1 Geology

The farms that form the study areas, Housedean, between Lewes and Falmer to the east, and Mile Oak on the northern edge of Brighton to the west, are situated on the Brighton Chalk Block Aquifer which is bounded by the Rivers Ouse and Adur, to the east and west respectively, the edge of which forms the northern scarp slope of the downs (Figure 2.3). The chalk in the Brighton Block Aquifer area is comprised of several separate chalk formations of which, in stratigraphical order, the Lewes

Nodular Chalk, the Seaford Chalk, the Newhaven Chalk and the Culver Chalk (a combination of the Tarrant and Spetsbury Chalks) are the predominant lithologies in the Brighton area (BGS, 2017) (Figure 2.4). Housedean Farm is situated in an area where the bedrock geology is dominated by the Newhaven Chalk while the Mile Oak site comprises both Newhaven Chalk and Culver Chalk formations (Figure 2.5).

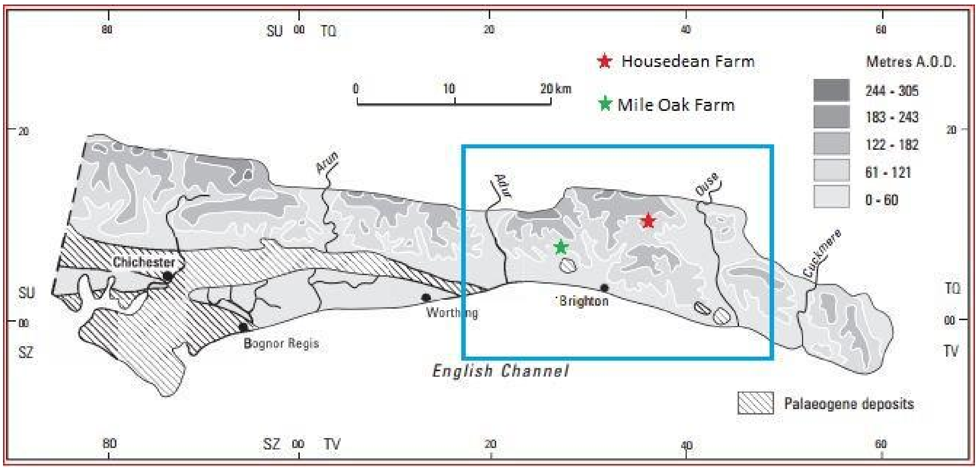

Figure 2.3. Map defining the Brighton Chalk Block aquifer and the location of the two study areas in the broader context of the South Downs Chalk aquifer (Jones and Robins, 1999).

According to Mortimore *et al*. (1990) the first three of these lithologies are rated to have good to high aquifer potential especially in localised areas where faulting and fractures occur. However, when considering the aquifer in a broader context as a single unit, its matrix porosity (the storage capacity of the aquifer) is generally between 15%-45% with a hydraulic conductivity (k) of between 10^{-5} and 10^{-8} ms^{-1} compared to the fractured lithologies with ranges of 0.5%-2% and 10^{-3} to 10^{-5} ms^{-1} respectively. This would suggest that although primary (matrix) permeability is low, secondary (fracture) permeability can be very high allowing the rapid movement of groundwater and contaminants such as nitrate.

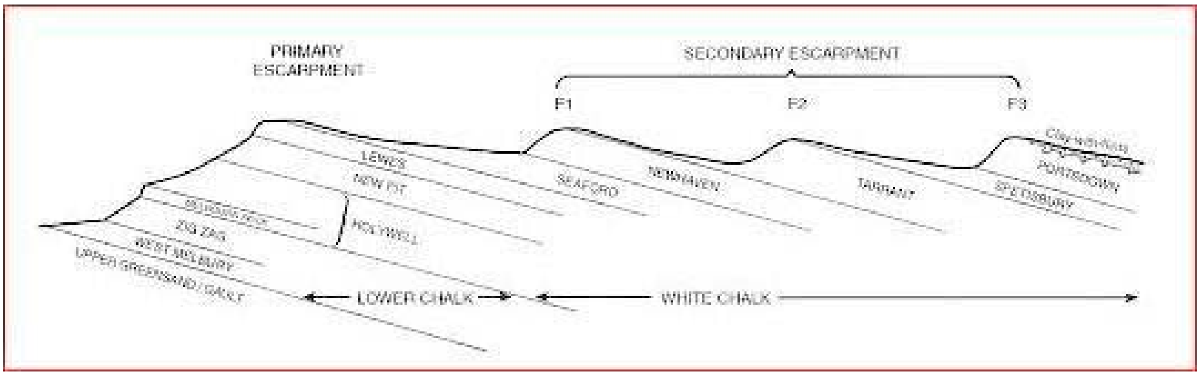

Figure 2.4. A schematic cross section to illustrate the relationship between the lithostratigraphical members of the Chalk Group and topographic features (Jones and Robins, 1999).

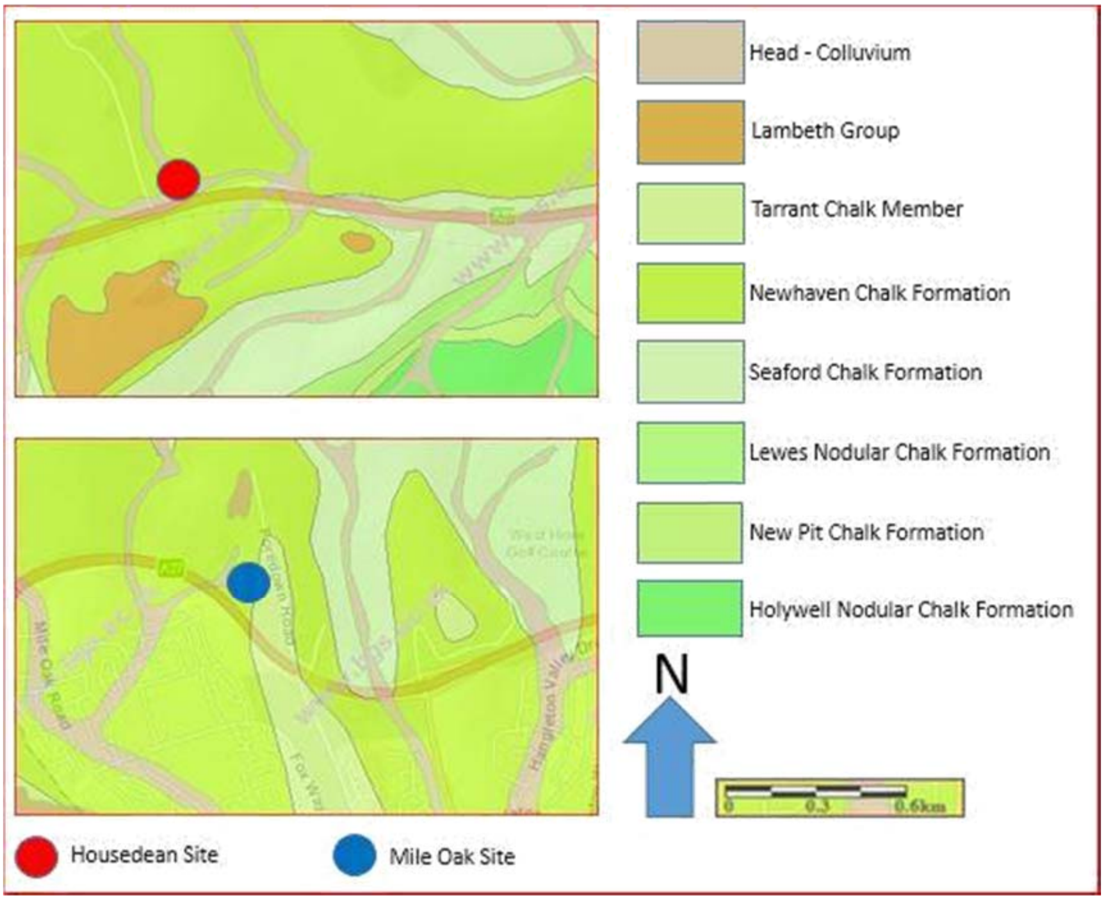

Figure 2.5. Geological maps showing the various Chalk formations that comprise the two study areas (BGS, 2018).

The aquifer properties are further influenced by the different lithologies of the various formations as well as the presence of marl layers and shelf flints. For example, the harder Chalk lithologies are more inclined to develop more numerous and better defined fracture sets that will enhance their aquifer potential by promoting groundwater flow (Mortimore *et al.,* 1990). Furthermore, areas where sheet flints are present, such as in the Newhaven Chalk where they widely occur in the Brighton Area (Mortimore, 2001), can lead to the formation of perched aquifers. A perched aquifer is one that develops above the regional water table in the vadose zone due to either an aquiclude or aquitard above the water table (figure 2.6). According to Niswonger *et al*. (2004) perched aquifers can be slow to discharge but will recharge quickly giving them the potential to disrupt groundwater flow and lead to the possible attenuation of contaminants.

The marl seams vary in thickness from a few millimetres to several centimetres and can be laterally continuous over hundreds of km which render them useful as correlation markers in mapping the Chalk (Mortimore, 2001). They are the result of the deposition of volcanic ash erupted concomitantly with the accumulation of the coccoliths that form the Chalk, the volcanic activity almost certainly being the result of increased ocean ridge activity due to the widening proto-Atlantic. The thickness and clay content of the marl, which Ward *et al*. (1968) suggests to be between 10-30%, will affect their permeability (Molyneux, 2012) and it has been suggested by Mortimore (2011) that chalk formations that contain abundant marl seams can be broadly characterised by conjugate sets of fractures that promote fracture flow of groundwater and therefore any contaminants contained therein.

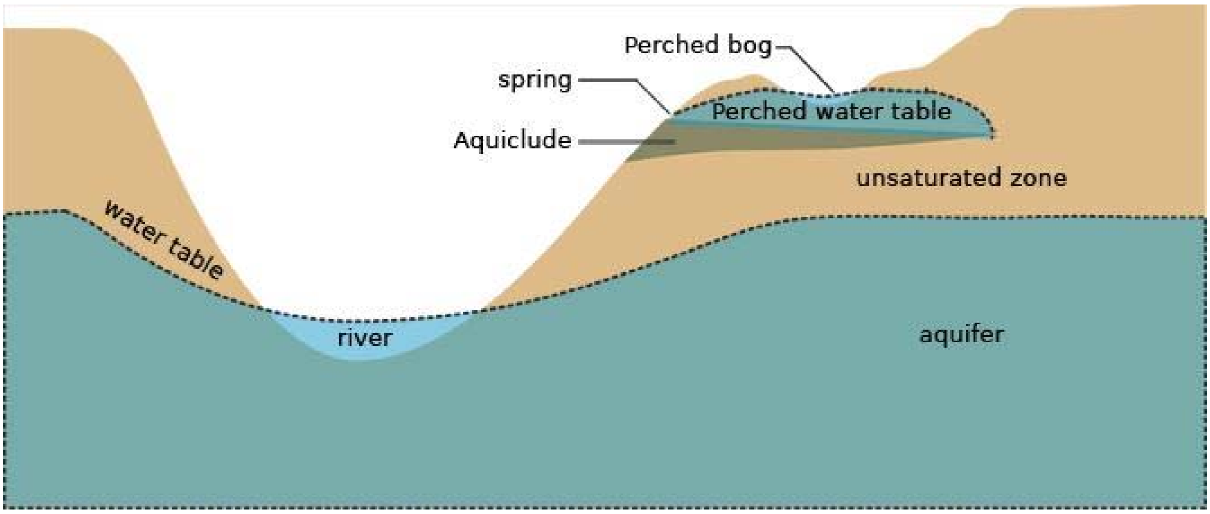

Figure 2.6. Simple schematic to illustrate the relationship between a perched aquifer and the main aquifer (Geocaching, 2014).

Furthermore, the presence of features such as the marl layers and sheet flints can promote preferential flow which can, potentially, lead to the development of dissolution features along the upper and lower boundaries with the surrounding Chalk, once again permitting the rapid flow of groundwater. However, these dissolution features can be relatively small scale when compared to the dissolution pipes that occur widely in the area. Dissolution pipes occur as sediment filled, conical cavities that can be several tens of meters' deep and are probably the most common karst feature in the Chalk of southern England, although other features such as sinkholes and stream sinks also occur (Farrant, 2001). These karstic features can have a major impact on engineering works (Mortimore, 1993) and are often not identified until the works are taking place. It is for this reason that many of the karst features in the Brighton area appear to coincide with the A27 Brighton bypass (Figure 2.7). As these features allow the rapid transportation of water and pollutants, including nitrate, an understanding of where they occur would be a useful tool in tackling contamination in vulnerable areas (Brighton ChaMP, 2017).

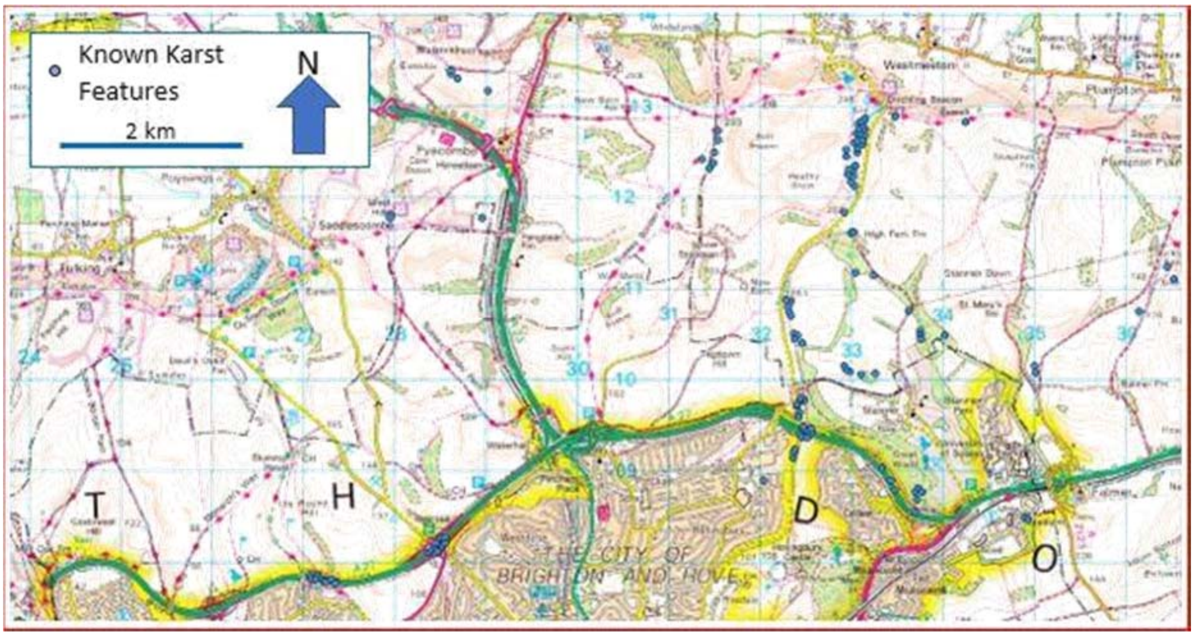

Figure 2.7. Map highlighting the locations of known karst features in the Brighton area (Brighton ChaMP, 2017).

2.4.2 Soil

In general, the soil types and conditions of both study sites are broadly similar. According to the BGS UK soils map viewer (2017) both areas comprise intermediate to shallow chalky loam soils, with belts of colluvium accumulating in the valley areas with both soil types being slightly alkaline and displaying similar average annual soil temperatures of 11.57^{O}C at Housedean and 11.48^{O}C at Mile Oak.

From observation, the soil at the Mile Oak site was on average slightly deeper and more clayey than that at Housedean which therefore has implications for contaminant diffusion throughout the soil layer and these are considered in more detail in Chapter 5.

2.5 Climatic Factors

Climatic factors, such as excessively high or low temperatures or drought/waterlogging, will affect a plant's growth and its ability to fix nitrogen from the soil, as well as rate of nitrate loss through the soil where seasonal peaks of nitrate leaching occur with higher rainfall in the autumn and winter.

For instance, Cuttle *et al*. (2003) was able to demonstrate how root nodule function was adversely affected by extremes in temperature and Rosenfeld and Rayns (2011) found that legumes could only fix soil nitrogen when soil temperatures were 8^{O}C or more. However, the effects of temperature will vary between different species and even between cultivars within the same species implying that some plant varieties used for cover crops will be more suited to certain climatic regions than others. For example, Power and Zachariassen (1993) performed glasshouse studies on the effects of temperature on total nitrogen uptake on several species of plant widely used as cover crops. They found that at 10^{O}C, hairy vetch and faba bean were the most efficient for uptake and fixation of total nitrogen but at 20^{O}C faba bean and soybean showed the best growth and nitrogen uptake while crimson clover and field pea did not perform well.

According to Met Office data, over winter temperatures (November to February) in southern England achieve a mean daily maximum of $<8^{O}$C suggesting that nodule formation in winter cover crops, especially those consisting predominantly of legumes and their ability to fix soil nitrogen, will be inhibited potentially allowing it to be leached from the soil. Therefore, early sowing allowing the establishment of the cover crop during the late summer or early autumn when growing conditions are more favourable can be seen to be an important factor when trying to maximise its efficacy.

As mentioned previously, the failure of surface and groundwater to achieve good status is predominantly caused by elevated nitrate concentrations which, according to Stuart *et al.* (2007), will continue to increase not only due to continuing impacts from present and ongoing sources but also from accumulations already in the aquifer that have not yet reached the abstraction boreholes. This has been termed the nitrate time bomb, the effects of which may be exacerbated by changes in leaching patterns, recharge mechanisms and groundwater levels as the result of climate change.

Recent climate predictions for the UK (UKCP09) and, more specifically for southern England, suggest that mean daily maximum temperatures could increase by 5.4^{O}C and that summer precipitation could decrease by up to 40%. It has also been suggested that there would likely be an increase in the occurrence of extreme rainfall events.

These factors could not only increase the amount and rate of nitrate rich leachate destined for the groundwater but would also increase the potential pathways that would allow it to reach the aquifer. For example, soil moisture content is dependent on the balance between precipitation and evotranspiration. Any increases in temperature in combination with decreases in overall rainfall could lead to shrinking and cracking, especially in clayey soils such as at the two study sites, and prolonged dry periods could result in the deepening and widening of cracks (Stuart *et al*., 2011). This, in turn, would permit increased infiltration during any extreme precipitation event with elevated concentrations of leachate being driven into the system (Figure 2.8). It can therefore be seen that climate change may not only affect recharge and discharge (abstraction) mechanisms but also the quality of the groundwater (Dragoni and Sukhija, 2008).

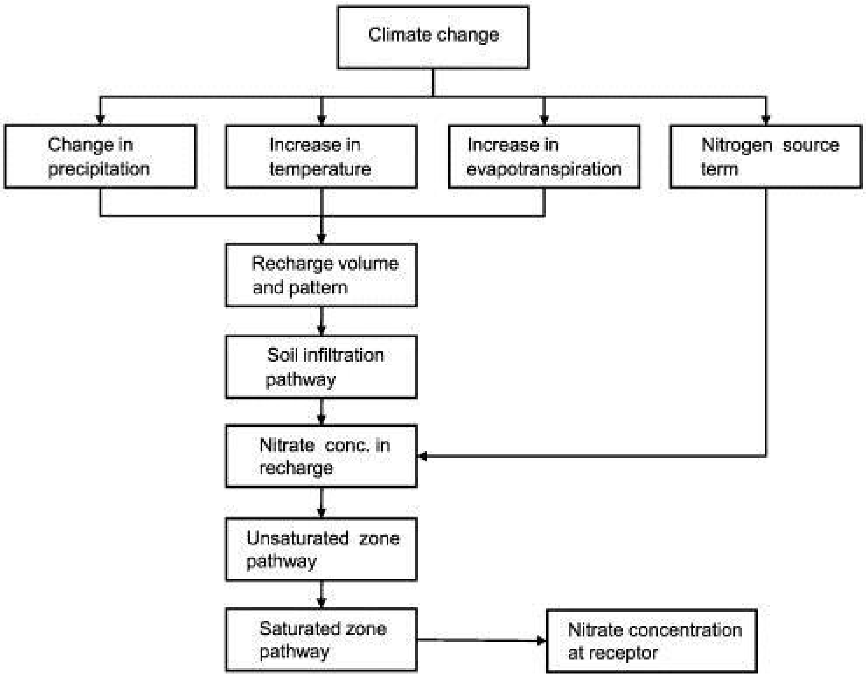

Figure 2.8. Routes for climate change impact on nitrate leaching pathways (Stuart *et al.,* 2011).

Chapter 3: Methods and Materials

This chapter presents the materials and methods used in both the fieldwork and the laboratory analysis. This includes the field sampling methods for the groundwater sampling, the configuration and composition of the cover crop plots, the physicochemical methods used for nitrate analysis, a brief overview of the slug survey and, finally, the statistical methods used for the subsequent analysis of the data.

3.1 Porous Pots and Cover Crop Varieties

In order to determine whether over winter cover crops reduce leaching of nitrate into the aquifer, two sites were established which were then subdivided into seven separate plots to test the effectiveness of different crop varieties (Figures 3.1 and 3.2)

In early October 2017, between one and six porous pots were drilled into each plot (typically four) to collect soil water samples which were collected from mid-October 2017 on a two weekly basis, then from January 2017 on a weekly basis to maximise the amount of data available for the study. This continued until 24/01/2018 for Housedean and 14/03/2018 for Mile Oak when sampling stopped and the porous pots were removed prior to drilling the subsequent crop. The control plots had to be set up slightly later as they required spraying to kill off any crop volunteers that may have established after drilling the cover crops. This was necessary as the control areas had to be free of any green cover to obtain meaningful results. Once both control plots had been treated three porous pots were installed at each site on 15/12/2017 and samples taken as per the cover crop plots.

Figures 3.1 and 3.2. Aerial views of the study areas at Housedean (left) and Mile Oak (right) showing the subdivisions for the cover crops and control plots.

The porous pots (Figure 3.3) were augured to a depth of approximately 0.9m which, in nearly all cases, was through the soil layer and into the underlying chalk, with the porous part of the device being surrounded by backfilled fine silica sand to ensure a good hydraulic contact and the rest of the hole backfilled with spoil and capped with a layer of bentonite clay in order to prevent the preferential flow of rain/surface water down the sides of the tubes to the ceramic bulb. Each device was then vacuum pumped to -20inHg (approximately -67.7kPa) each time samples were taken. The groundwater samples were collected using a vacuum hand pump (Figure 3.4) and decanted into sealed, sterilised 500ml plastic bottles with the approximate volume of the sample being recorded from 29/11/2017 onwards (Appendix 1). They were then delivered to the Southern Water Laboratories for subsequent testing to determine levels of nitrate. The amount of groundwater collected varied between pots and from week to week (Appendix 1) although all samples, however small, were delivered for analysis.

Figures 3.3 and 3.4. One of the porous pots used in the study and the vacuum pump apparatus used to extract the water sample. Each porous pot is approximately 1 meter long with the white, ceramic bulb being approximately 10 cm long.

Testing the groundwater samples involved the use of the Aquakem 600 Discreet Analyser to measure the concentrations of contaminants and comparing the coloured complexes that are created to calibrated samples with known concentrations of the determinant, in this case nitrate. The analysis calculated concentrations of NO_2 followed by total oxidised nitrogen (TON). The concentration of nitrate as NO_3 can then be calculated using:

(TON as N) - (NO_2 as N) = (NO_3 as N) (ALS Environmental, 2015).

In this method the nitrate is reduced to NO_2 using a cu/hydrazine reducing agent and the concentration of NO_2 produced is calculated using the standard method, the results being expressed in mgl^{-1} of nitrate.

Each study site was divided into seven strips, six of which were then planted with different varieties of seed mixes leaving one strip left bare to act as a control (figure 3.5). The seed mixes and their respective recipes are shown in Table 3.1 together with which combinations were used at which site and Table 3.2 highlights some of the main characteristics of each plant variety. Both sites were established in August 2017 (cover crops being drilled at Housedean on 10/08/2017 and Mile Oak on 29/08/217) after the harvest of the spring barley crop which had received the standard applications of both fertiliser and pesticide. Prior to the spring barley crop the areas had been used to grow winter wheat. No organic fertiliser or slurry was applied to either site prior to the study and data for inorganic fertiliser application at Mile Oak was unavailable.

Figure 3.5. Original plot designations of cover crop and control plots for Housedean (left) and Mile Oak (right). However, for the final study, Housedean did not include Long Cover and Mile Oak did not include Complex EFA.

Further soil testing, conducted by the Farming and Wildlife Advisory Group (FWAG) was carried out both prior to and during the study period (06/09/2017 and 24/01/2018 respectively) at both sites. The tests were performed on soil samples taken from a depth of 0-30cm from beneath all cover crop varieties regardless of their inclusion or not in the study. The results of their analyses are shown in Chapter 4.3 and considered further in Chapter 5.2.

Table 3.1. Varieties of cover crop plants and the various recipes used to test the efficacy of cover crops for the study (HD=Housedean; MO=Mile Oak).

Seed Mix Name	Recipe		Bag Weight (kg)	Target Drilling Rate (kg/ha)	Sites at which used
Simple EFA	Oat Mustard	80% 20%	15	20	HD and MO
Complex EFA	Rye – Humbolt Radish – Barracuda Phacelia Vetch	56% 20% 4% 20%	20	25	HD
Short Catch	Black Oat Linseed Buckwheat Mustard Radish – Compass UK Peas	15% 20% 20% 10% 15% 20%	15	20	HD and MO

Long Cover	Rye – Humbolt 35% Phacelia 5% Vetch 25% Jupiter Turnip Rape 15% Radish - Barracuda 20%	15	25	MO
Grazing	UK Winter Oat 70% Jupiter Turnip Rape 15% Barkant Stubble Turnips 15%	15	25	HD and MO
Multi mix	Winter Oats 20% Rye – Humbolt 20% Radish – Siletta Nova 15% Phacelia 5% Buckwheat 10% Crimson Clover 5% Berseem Clover 5% Linseed 10% Sunflowers 10%	15	25	HD and MO
Control (Bare)	N/A	N/A	N/A	HD and MO

Table 3.2. Attributes of the various plant types that have been used in the cover crop recipes in this study.

Barkant Stubble Turnips – Fast growing catch crop preferring free draining light, loamy soils. Cold and frost resistant.
Berseem Clover - shallow tap root but can grow to 80 cm tall. Moderate tolerance of cold conditions and short periods of waterlogging but will not tolerate shading.
Black Oat - Upright, winter annual member of the grasses that grows best in sandy or loamy soils but can also grow in heavy clay and soils with low nutrient value. Not frost tolerant.
Buckwheat - Best growth in cool moist climates and it is sensitive to climate extremes. Not particularly winter hardy but can establish a substantial rooting system in autumn.
Crimson Clover - Deep rooted and helps to improve soil structure. Is fast growing and therefore good for smothering weeds. Intolerant of prolonged, hard cold weather.
Jupiter Turnip Rape – Fast growing with dense foliage that suppresses weeds and aids against soil erosion. Suitable for late sowing and will absorb nitrogen quickly. Good winter hardiness that prevents nutrient leaching.
Linseed - Light, well-drained but moisture retentive soils are best for growth. Fibrous roots that Improve soil structure.
Mustard - Thrive in warmer weather but will survive well in cooler temperatures. They do not usually require fertiliser and are likely to survive cover cropping.
Oats – Good nutrient scavengers with deep branched roots. Good suppression of weeds and volunteers. Not cold or frost resistant.
Phacelia - Quick establishment with fast growth and fine root structures that will penetrate quite deeply. It is a nitrogen collector that is tolerant of colder temperatures.
Radish (Barracuda) - Deep penetrating taproots, puncturing the soil helping drainage. Bulky cover on the surface increasing soil organic matter. It is a nitrogen collector and is frost resistant.

Radish (Compass) - Long vegetative growth with deep and intense root penetration which will improve soil structure.
Radish (Siletta Nova) - Deep penetrating tap roots with good surface cover aiding weed suppression and helping against soil erosion. Also good for nitrogen conservation and humus formation. Drought tolerant but not so for frost.
Rye – A fast growing annual that is usually grown as a winter crop where temperatures are too low for winter wheat.
Sunflowers - Extensive and prolific root system with the ability to soak up residual nutrients. Rapid early season establishment so can be used as support by other vining/climbing cover crop plants.
UK Peas - Good nitrogen fixer. Needs an open sunny position with good soil drainage. Prefers cooler weather.
Vetch- Fast establishing and good at fixing nitrogen although very frost sensitive.

3.2 Slug Trial Data

Studies were conducted to ascertain whether over winter cover crops increased slug populations therefore increasing workload/pesticide costs for the land owner and creating a potential pollution swapping issue should increased quantities of pesticides be required. Pollution swapping is defined as the increase in concentration of one contaminant while trying to reduce concentrations off another, in this case exacerbating the concentrations of metaldehyde in groundwater derived from slug pellets whilst trying to reduce nitrate concentrations by planting cover crops. The study, conducted by Eley (2018), used baited traps that were attended every two weeks (between 11/11/2017 and 07/03/2018) where slugs of the species *Derocerus reticulatum* and *Arion hortensis* were counted and then removed from the areas in order to avoid counting them more than once on subsequent site visits. The bait used was Marriage's Farmyard layer's mash, a poultry feed that is non-GM and free from both medication and chemical pigments and has been identified as an appropriate bait for slugs by the AHDB as it poses no threat to the environment or the slugs. Approximately 2-3 tbsp. were placed beneath an upturned plastic flowerpot on each visit, any bait left from the previous visit being cleared away both for the sake of consistency regarding the amount of bait and to prevent any mould growth. The results of this study are given in Appendix 2 and for greater detail refer to Eley (2018).

3.3 Weather Data

Weather data for the duration of the study was collected from two weather stations close to the study areas, primarily for the rainfall data, these being:

Housedean: Falmer Sports Facilities, University of Brighton (TQ 34654 08497)

Mile Oak: Peter Gladwin Primary School, Drive Road, Portslade (TQ 25565 06520)

The data collected included Average Air Temperature (AAT, ^{O}C), Total Rainfall (TR, mm) and Relative Humidity (RH, %) and was recorded over 24 hours every day between 16/10/2017 and 14/03/2018. However, the TR data was shown to be incorrect for multiple entries and was therefore deemed unusable. Alternative rainfall data was acquired from the Environment Agency which used weather stations located at Housedean Farm (TQ 36917 09304), Applesham Farm (TQ 19486 07183) and Ditchling Road, Brighton (TQ 31486 07647). For this study, the Applesham Farm data was used as it is slightly closer to Mile Oak than Ditchling Road and it is a more rural location, better reflecting conditions at the study site.

3.4 Statistical Analysis

All data sets were collated on Excel and then transferred to Minitab 17.3 for more detailed analysis which began with normality testing to establish whether parametric or non-parametric tests would be most suitable to determine whether any statistically significant relationship exists between the use of cover crops and nitrate reduction in groundwater. The Ryan-Joiner normality test was used as it is similar to the Shapiro-Wilks test and as such is recommended for use on datasets with less than 50 items of data. Consequently, the test deemed most suitable was the Mann-Whitney U test. Spearman's Rho was used to determine whether there was a correlation between mean concentration of nitrate and mean rainfall over the study period at each of the sites. All statistical tests used a confidence level of 95% (i.e. $\alpha = 0.05$) where the null hypotheses are stated as:

H_0 = the data follow a normal distribution

H_0 = there is no statistical significance between the use of cover crops and reduction in nitrate in groundwater.

and the alternative hypotheses are stated as:

H_1 = the data do not follow a normal distribution

H_1 = there is a statistical significance between use of cover crops and reduced concentrations of nitrate in the groundwater.

The results for normality testing are given in Appendix 3 while the results of the non-parametric Mann-Whitney U tests are shown in Chapter 4.2 and discussed in greater detail in Chapter 5.

In order to perform any correlation testing, Minitab requires the datasets to have the same amount of data. Therefore, each set of cover crop data (including control plots) was paired with the rainfall data from corresponding dates to provide datasets of the same length resulting in groups ranging in size from 16 for the Mile Oak Simple EFA to 5 for the Control Plot at Housedean.

Further statistical analysis was conducted utilising the Mann-Whitney U test as it is used to determine whether there is a statistically significant difference between two unrelated and independent groups on a dependent variable i.e. between the control plot and cover crop plots on the concentration of nitrate in the groundwater. The test has four assumptions which must be met for the results to be valid:

1- That the dependent variable is measured on a continuous or ordinal scale;

2- That the independent variables consist of two categorical and unrelated groups;

3- That there is independence of observations i.e. “that there is no relationship between the observations in each group or between the groups themselves” (Laerd Statistics, 2018).

4- That the distributions of the datasets are of a similar shape.

For this study, all of the above assumptions are met the final one having been verified with Minitab, the resulting graphs being shown in Appendix 4. The only problematic sample was the Long Cover plot at Mile Oak where the sample size was only 11. This group tested normal for distribution (i.e. H_0 cannot be rejected) as did the Control plot and, therefore, a parametric test would normally be selected for this pairing. However, the disparity in group size (Control=32, Long cover=11) means that assumptions for homogeneity of variance and/or normality cannot be made (Pagano, 2004) and although some deviations in sample size can be accommodated, for example, Morgan *et al*. (2004) who suggest sample sizes can be considered equal if the larger group is not more than 1½ times larger than the smaller group, this is certainly not the case in this study and therefore the Mann-Whitney U test was used for these samples also.

Chapter 4: Results

This chapter presents the results of the Aquakem analysis for nitrate, the statistical analyses of these results (including rainfall) and the nitrate and ammonia results of the FWAG soil testing. The Environment Agency rainfall data and the full FWAG soil testing results are given in Appendices 5 and 6.

4.1 Groundwater Samples

Tables 4.1 and 4.2 show the results of Southern Water's nitrate analysis for the samples collected from the two study sites. Maximum concentrations range from 112 mgl^{-1} and 0.65 mgl^{-1} at Housedean (Control and Complex EFA respectively) and 209 mgl^{-1} and 92 mgl^{-1} at Mile Oak (Simple EFA and Control respectively) to minimum concentrations of 69.1 mgl^{-1} and 0.09 mgl^{-1} at Housedean (Control and all cover crop recipes respectively) and 65.7 mgl^{-1} and 0.09 mgl^{-1} at Mile Oak (both recorded from Multi Mix) help to illustrate the differences in both cover type and location. Simple graphs constructed using the median values of the nitrate concentrations for each plot would certainly suggest that groundwater sampled from below the cover crop plots contained less nitrate than the control plot samples (Figures 4.1 and 4.2) by as much as 99% at Housedean (Control vs Complex EFA) and 98.8% at Mile Oak (Control vs Multi-mix). Also, it can be seen that all cover crop varieties represent a significant reduction compared to the Control plot with no green cover.

Figure 4.3 illustrates the general trends of nitrate concentrations and rainfall over the study period using the weekly mean nitrate values for each plot and appears to show that generally concentrations reduce with time. The obvious exception is the Short Catch plot at Housedean where mean nitrate concentrations gradually begin to increase after 13/12/2017 reaching concentrations of 25.38 mgl^{-1} by 10/1/2018, similar to earlier concentrations on 15/11/2017 of 26.45 mgl^{-1}.

Although fewer results were obtained for groundwater analysis for the control plots at both sites, there would appear to be a general relationship between nitrate concentrations from beneath the control plots and the amount of rainfall (Figure 4.2), peaks and troughs in nitrate concentration/amount of rainfall generally following a similar, if slightly offset, pattern. This is, however, refuted by the statistical analysis (see below).

4.2 Statistical Analysis

The results for normality testing are shown in Tables 4.3 and 4.4 and the graphs illustrating the normality and distribution of the data are shown in Appendices 3 and 4. The results of the Mann-Whitney U tests are given in Tables 4.5 and 4.6 and it can be seen that for both Mile Oak and Housedean that the median values for nitrate concentrations are higher for the control plots than those for the cover crop plots. Furthermore, *p* values in all instances are less than the significance level at 95% confidence (i.e. $p < 0.05$) suggesting that there is a statistically significant difference in median nitrate concentrations between the two groups i.e. Control (no cover) and cover crops.

Correlation testing performed on the study plot nitrate concentrations and the Environment Agency rainfall data using Spearman's Rho suggest that there is no significant statistical correlation between these two elements of the study at either Housedean or Mile Oak Farms (Tables 4.7 and 4.8) although the p value for the correlation between mean rainfall and mean nitrate from beneath the control plot at Mile Oak (p=0.067) is approaching the confidence level at 95% ($\propto$=0.05) and is certainly far closer than any of the other correlation statistics.

4.3 FWAG Soil Testing

The FWAG soil test results for nitrate and ammonia are shown in Table 4.9 and it can be seen that at both the Housedean and Mile Oak sites over the study period the amount of nitrate decreased while that of NO_4 increased. These concentrations ranged from 40.7 and 2.8 kg/Ha to 17.6 and 8.5 kg/Ha (nitrate and ammonia respectively) at Housedean and 54.8 and 3.3 kg/Ha to 25.1 and 23.5 kg/Ha (nitrate and ammonia respectively) at Mile Oak. Assuming a soil bulk density of 1000 kgm^{-3} and a sampling depth of 30cm, this gives nitrate concentrations in the range of approximately 13.6 mgl^{-1} to 5.9 mgl^{-1} at Housedean and 18.3 mgl^{-1} to 8.4 mgl^{-1} at Mile Oak. At both study sites, the initial ratio of mean NO_3:NH_4, over the entire site, was approximately 10:1 which, in both cases, had altered to approximately 3:1 by 24/01/2018.

Table 4.1. Results of the nitrate analysis performed by Southern Water and total and mean weekly rainfall calculated from the Environment Agency data for the Housedean study site.

																								Total Weekly	Mean Weekly
		Simple EFA				Complex EFA				Short Catch				Grazing				Multi Mix				Control		Rainfall (mm)	Rainfall (mm)
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23		
18/10/2017	7.41	6.63	5.04	35.6	-	-	20.8	22.3	-	41	-	54.5	50.5	45.9	25.7	49.5	-	-	28.5	36	-	-	-	27	3.86
01/11/2017	-	1.4	-	-	-	-	-	-	-	-	6.6	26.6		25.3	-	-	9.15	-	-	12.7	-	-	-	4	0.57
15/11/2017	10.2	0.71	-	-	8	-	-	-	52.3	35.2	1.21	17.1	5.84	17.6	-	-	2.18	-	2.7	1.95	-	-	-	2.1	0.3
29/11/2017	6.08	0.78	0.69	0.91	1.18	0.65	1.2	9.58	20.6	31.6	0.7	3.3	1.14	2.95	11.3	29.2	1.24	22.6	1.34	1.34	-	-	-	3.9	0.56
13/12/2017	-	0.09	-	0.09	0.09	0.09	0.09	-	7.4	32.2	0.09	0.09	0.09	1.02	10.9	23.7	0.09	21.1	1.51	1.15	-	-	-	26.6	3.8
20/12/2017	-	0.84	0.97	1.3	0.71	0.61	0.96	6.23	12.9	31.6	0.8	1.53	0.73	1.88	7.92	14.	1.1	15.6	5.34	1.67	74.8	112.	47.5	8.3	1.19
03/01/2018	-	0.93	0.82	1.25	0.67	0.58	0.85	5.46	23.5	32.	-	1.51	1.13	1.48	6.	12.5	1.14	13.6	4.61	1.75	79.6	111.	44.7	41.3	5.9
10/01/2018	7.84	0.79	0.95	3.54	0.37	0.37	0.51	4.64	34.9	37.3	-	3.93	0.37	1.21	4.37	6.4	0.63	21.6	5.61	1.5	-	79.2	23.7	1.6	0.23
17/01/2018	7.52	0.38	0.71	3.56	0.4	0.37	0.46	4.61	36.2	37.4	0.62	3.47	0.37	0.88	4.32	7.65	0.85	26.3	3.49	2.09	-	76.2	52.8	25.80	3.69
24/01/2018	8.01	0.72	0.89	4.78	0.61	0.55	3.27	5.58	34.2	38.7	0.7	4.28	0.62	0.84	4.06	7.12	1.47	27.5	2.97	2.67	-	69.1	52.	38.70	5.53
Mean	7.84	1.33	1.44	6.38	1.50	0.46	3.52	8.34	27.75	35.22	1.53	11.63	6.75	9.91	9.32	18.76	1.98	21.19	6.23	6.28	77.20	89.50	44.14	17.93	-
Median	7.68	0.79	0.89	2.42	0.64	0.55	0.91	5.58	28.9	35.2	0.7	3.7	0.73	1.68	6.96	13.3	1.14	21.6	3.49	1.85	77.2	79.2	47.5	17.05	-
Max	10.2	6.63	5.04	35.6	8	0.65	20.8	22.3	52.3	41	6.6	54.5	50.5	45.9	25.7	49.5	9.15	27.5	28.5	36	79.6	112	52.8	41.3	5.9
Min	6.08	0.09	0.69	0.09	0.09	0.09	0.09	4.61	7.4	31.6	0.09	0.09	0.09	0.84	4.06	6.4	0.09	13.6	1.34	1.15	74.8	69.1	23.7	1.6	0.23
Gp. Median	0.97				0.69				18.85				5.84				2.67				71.95				

Table 4.2. Results of the nitrate analysis performed by Southern Water and total and mean weekly rainfall calculated from the Environment Agency data for the Mile Oak study site.

		Simple EFA						Short Catch			Long Cover			Grazing				Multi Mix				Control		Total Weekly Rainfall (mm)	Mean Weekly Rainfall (mm)
Date	1	2	3	4	5	6	7	8	9	10	12	11	13	14	15	16	17	18	19	20	21	22	23		
18/10/2017	-	-	-	103	-	-	-	-	-	-	-	-	-	-	56.6	-	-	-	-	-	-	-	-	25.6	3.66
01/11/2017	-	-	-	129	-	-	-	-	-	134	-	-	-	-	-	-	-	58.3	31.2	7.08	-	-	-	5.6	0.8
15/11/2017	180	-	-	99.1	209	66.2	-	-	-	-	-	-	-	-	-	-	65.7	41.5	47.8	7.94	-	-	-	2.9	0.41
29/11/2017	92.2	-	-	96.5	165.	49.	10.2	35.5	-	8.33	-	91.9	2.32	1.19	0.8	74.3	-	34.4	41.6	2.78	-	-	-	5.2	0.74
13/12/2017	27.1	0.09	-	74.4	116.	27.1	2.84	23.3	22.3	7.49	-	13.8	1.73	1.59	0.09	-	-	-	-	0.09	-	-	-	26	3.71
20/12/2017	27.2	0.92	14.3	68.9	93.3	14.6	16.9	-	56.6	17.2	21.1	41.	5.31	7.42	0.82	2.89	-	-	0.73	0.63	82.7	-	68.6	5.4	0.77
03/01/2018	29.4	0.93	-	57.7	69.8	15.2	15.8	49.5	74.4	7.34	6.71	27.4	2.07	2.59	0.76	-	-	-	0.6	0.56	92.	81.4	68.4	35.2	5.03
10/01/2018	36.8	3.58	3.64	30.1	42.7	9.74	8.55	33.8	59.	7.32	15.7	20.4	2.2	0.37	0.58	-	-	-	0.37	0.37	41.2	53.7	56.6	2.1	0.30
17/01/2018	40.5	2.41	-	17.9	25.3	8.23	6.07	26.8	58.6	4.	16.	9.36	1.11	0.73	0.55	-	-	-	0.37	0.37	54.7	62.5	62.4	28.1	4.01
24/01/2018	47.	16.6	2.21	11.1	15.2	5.71	4.38	19.2	49.8	4.32	18.4	8.57	0.61	0.69	0.82	-	-	-	0.37	0.54	45.7	52.8	58.8	31.1	4.44
31/01/2018	50.4	15.6	-	4.68	-	3.57	2.41	11.6	32.5	3.63	11.2	10.5	1.07	0.98	0.75	-	-	-	0.62	0.46	27.4	48.3	53.5	11.7	1.67
07/02/2018	54.2	4.7	0.75	2.02	8.01	1.71	1.31	7.69	18.5	3.64	7.07	8.68	0.49	0.46	0.4	-	-	-	0.37	0.37	33.9	62.7	51.7	15	2.14
14/02/2018	54.8	2.9	0.92	0.37	6.96	1.64	3.98	7.14	12.1	6.57	5.8	3.29	0.73	0.86	0.83	-	-	-	0.63	0.39	54.7	68	60.3	30.1	4.30
21/02/2018	60.5	2.07	1.23	1.06	5.89	2.22	4	6.29	4.6	7.03	5.24	1.52	1.11	1.18	0.98	-	-	-	1.03	0.81	31.4	61.8	55.6	2.2	0.31
07/03/2018	60.4	2.67	-	0.37	4.57	-	3.9	5.89	1.14	6.64	3.37	1.18	0.38	0.37	0.63	-	-	-	0.79	0.37	59.1	65.1	58.3	28.1	4.01
14/03/2018	60.8	2.15	-	0.62	4.88	5.48	4.72	4.62	0.88	8.62	9.81	1.27	1.5	0.68	2.43	-	-	-	1.23	0.97	71.5	71.8	69.4	29.1	4.85
Mean	58.66	4.55	3.84	43.55	58.97	16.18	6.54	19.28	32.54	16.15	10.95	18.37	1.59	1.47	4.79	38.60	65.70	44.73	9.12	1.58	54.03	62.81	60.33	17.71	-
Median	52.3	2.54	1.72	24	25.3	8.23	4.38	15.4	27.4	7.175	9.81	9.36	1.11	0.86	0.78	38.595	65.7	41.5	0.68	0.54	54.7	62.6	58.8	20.3	-
Max	180	16.6	14.3	129	209	66.2	16.9	49.5	74.4	134	21.1	91.9	5.31	7.42	56.6	74.3	65.7	58.3	47.8	7.94	92	81.4	69.4	35.2	5.03
Min	27.1	0.09	0.75	0.37	4.57	1.64	1.31	4.62	0.88	3.63	3.37	1.18	0.38	0.37	0.09	2.89	65.7	34.4	0.37	0.09	27.4	48.3	51.7	2.1	0.3
Gp. Median	14.90								7.49		9.81		1.11				0.73				58.95				

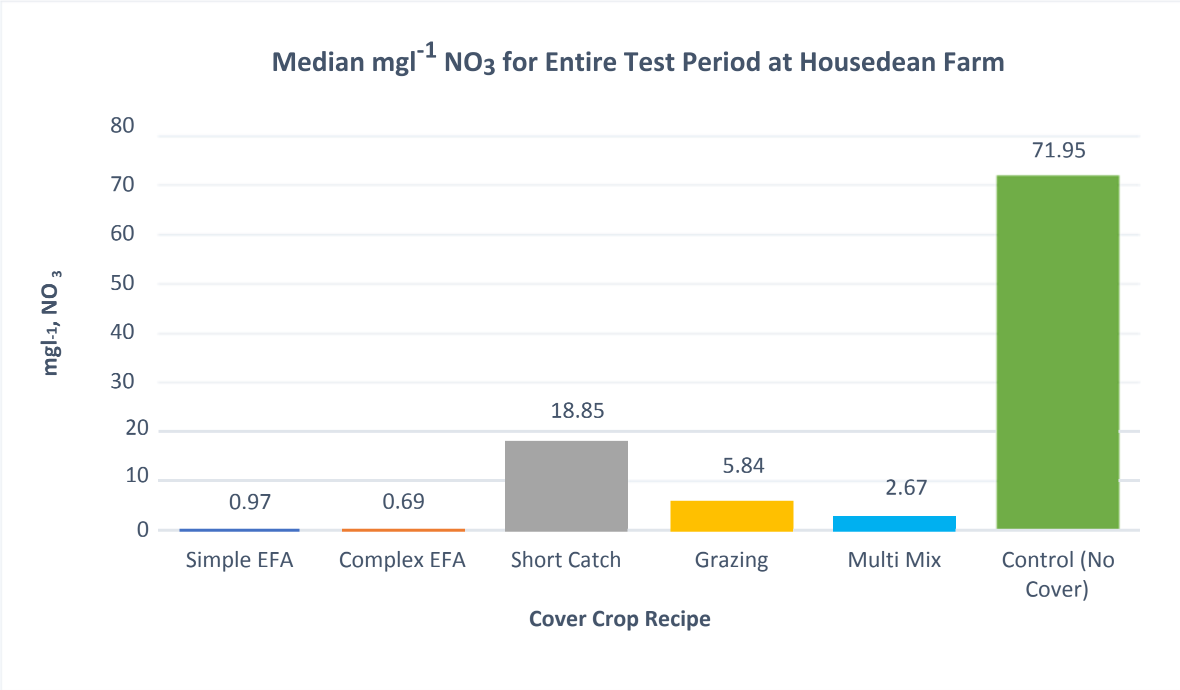

Figure 4.1. Simple histogram illustrating the median concentrations of nitrate (NO_3) in groundwater samples over the study period at Housedean Farm.

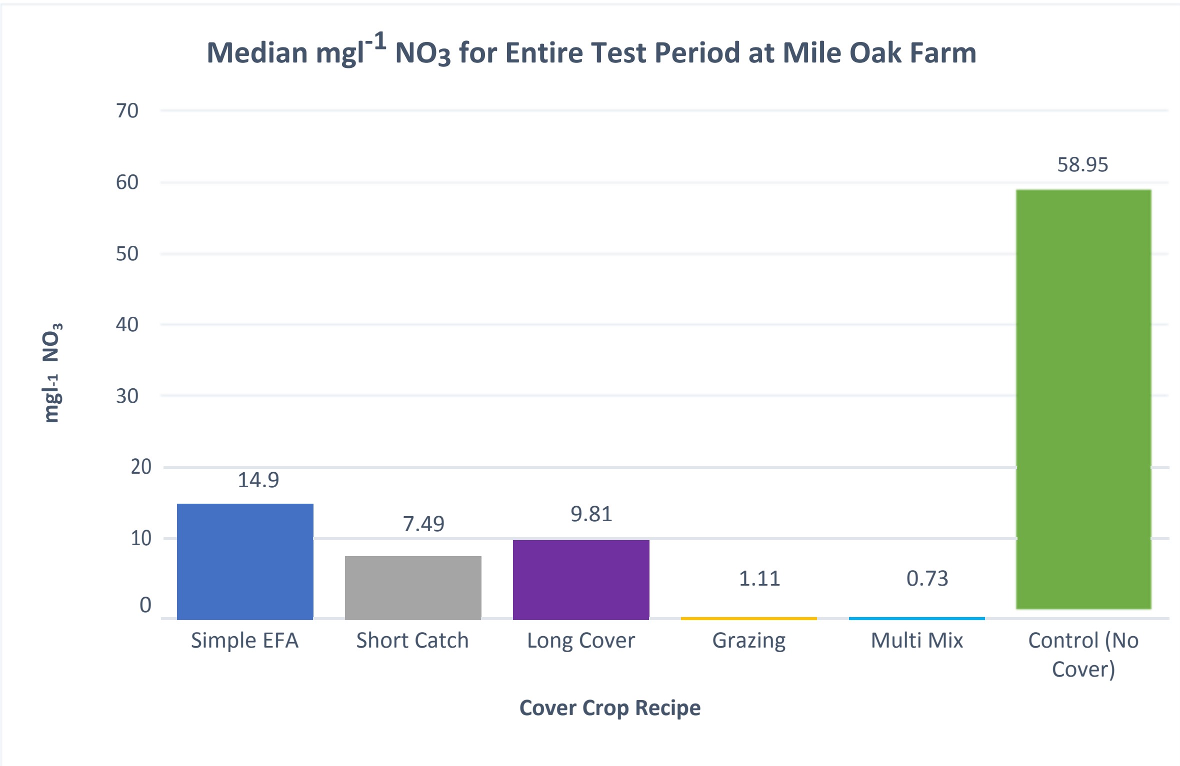

Figure 4.2. Simple histogram illustrating the median concentrations of nitrate in groundwater samples over the study period at Mile Oak Farm.

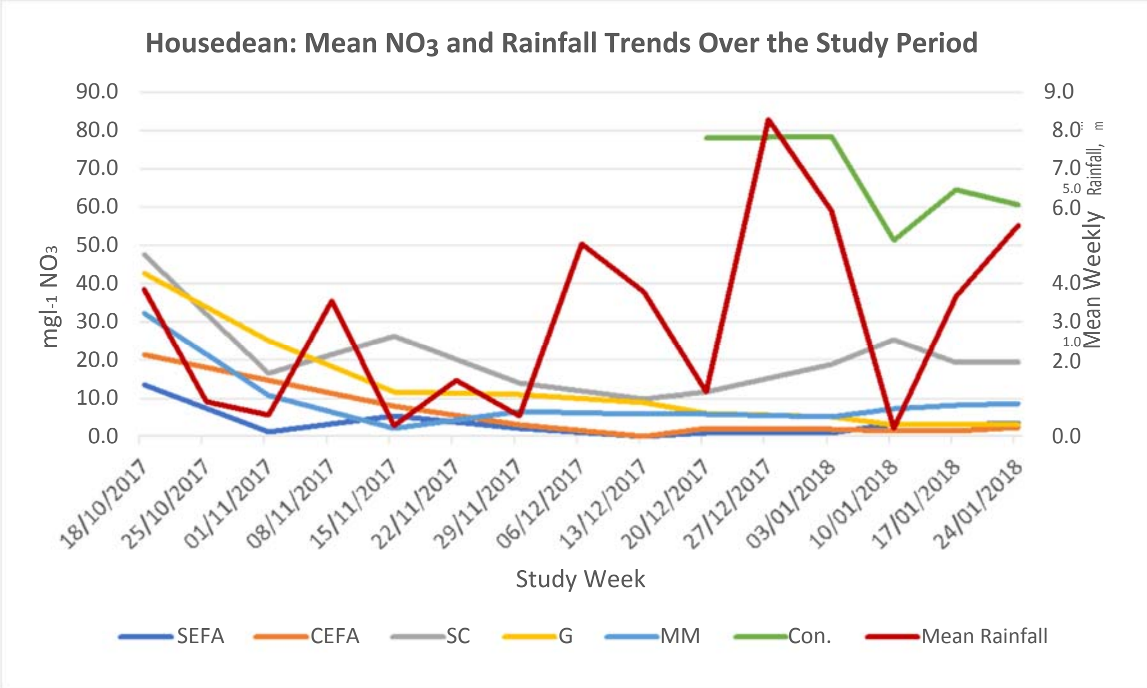

Figure 4.3. Line graph to illustrate the general trends in nitrate (NO_3) concentrations and mean weekly rainfall for the entire study period at Housedean Farm.

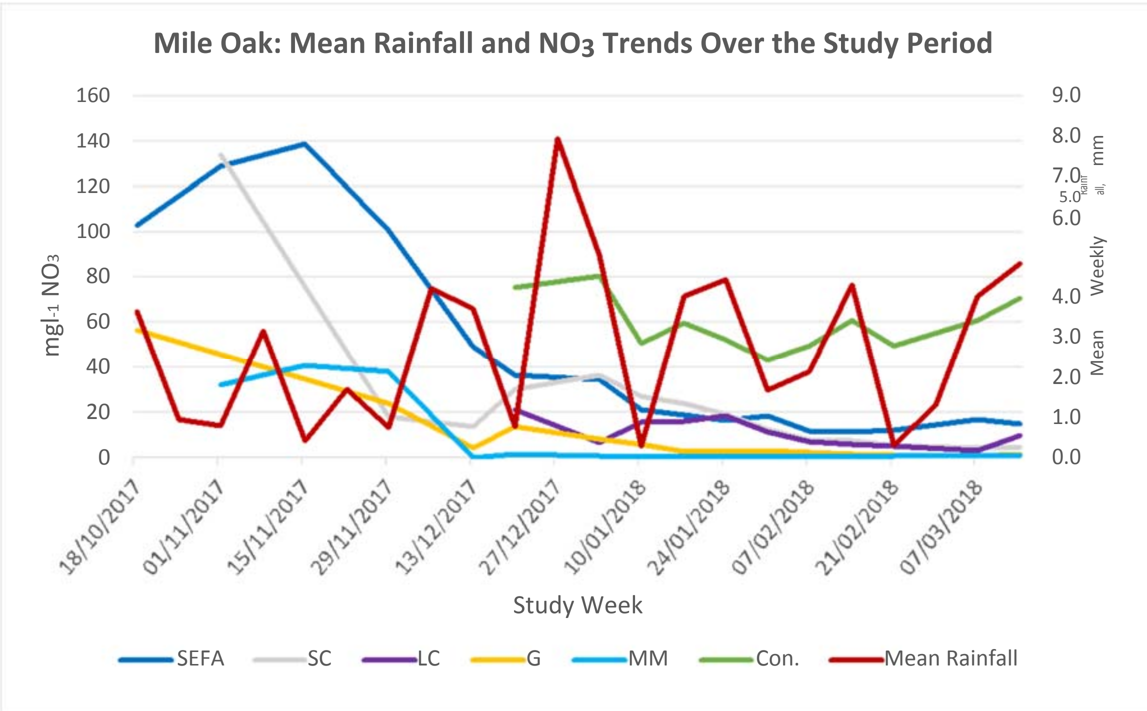

Figure 4.4. Line graph to illustrate the general trends in nitrate concentrations and mean weekly rainfall for the entire study period at Mile Oak Farm.

Table 4.3. Results of the Ryan-Joiner Normality testing for the nitrate concentrations at Housedean Farm.

	Simple EFA	**Comp. EFA**	**Short Catch**	**Grazing**	**Multi Mix**	**Control**
N	31	30	34	35	35	12
α	0.05 (95%)	0.05 (95%)	0.05 (95%)	0.05 (95%)	0.05 (95%)	0.05 (95%)
p	<0.010	<0.010	<0.010	<0.010	<0.010	>0.100
RJ val.	0.715	0.785	0.943	0.862	0.863	0.973
Crit. Val.	0.965	0.964	0.968	0.969	0.969	0.928
Result	Rej. H_0	Rej. H_0	Rej. H_0	Rej. H_0	Rej. H_0	Cannot rej. H_0

Table 4.4. Results of the Ryan-Joiner Normality testing for the nitrate concentrations at Mile Oak Farm.

	Simple EFA	**Short Catch**	**Long Cover**	**Grazing**	**Multi Mix**	**Control**
N	74	51	11	53	35	32
α	0.05 (95%)	0.05 (95%)	0.05 (95%)	0.05 (95%)	0.05 (95%)	0.05 (95%)
p	<0.010	<0.010	>0.100	<0.010	<0.010	>0.100
RJ val.	0.871	0.806	0.969	0.643	0.797	0.984
Crit. Val.	0.981	0.977	0.923	0.978	0.969	0.966
Result	Rej. H_0	Rej. H_0	Cannot rej. H_0	Rej. H_0	Rej. H_0	Cannot rej. H_0

Table 4.5. Results of the Mann-Whitney U test for the nitrate concentrations at Housedean Farm.

	Control Plot (median = 71.95) vs				
	Simple EFA	**Complex EFA**	**Short Catch**	**Grazing**	**Multi Mix**
α	0.05 (95%)	0.05 (95%)	0.05 (95%)	0.05 (95%)	0.05 (95%)
p	0.000	0.000	0.000	0.000	0.000
AC (%)	95.0	95.0	95.0	95.0	95.0
W	449.0	438.0	464.0	486.5	494.0
Median	0.97	0.69	18.85	5.84	2.67

AC = Confidence level achieved by the Mann-Whitney U test; W = the Mann-Whitney statistic used to calculate the *p* value.

Table 4.6. Results of the Mann-Whitney U test for the nitrate concentrations at Mile Oak Farm.

	Control Plot (median = 58.95) vs				
	Simple EFA	**Short Catch**	**Long Cover**	**Grazing**	**Multi Mix**
α	0.05 (95%)	0.05 (95%)	0.05 (95%)	0.05 (95%)	0.05 (95%)
p	0.000	0.000	0.000	0.000	0.000
AC (%)	95.1	95.0	95.0	95.0	95.1
W	2352.0	2035.0	880.0	2176.5	1564.0
Median	14.9	7.49	9.81	1.11	0.73

AC = Confidence level achieved by the Mann-Whitney U test; W = the Mann-Whitney statistic used to calculate the *p* value.

Table 4.7. Results of the Spearman's Rho correlation testing between mean weekly rainfall and groundwater nitrate concentration at Housedean Farm.

Mean Weekly Rainfall vs						
	Simple EFA	**Complex EFA**	**Short Catch**	**Grazing**	**Multi Mix**	**Control**
$\propto$	0.05	0.05	0.05	0.05	0.05	0.05
p	0.580	0.932	0.855	0.855	0.651	0.285

Table 4.8. Results of the Spearman's Rho correlation testing between mean weekly rainfall and groundwater nitrate concentration at Mile Oak Farm.

Mean Weekly Rainfall vs						
	Simple EFA	**Short Catch**	**Long Cover**	**Grazing**	**Multi Mix**	**Control**
$\propto$	0.05	0.05	0.05	0.05	0.05	0.05
p	0.669	0.842	0.689	0.729	0.762	0.067

Table 4.9. Nitrate and ammonia concentrations from the FWAG soil testing for both the Housedean and Mile Oak study sites.

	Housedean				**Mile Oak**			
	06/09/2017		**24/01/2018**		**06/09/2017**		**24/01/2018**	
Cover	**NO_3**	**NH_4**	**NO_3**	**NH_4**	**NO_3**	**NH_4**	**NO_3**	**NH_4**
SEFA	36.8	3.8	19.1	5.2	48.8	3.3	34.7	10.0
CEFA	38.7	2.8	18.7	8.5	41.4	4.3	28.5	9.2
SC	40.7	4.5	19.2	6.6	47.4	4.2	36.9	23.5
LC	27.4	3.7	18.8	6.9	46.4	6.8	27.6	11.8
G	30.7	3.3	17.6	8.2	46.3	5.3	25.1	9.2
MM	38.4	4.0	23.8	5.1	32.5	3.5	25.5	5.6
Control	39.6	3.1	19.8	7.5	54.8	4.3	29.8	8.3
Mean	**36.0**	**3.6**	**19.6**	**6.9**	**45.4**	**4.5**	**29.7**	**11.1**

4.4 Slug Survey

The results of the slug survey can be seen in Appendix 2 and show that there was no significant increase in the slug population due to the planting of over winter green cover. As this study is principally concerned with the reduction of nitrates in groundwater, please refer to Eley (2018) for the full details of the slug survey and the analysis and interpretation of the results.

Chapter 5: Discussion and Limitations of the Study

Chapter five considers the implications of the results presented in the preceding chapter and offers some suggestions as to the reasons for them. It also presents the main issues and limitations in conducting the research for this study.

5.1 Limitations of the study

The two most significant limitations encountered during the study were the relatively short overall duration of the study period and the late emplacement of the porous pots in the control areas, both factors leading to a reduction in the amount of data available for analysis and therefore any effects due to seasonal or temporal variations. Other considerations included the different porous pot layouts and cover crop inclusions at each site, disallowing a direct comparison of Complex EFA and Long Cover, and the vandalism/removal of three of the porous pots at Mile Oak Farm. The removal/vandalism of some of the porous pots at Mile Oak are very likely a consequence of their close proximity to footpaths that lead to and around the field where the study was conducted. Conversations held between the researcher and members of the public suggested that several people thought the pots and their markers were either lures for local shooting meets or they were connected to possible redevelopment of the site. Some of these limitations are dealt with in context in 5.2 and 5.3 below.

However, this study, together with the associated slug survey, has strongly indicated that the planting of cover crops significantly reduces the amount of NO_3 leaching to groundwater with no discernible increase in the number of pests, regardless of the cover crop recipe, although the efficacy of the different recipes differed between study areas. For example, the group median concentration of groundwater nitrate for simple EFA at Housedean Farm, was 0.97mgl^{-1} but 14.90mgl^{-1} at Mile Oak Farm, and, conversely, for short catch the figure was 18.85 mgl^{-1} at Housedean but only 7.49 mgl^{-1} at Mile Oak, suggesting that site specific factors are influential if the cover crop recipes are identical for both study areas. These site specific factors are likely to include the soil and underlying geology, which concurs with similar studies such as Hansen and Djurhuus (1997), Hooker *et al.* (2008) and Tan *et al*. (2002), where it was observed that the hydraulic conductivity of fine textured silt loams, clay loams and clays, being markedly different from that of coarse sandy soils, affected their leaching rates and concentration of contaminants. Other influencing factors highlighted by other researchers include tillage practices and temporal and seasonal variations. These influences are considered below.

5.2 Soil, Geology and Tillage Variations

The observed differences in soil texture at the two study sites and their influence on the transport of attenuation of contaminants was alluded to in Chapter 2 and, from the results shown in table 4.9, it would appear that the more clayey soil at Mile Oak Farm has led to the attenuation of both nitrate and NH_4 in the soil layer. This is in agreement with a study conducted by Gaines and Gaines (1994) who observed that sandy soil adsorbed 119 mgl^{-1} of nitrate compared to a sandy clay loam adsorbing 173 mgl^{-1} both test cylinders of soil being saturated for 7 days in a 240 mgl^{-1} solution. Although this may be perceived as a benefit in stemming the amount of nitrate reaching the groundwater, it has also been suggested by Helliwell (2011) that the drying and cracking of clay soils can form preferential flow pathways that can actually promote significant leaching. This is a particular concern when the aquifer is shallow and/or unconfined, as is the case in the study area, as these shrinkage cracks will increase the risk of contamination especially when the clay/soil layer is thinner, again as is generally the case in this area (Oostindie and Bronswijk, 1995). These effects will almost certainly be exacerbated by the underlying geology where lithostratigraphical controls on the aquifer properties play a major role in the transport and attenuation of groundwater and groundwater pollution. The Newhaven Chalk Formation, which occurs in both study areas, contains numerous marl seams as well as well-developed flint courses whereas the Culver Chalk Member which overlays it and is present at the Mile Oak site, is generally pure, soft white chalk and is relatively marl free although some marl seams can be present in the basal few meters as well as some large tabular flints (Jones and Robins, 1999). The presence of these features is highly influential on the density and style of fracturing which, according to Mortimore (1979 and 1990), leads to the softer Culver Chalk remaining generally unfractured or exhibiting regular joint sets compared to the Newhaven Chalk in which steeply inclined, conjugate joint sets often occur which may allow rainfall to rapidly and directly enter the aquifer. This highlights once again the importance of establishing over winter cover quickly where soil and/or underlying geology allow rapid infiltration of nitrate to the aquifer as appears to be the case at Housedean.

Both groundwater testing and the FWAG soil analysis highlighted an overall decrease in nitrate over the test period although the latter also showed an overall increase of ammonia at both sites. This was approximately in a ratio of 10:1 ($NO_3 : NH_4$) for the first test at both sites reducing to a little under 3:1 ($NO_3 : NH_4$) for the second test. This could be suggestive of the way in which the cover crops uptake the available mineralised forms of nitrogen or of denitrification, i.e. the chemical reduction of nitrate to ammonia. It has been suggested on the Plant and Soil Sciences eLibrary (2010) that the uptake of ammonia generally occurs early on in the growing season where it is metabolised in the root system and can be utilised in cooler weather whereas the uptake of nitrate will generally occur later on and is metabolised in the leafy tissues. Furthermore, as nitrate uptake increases so does the soil pH which depresses the uptake of ammonia and, although no readings do suggest that the soil was tending to be more alkaline. However, on thin soils covering chalk bedrock this is to be expected. Also, denitrification depends on high soil moisture content and readily available organic matter, both of which were observed at each of the study sites.

The amount of available organic matter is greatly affected by the tillage methods used. For example, according to a study conducted by Woods (1989), low intensity, reduced tillage can improve the soils ability to incorporate organic matter as opposed to conventional tillage which reduces the amount of organic matter and, therefore, microbial activity. This has the effect of increased nitrate loss from conventionally tilled soils compared to reduced or no tillage operations (Bouma *et al*., 1982; Drury *et al*., 1993). However, Premrov *et al*. (2014) found no significant effect of tillage practices on nitrate concentrations. Tillage practices at both of the study sites involved direct drilling, a low intensity method, thus providing the organic matter needed for the microbial activity to encourage denitrification. The higher concentrations at Mile Oak perhaps indicative of the more clayey soil and its ability to retain more water, thus increasing the anaerobic conditions also required for denitrification.

5.3 Temporal and Seasonal Variations

Temporal variations in this study may also have influenced the soil nitrate and ammonia concentrations due to the drilling dates for each of the two sites. As stated in Chapter 3.1, the cover crops at Housedean Farm were drilled on 10/08/2017, more than two weeks before those at Mile Oak (29/08/2017), giving them longer to establish, which is an important factor when trying to reduce nitrate leaching as has been stated in several studies including Stover and Brinsfield (1998) and Premrov *et al*. (2014). This will almost certainly have had some influence on the marked differences in soil nitrate and ammonia concentrations between 06/09/2017 and 24/01/2018 although overall effect on groundwater concentrations are more difficult to determine as testing continued at Mile Oak until 14/03/2018, which highlights another temporal anomaly. However, a similar study conducted by Macdonald *et al*. (2005) in the south-east of England showed that early sown cover crops, when compared to bare fallow, reduced nitrate leaching by up to 91%.

The average (mean and median) groundwater nitrate concentrations over the study period were all statistically significantly lower beneath the cover crops than the control (p = 0.000: $p < 0.05$) at both study locations and when compared to results from other studies, for example Premrov *et al*. (2012), Staver and Brinsfield (1998) or Meisinger *et al*. (1991), nitrate reductions in groundwater were similar or better. However, one of the noticeable differences between these studies is their duration ranging from one year (Meisinger *et al*., 1991) to 7 years (Brinsfield and Staver, 1998). There has also been a cover crop/nitrate reduction study conducted by Feaga (2011) that collected data over an 11-year study period. The sampling duration for this study was between 15 weeks (Housedean Farm) and 22 weeks (Mile Oak Farm) and although a noticeable reduction in groundwater nitrate was recorded, any longer term effects on nitrate concentrations for each cover crop variety could not be observed. For example, Premrov *et al*. (2012) observed high but decreasing nitrate concentrations in 2006 but with gradually decreasing overall concentrations over the next two sampling years (2007/2008 and 2008/2009) i.e. there was shown to be a cumulative and consistent decrease in nitrate concentrations in the groundwater over time almost certainly due to the planting of over winter green cover.

Furthermore, a longer term study would also highlight any seasonal variations and the effects of any extreme weather events such as warmer and more prolonged dry periods cracking the soil layer or more sudden, intense episodes of rainfall. Once again, Premrov *et al*. (2012) were able to observe the effects on groundwater when the cover crop growth periods overlapped with winter recharge periods and they found that groundwater nitrate concentrations were far more strongly influenced by the effects of cover crops than by recharge although work conducted by Gardner *et al*., (1990) on primary and secondary flow through the Chalk concluded that exceptional, high intensity rainfall events can increase the potential for rapid bypass flow to occur, even in areas where matrix, or primary, flow was generally below -5 kPa. Therefore, for this study, due to the results of the correlation testing assessing the relationship between rainfall and nitrate concentrations, influences due to seasonal variations in rainfall had to be largely discounted, where mean weekly rainfall figures up to 24/01/2018 were broadly similar, these being 2.92 mm for Housedean and 2.73 mm for Mile Oak highlighting that differences in cover crop efficacy at the two sites are unlikely to be the result of rainfall. However, the *p* value for the correlation between rainfall and the nitrate concentrations from beneath the control at Mile Oak are approaching the significance level of $\alpha=0.05$ ($p=0.067$) suggesting that a greater number of results from a longer term study may provide a better reflection of the effects of rainfall, especially on bare fallow. Annual average soil temperatures of 11.57^{O}C and 11.48^{O}C for Housedean and Mile Oak respectively also highlight the similarities in temperature for the two sites suggesting that any differences in groundwater concentrations of contaminants between them are also unlikely to be the result of temperature although, as stated by MacDuff and White (1985), temperate regions can experience high nitrogen mineralisation over winter as soil temperature gradually increases. A good example of this is presented in an Irish study conducted by Richards (1999) where very high mean mineralisation rates of 60 kgN ha^{-1} were recorded between October and March and, once again, a longer term study on the two sites used for this research could potentially identify any longer term effects on nitrogen mineralisation and nitrate leaching with regards to temperature.

Chapter 6: Conclusion and Suggestions for Further Work

Farmers and those involved in land management may perceive that growing a cover crop will lead to increased expenditure through additional costs for seed, tillage to establish the cover crop, and application of herbicides prior to drilling, as well as the undesirable effects of increased pests, diseases and weed issues and the treatment thereof (White *et al.*, 2016). However, improving and maintaining groundwater quality is also of great importance, especially in Brighton and the surrounding district where 100% of the supply is from groundwater abstraction.

The results of this study have shown that between October 2017 and January 2018 and March 2018 at Housedean and Mile Oak Farms respectively, the use of cover crops of all varieties significantly reduced the leaching of nitrate to groundwater compared to soil with no green cover. At the Housedean and Mile Oak sites the most effective over winter cover crops were Complex EFA and Multi Mix respectively reducing median concentrations of nitrate by approximately 99% and although no direct comparison is available for the Complex EFA and Long Cover mixes, comparison of the results for the other recipes to the Control plots would strongly suggest that the clayey soil texture at Mile Oak and the slightly more freely draining soil at Housedean play an important role in the leaching of nitrate when other parameters are identical (cover crop recipes) or very similar (mean rainfall and soil temperature). For example, median values for the control plots of 71.95 mgl^{-1} at Housedean and 58.95 mgl^{-1} at Mile Oak indicate that the Housedean site has a higher tendency to leaching even though the cover crops were planted earlier than at Mile Oak, giving them longer to establish, although the different soil textures may be more or less suited to different cover crop mixes explaining the differing efficacies at each site. However, the full effects of the timing of the planting the cover crop, although strongly emphasised by other researchers, cannot be fully understood from this study. The same is true for any seasonal or temporal variations. In order to better understand these factors, further longer term investigation would be required by repeating the experiment over a number of winters.

This does, however, emphasise the site specific nature of the problem of nitrate leaching where very specific cover crop recipes should be prepared according to the soil texture, underlying geology and the climatic factors of the farmland where they are to be grown. As shown in this study, even farms in relatively close proximity can present slight differences that affect the efficacy of different cover crop varieties.

Concerns raised over problems regarding increased numbers of pests due to over winter green cover were also shown to be unfounded by the results of the associated slug survey which found that slug activity was affected more by climatic factors such as temperature and humidity than by the planting of over winter green cover. Indeed, by the end of the survey, it was found that the majority of slugs over the duration of the study were found in the control plot, which was devoid of any green cover, where slug numbers were greater than all the other plot's combined. However, the relatively high slug numbers found in the plots comprising the Grazing and Multi mixes at Mile Oak, where some naturally occurring grasses and other volunteers were present, suggest that slugs are attracted to slightly weedy fields or weedy plant species. This, according to several studies, may actually limit any damage to the required crop by providing an alternative food source for the slugs. Therefore, any concerns over issues of pollution swapping are effectively cancelled as metaldehyde pollution will not increase for the sake of nitrate reduction.

With regards to the problem of the removal and vandalism of the porous pots, it may be worthwhile for future studies to include information boards detailing the purpose of the pots and the reason for the study, especially if the study area is adjacent to footpaths or bridleways. This could even be considered as further stakeholder engagement where water company customers could be encouraged to follow the study and perhaps, take more interest in water as a resource.

Therefore, in conclusion, it can be seen that this study has successfully demonstrated the efficacy of cover crops in reducing leaching of nitrate to the underlying aquifer when incorporated into the farmer's/landholder's annual agricultural cycle, without increasing any pest problems that may have been originally associated with the scheme. Furthermore, with other potential benefits such as reducing the amount of fertiliser needed for the subsequent crop, improved soil health, the availability of subsidies to encourage adoption of the scheme where appropriate and a number of environmental benefits including habitat creation, the inclusion of over winter cover crops should be actively encouraged, especially in areas where groundwater degradation is an issue and local soil and geology may exacerbate the problem.

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Appendix 1: Volumes of Groundwater Samples

Table A.1. Approximate volumes of the samples collected at the Housedean Farm study site.

HOUSEDEAN Sample Quantities																							
	Site No.																						
	Simple EFA				Complex EFA				Short Catch				Grazing				Multi Mix				Control		
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
29/11/2017	350	200	350	100	350	280	350	350	200	250	150	350	370	350	330	300	330	350	350	380	-	-	-
13/12/2017	-	100	-	380	330	350	400	-	200	350	100	360	370	380	360	300	300	350	350	370	-	-	-
20/12/2017	-	300	350	380	330	330	350	360	230	300	150	380	250	390	380	380	400	370	350	350	400	200	420
03/01/2018	-	200	370	400	350	320	360	250	250	330	-	370	350	350	350	320	330	350	270	330	300	370	-
10/01/2018	380	250	380	390	370	370	360	380	300	350	-	370	380	390	380	340	370	360	380	380	-	370	320
17/01/2018	320	220	380	360	350	370	300	100	210	350	220	370	370	380	370	350	370	380	300	380	-	370	360
24/01/2018	370	220	350	390	370	380	360	370	230	370	230	350	390	350	370	360	370	340	370	360	-	370	330
Mean	355	212.9	363.3	342.9	350	342.9	354.3	301.7	231.4	328.6	170	364.3	354.3	370	362.9	335.7	352.9	357.1	338.6	364.3	350	336	357.5
Group Mean	312.1				338.5				281.5				355.7				353.2				346.4		

Table A.2. Approximate volumes of the samples collected at the Mile Oak Farm study site.

Mile Oak Sample Quantities																							
Site No.																							
	Simple EFA						Short Catch				Long Cover	Grazing				Multi Mix					Control		
Date	1	2	3	4	5	6	7	8	9	10	12	11	13	14	15	16	17	18	19	20	21	22	23
29/11/2017	60	-	-	380	200	370	250	280	-	150	-	350	200	330	250	150	-	150	180	180	-	-	-
13/12/2017	280	200	-	330	250	350	370	200	150	250	-	380	250	300	320	-	-	-	-	180	-	-	-
20/12/2017	150	300	100	350	200	380	380	-	180	300	-	380	370	350	350	300	-	-	200	370	50	-	350
03/01/2018	310	320	-	330	280	370	350	250	150	320	370	350	370	370	370	-	-	-	170	350	200	300	320
10/01/2018	230	330	70	330	300	380	370	350	200	50	380	370	380	370	390	-	-	-	200	350	390	330	350
17/01/2018	70	260	-	350	150	350	350	330	350	170	350	370	330	400	370	-	-	-	190	380	390	300	320
24/01/2018	220	300	60	380	230	370	380	380	200	350	390	360	370	370	360	-	-	-	200	370	300	330	370
31/01/2018	270	330	-	380	-	370	350	360	200	380	350	390	360	350	360	-	-	-	200	370	370	330	380
07/02/2018	100	300	100	380	220	350	380	380	210	350	360	360	380	400	360	-	-	-	200	380	370	320	360
14/02/2018	100	180	50	350	150	220	360	290	170	330	320	380	350	360	350	-	-	-	180	370	350	290	280
21/02/2018	380	230	100	390	260	310	380	370	230	380	400	390	380	370	380	-	-	-	200	390	370	340	320
28/02/2018	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
07/03/2018	100	100	-	330	180	-	380	330	170	330	360	360	340	350	320	-	-	-	150	370	380	280	280
14/03/2018	260	280	-	380	230	390	370	100	200	370	380	380	330	380	390	-	-	-	190	230	380	320	300
Mean	194.62	260.83	80.00	358.46	220.83	350.83	359.23	301.67	200.83	286.92	366.00	370.77	339.23	361.54	351.54	225.00	-	150.00	188.33	330.00	322.73	314.00	330.00
Group Mean	259.7						288.6				366	355.8				255.4					322.5		

Appendix 2: Slug Study Results.

Results of the slug surveys conducted at Housedean Farm.

1.11.17	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	12	25	37	Small snails
		Simple EFA	2S	6	8	14	
		Simple EFA	3S	2	5	7	
	2	Complex EFA	4S	2	2	4	Ground more solid, less vegetation, comparitvely low crop density
		Complex EFA	5S	2	10	12	
		Complex EFA	6S	7	7	14	
	3	Short catch	7S	3	11	14	
		Short catch	8S	1	5	6	
		Short catch	9S	1	0	1	1 snail and jumping insects
	4	Long cover	10S	1	0	1	d.r. was inside the pot trap
		Long cover	11S	0	0	0	
		Long cover	12S	1	2	3	
	5	Grazing	13S	2	0	2	2 snails inside the trap
		Grazing	14S	1	1	2	
		Grazing	15S	0	0	0	very dry and much less vegetation
	6	Multi mix	16S	0	0	0	
		Multi mix	17S	1	0	1	most level trap and hardly anything, why?
		Multi mix	18S	1	0	1	
	7	Control (bare)	19S	1	0	1	Slug was found inside the pot trap, more snails here
		Control (bare)	20S	2	0	2	Pot trap had been knocked off its pegs,no bait pile, it had all blown away
		Control (bare)	21S	3	1	4	softer soil, less rocky
TOTAL				**49**	**77**	**126**	

15.11.17	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	4	28	32	
		Simple EFA	2S	3	11	14	less dense vegetation
		Simple EFA	3S	1	6	7	
	2	Complex EFA	4S	1	6	7	
		Complex EFA	5S	1	9	10	
		Complex EFA	6S	0	6	6	
	3	Short catch	7S	0	7	7	more level than the other traps on this extreme side
		Short catch	8S	0	0	0	very unusual, dense vegetation, 1m high but no slugs at all, couldn't even see any outside of the trap paramenters
		Short catch	9S	0	3	3	
	4	Long cover	10S	0	1	1	
		Long cover	11S	1	0	1	
		Long cover	12S	0	1	1	inside trap
	5	Grazing	13S	1	2	3	
		Grazing	14S	1	0	1	inside trap
		Grazing	15S	2	1	3	DR. in trap
	6	Multi mix	16S	2	0	2	inside trap
		Multi mix	17S	0	0	0	unsual
		Multi mix	18S	2	4	6	
	7	Control (bare)	19S	2	0	2	fewer slugs than expected
		Control (bare)	20S	3	24	27	They love it here
		Control (bare)	21S	1	3	4	
TOTAL				**25**	**112**	**137**	

29.11.17	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	0	0	0	
		Simple EFA	2S	0	0	0	
		Simple EFA	3S	0	0	0	
	2	Complex EFA	4S	0	0	0	
		Complex EFA	5S	0	0	0	
		Complex EFA	6S	0	0	0	
	3	Short catch	7S	0	0	0	
		Short catch	8S	0	0	0	
		Short catch	9S	0	0	0	
	4	Long cover	10S	0	0	0	
		Long cover	11S	0	0	0	
		Long cover	12S	0	0	0	
	5	Grazing	13S	0	0	0	
		Grazing	14S	0	0	0	
		Grazing	15S	0	0	0	
	6	Multi mix	16S	0	0	0	
		Multi mix	17S	0	1	1	only slug in the whole site.
		Multi mix	18S	0	0	0	
	7	Control (bare)	19S	0	0	0	
		Control (bare)	20S	0	0	0	
		Control (bare)	21S	0	0	0	
TOTAL				**0**	**1**	**1**	

13.12.17	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	4	3	7	all inside trap
		Simple EFA	2S	4	7	11	
		Simple EFA	3S	0	1	1	rabbit poo present
	2	Complex EFA	4S	0	0	0	
		Complex EFA	5S	1	5	6	
		Complex EFA	6S	5	5	10	
	3	Short catch	7S	0	0	0	
		Short catch	8S	1	1	2	
		Short catch	9S	0	0	0	
	4	Long cover	10S	2	1	3	
		Long cover	11S	0	1	1	
		Long cover	12S	1	0	1	
	5	Grazing	13S	0	0	0	
		Grazing	14S	1	0	1	
		Grazing	15S	1	1	2	
	6	Multi mix	16S	0	0	0	
		Multi mix	17S	0	1	1	
		Multi mix	18S	2	0	2	
	7	Control (bare)	19S	2	0	2	
		Control (bare)	20S	2	3	5	
		Control (bare)	21S	3	0	3	
TOTAL				**29**	**29**	**58**	

29.12.17	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	0	0	0	wet mash
		Simple EFA	2S	0	2	2	wet mash, both slugs in trap
		Simple EFA	3S	0	0	0	wet mash, rabbit poo
	2	Complex EFA	4S	0	3	3	wet mash
		Complex EFA	5S	0	0	0	dry mash
		Complex EFA	6S	1	0	1	wet mash
	3	Short catch	7S	0	0	0	wet mash
		Short catch	8S	0	0	0	dry mash,destroyed vegetation around trap
		Short catch	9S	0	0	0	wet mash
	4	Long cover	10S	0	0	0	dry mash
		Long cover	11S	0	1	1	wet mash
		Long cover	12S	1	1	2	wet mash
	5	Grazing	13S	1	0	1	wet mash, trap disturbed, bait eaten/moved around by animal/wind
		Grazing	14S	0	0	0	wet mash
		Grazing	15S	1	0	1	dry mash
	6	Multi mix	16S	0	0	0	wet mash, comparatively damper plot, more vegetation, wetter soil
		Multi mix	17S	0	0	0	wet mash
		Multi mix	18S	0	0	0	wet mash
	7	Control (bare)	19S	1	0	1	dry mash
		Control (bare)	20S	0	0	0	dry mash
		Control (bare)	21S	1	1	2	dry mash, in trap
TOTALS:				**6**	**8**	**14**	

17.01.18	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	0	0	0	dry mash
		Simple EFA	2S	0	0	0	dry mash
		Simple EFA	3S	0	0	0	dry mash
	2	Complex EFA	4S	0	0	0	dry mash
		Complex EFA	5S	0	0	0	pot dismantled, no bait
		Complex EFA	6S	0	0	0	pot dismantled, no bait - possible eaten by animal or blown away by the wind
	3	Short catch	7S	0	0	0	wet bait
		Short catch	8S	0	0	0	wet bait
		Short catch	9S	0	0	0	wet bait
	4	Long cover	10S	0	0	0	wet bait
		Long cover	11S	0	0	0	wet bait
		Long cover	12S	0	0	0	pot dismantled, no bait - photo evidence
	5	Grazing	13S	0	0	0	pot dismantled, no bait
		Grazing	14S	0	0	0	wet bait
		Grazing	15S	0	0	0	wet bait
	6	Multi mix	16S	0	0	0	wet bait
		Multi mix	17S	0	0	0	wet bait
		Multi mix	18S	0	0	0	wet bait - always tends to be damper and sparsely spaced
	7	Control (bare)	19S	0	0	0	white shelled snails
		Control (bare)	20S	3	0	3	dry bait
		Control (bare)	21S	0	0	0	pot missing, pegs present so replaced pot
TOTAL:				**3**	**0**	**3**	

24.01.18	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	9	4	13	dry bait
		Simple EFA	2S	1	6	7	wet bait
		Simple EFA	3S	2	0	2	both slugs in trap, wet bait
	2	Complex EFA	4S	1	3	4	wet bait
		Complex EFA	5S	1	2	3	wet bait
		Complex EFA	6S	4	1	5	wet bait
	3	Short catch	7S	2	3	5	4 inside trap, wet bait
		Short catch	8S	5	2	7	
		Short catch	9S	0	0	0	wet bait
	4	Long cover	10S	3	5	8	dry bait
		Long cover	11S	8	1	9	
		Long cover	12S	2	0	2	
	5	Grazing	13S	0	0	0	
		Grazing	14S	5	0	5	wet bait
		Grazing	15S	6	1	7	dry bait
	6	Multi mix	16S	1	1	2	wet bait
		Multi mix	17S	1	0	1	
		Multi mix	18S	3	1	4	wet bait
	7	Control (bare)	19S	8	8	16	wet bait
		Control (bare)	20S	4	10	14	trap blown away, wet and virturally no bait
		Control (bare)	21S	16	0	16	trap blown away, wet and virturally no bait
TOTAL:				**82**	**48**	**130**	

<u>Results of the slug surveys conducted at Mile Oak Farm</u>.

	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
1.11.17				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	0	0	0	Damp and grassy
		Simple EFA	2S	1	0	1	some small snails present, both normal and vertical spiraled
		Simple EFA	3S	1	0	1	Bait was already spread out
	2	Complex EFA	4S	0	1	1	Poppy's nearby
		Complex EFA	5S	4	2	6	The 4 d.r. were babies and were inside the pot trap
		Complex EFA	6S	0	0	0	
	3	Short catch	7S	6	0	6	All d.r. were found inside the pot trap
		Short catch	8S	0	0	0	lots of snails inside
		Short catch	9S	1	0	1	d.r. was inside the pot trap
	4	Control (bare)	10S	1	1	2	
		Control (bare)	11S	0	1	1	both s.p. of snails were found outside the pot trap
		Control (bare)	12S	12	4	16	Very grassy
	5	Long cover	13S	3	7	10	Deep mass of vegetation
		Long cover	14S	5	1	6	vertical snails abundant
		Long cover	15S	2	1	3	2 d.r. babies
	6	Grazing	16S	1	1	2	
		Grazing	17S	6	7	13	
		Grazing	18S	3	5	8	
	7	Multi mix	19S	0	0	0	
		Multi mix	20S	3	23	26	
		Multi mix	21S	1	1	2	2 little snails inside the pot trap
TOTAL:				**50**	**55**	**105**	

15.11.17	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	0	0	0	very damp
		Simple EFA	2S	1	0	1	matted vegetation and grassy
		Simple EFA	3S	0	0	0	small snaimsl and slug excrement on top of trap (evidence they had been there)
	2	Complex EFA	4S	2	5	7	mostly inside the trap
		Complex EFA	5S	2	0	2	vertical spirally snail
		Complex EFA	6S	2	0	2	
	3	Short catch	7S	7	4	11	grassy
		Short catch	8S	3	5	8	
		Short catch	9S	3	5	8	one snail on thistle leaf
	4	Control (bare)	10S	0	3	3	
		Control (bare)	11S	3	1	4	two worms
		Control (bare)	12S	5	2	7	
	5	Long cover	13S	4	13	17	mesh of dead grass
		Long cover	14S	2	8	10	dense grass
		Long cover	15S	1	3	4	worm
	6	Grazing	16S	7	7	14	
		Grazing	17S	5	28	33	mesh of wet sticks, perfect slug environment
		Grazing	18S	6	10	16	
	7	Multi mix	19S	2	4	6	no vegetation around the trap
		Multi mix	20S	3	43	46	
		Multi mix	21S	1	7	8	
TOTAL				**59**	**148**	**207**	

29.11.17	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	0	0	0	
		Simple EFA	2S	0	0	0	
		Simple EFA	3S	0	0	0	
	2	Complex EFA	4S	0	0	0	
		Complex EFA	5S	0	0	0	
		Complex EFA	6S	0	0	0	
	3	Short catch	7S	0	0	0	
		Short catch	8S	0	0	0	
		Short catch	9S	0	0	0	
	4	Control (bare)	10S	0	0	0	very dry soil
		Control (bare)	11S	0	0	0	very dry soil
		Control (bare)	12S	1	0	1	inside trap
	5	Long cover	13S	0	0	0	
		Long cover	14S	0	2	2	microhabitat better for slugs; mesh of damp/dead twigs and grass
		Long cover	15S	0	1	1	inside trap
	6	Grazing	16S	0	0	0	
		Grazing	17S	0	1	1	spanish slug (no orange underbelly)
		Grazing	18S	1	0	1	
	7	Multi mix	19S	0	0	0	
		Multi mix	20S	0	0	0	
		Multi mix	21S	1	0	1	inside trap
Total				3	**4**	**7**	

13.12.17	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	0	0	0	mesh
		Simple EFA	2S	1	0	1	wet mash
		Simple EFA	3S	0	0	0	wet mash
	2	Complex EFA	4S	1	0	1	
		Complex EFA	5S	3	0	3	1 in, 2 out
		Complex EFA	6S	2	0	2	lots of snails
	3	Short catch	7S	1	0	1	wet mash
		Short catch	8S	3	0	3	2 in trap, 1 out
		Short catch	9S	3	0	3	baby slug
	4	Control (bare)	10S	1	0	1	
		Control (bare)	11S	1	0	1	in trap
		Control (bare)	12S	17	0	17	mostly babies (nursery?)
	5	Long cover	13S	4	4	8	
		Long cover	14S	5	21	26	1 spanish slug found!
		Long cover	15S	4	4	8	
	6	Grazing	16S	0	1	1	
		Grazing	17S	12	31	43	
		Grazing	18S	4	8	12	
	7	Multi mix	19S	2	2	4	
		Multi mix	20S	6	12	18	1 spanish slug found!
		Multi mix	21S	3	2	5	
TOTAL				**73**	**85**	**158**	

29.12.17	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	0	0	0	wet mash
		Simple EFA	2S	0	0	0	wet mash
		Simple EFA	3S	0	0	0	wet mash
	2	Complex EFA	4S	0	0	0	wet mash
		Complex EFA	5S	0	0	0	wet mash
		Complex EFA	6S	0	0	0	wet mash
	3	Short catch	7S	3	1	4	wet mash
		Short catch	8S	0	0	0	wet mash, lots of slug poo but no slugs
		Short catch	9S	1	0	1	wet mash
	4	Control (bare)	10S	0	0	0	wet mash
		Control (bare)	11S	0	0	0	dry mash
		Control (bare)	12S	2	0	2	dry mash
	5	Long cover	13S	3	0	3	wet mash
		Long cover	14S	0	6	6	wet mash, all outside of trap
		Long cover	15S	0	0	0	dry mash, lots of snails
	6	Grazing	16S	3	0	3	wet mash
		Grazing	17S	3	14	17	dry mash
		Grazing	18S	2	6	8	wet mash
	7	Multi mix	19S	0	0	0	wet mash
		Multi mix	20S	4	9	13	wet mash, also 1 spanish slug and a caterpillar
		Multi mix	21S	0	0	0	wet mash
TOTALS:				**21**	**36**	**57**	

17.01.18	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	0	0	0	wet mash
		Simple EFA	2S	0	0	0	wet mash
		Simple EFA	3S	0	0	0	wet mash
	2	Complex EFA	4S	0	0	0	wet mash
		Complex EFA	5S	0	0	0	wet mash
		Complex EFA	6S	0	0	0	wet mash
	3	Short catch	7S	0	0	0	wet mash
		Short catch	8S	0	0	0	wet mash
		Short catch	9S	0	0	0	wet mash
	4	Control (bare)	10S	0	0	0	
		Control (bare)	11S	0	0	0	
		Control (bare)	12S	9	7	16	abundance here and also found eggs, perhaps slug eggs (photo evidence)
	5	Long cover	13S	0	0	0	
		Long cover	14S	0	0	0	
		Long cover	15S	0	0	0	hald dry bait, half wet
	6	Grazing	16S	0	0	0	wet mash
		Grazing	17S	1	5	6	white slug in trap, others outside
		Grazing	18S	3	1	4	wet mash
	7	Multi mix	19S	0	0	0	wet mash
		Multi mix	20S	0	6	6	wet mash
		Multi mix	21S	1	0	1	wet mash
TOTAL:				**14**	**19**	**33**	

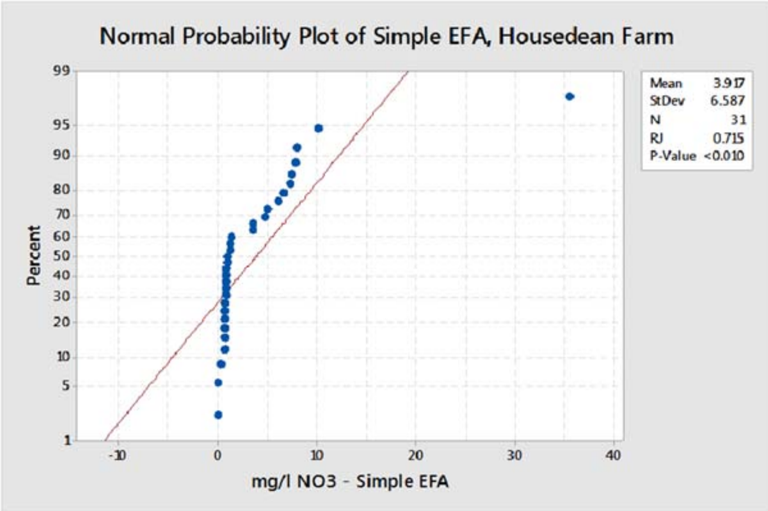
24.01.18	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	0	0	0	wet bait
		Simple EFA	2S	3	0	3	wet bait
		Simple EFA	3S	2	1	3	wet bait
	2	Complex EFA	4S	2	1	3	wet bait
		Complex EFA	5S	5	1	6	
		Complex EFA	6S	4	0	4	dry bait
	3	Short catch	7S	4	1	5	
		Short catch	8S	4	1	5	half wet half dry bait
		Short catch	9S	1	2	3	wet bait
	4	Control (bare)	10S	16	6	22	wet bait
		Control (bare)	11S	6	0	6	dry bait
		Control (bare)	12S	44	14	58	dry bait
	5	Long cover	13S	9	16	25	wet bait
		Long cover	14S	6	2	8	wet bait
		Long cover	15S	2	0	2	
	6	Grazing	16S	5	1	6	wet bait
		Grazing	17S	13	15	28	
		Grazing	18S	10	6	16	2 spanish slugs, wet bait
	7	Multi mix	19S	9	2	11	wet bait
		Multi mix	20S	14	33	47	11 spanish slugs too, dry bait
		Multi mix	21S	10	3	13	1 spanish slug, wet bait
TOTAL:				**169**	**105**	**274**	

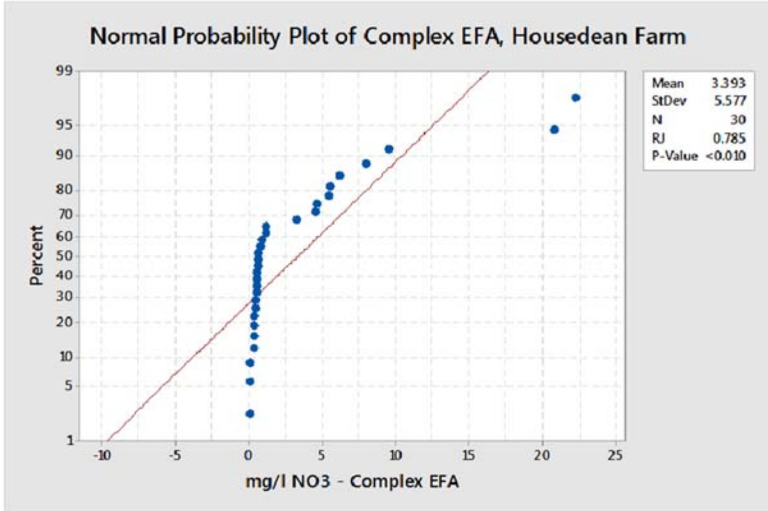
7.02.18	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	0	0	0	dry bait
		Simple EFA	2S	0	0	0	A lot of scattered bait, more or less dry
		Simple EFA	3S	0	0	0	thin layer of bait remaining
	2	Complex EFA	4S	0	0	0	bait completely undisturbed, dry
		Complex EFA	5S	0	0	0	bait scattered
		Complex EFA	6S	0	0	0	trap broken slightly at the holes and bait dispursed around trap, bait inside was more or less dry
	3	Short catch	7S	0	0	0	dry bait
		Short catch	8S	0	0	0	scattered bait
		Short catch	9S	0	0	0	dry bait
	4	Control (bare)	10S	0	0	0	dry bait, looser soil
		Control (bare)	11S	0	0	0	dry bait, but scattered
		Control (bare)	12S	0	0	0	dry bait
	5	Long cover	13S	0	0	0	dry bait, but scattered
		Long cover	14S	0	0	0	dry bait, just across from 17 where I found 8 slugs, bizarre how they choose to hang out there but not here
		Long cover	15S	0	0	0	completely undisturbed dry bait
	6	Grazing	16S	0	0	0	dry bait
		Grazing	17S	3	3	6	dry bait. Also, two spanish slugs, possibly one of them being something different, appeared to resemble a darker version of derocerus reticulatum
		Grazing	18S	0	0	0	dry bait
	7	Multi mix	19S	0	0	0	dry bait,plently of flowering plants in this plot, surprising especially after the frost, but flowers of yellow, white and purple have all emerged over the passed month
		Multi mix	20S	1	0	1	slug in trap, dry bait
		Multi mix	21S	0	0	0	dry bait
Totals				4	**3**	**7**	

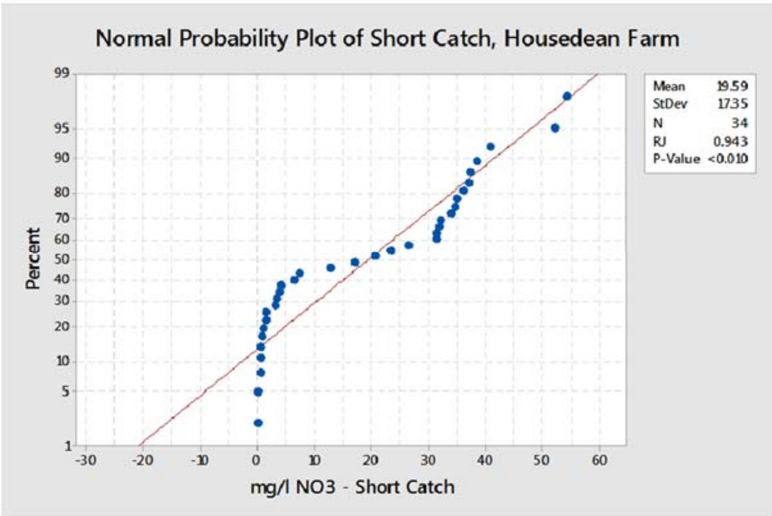
21.02.18	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	0	0	0	
		Simple EFA	2S	0	0	0	
		Simple EFA	3S	0	0	0	
	2	Complex EFA	4S	0	0	0	
		Complex EFA	5S	0	0	0	
		Complex EFA	6S	0	0	0	
	3	Short catch	7S	0	0	0	
		Short catch	8S	2	0	2	
		Short catch	9S	0	0	0	
	4	Control (bare)	10S	0	0	0	
		Control (bare)	11S	7	0	7	all in trap
		Control (bare)	12S	8	0	8	1 spanish slug
	5	Long cover	13S	3	1	4	
		Long cover	14S	0	2	2	
		Long cover	15S	1	0	1	white was adult and fat
	6	Grazing	16S	1	0	1	white was adult and fat
		Grazing	17S	8	15	23	1 spanish slug
		Grazing	18S	3	0	3	
	7	Multi mix	19S	1	1	2	
		Multi mix	20S	4	9	13	
		Multi mix	21S	1	0	1	white was adult and fat
total:				**39**	**28**	**67**	

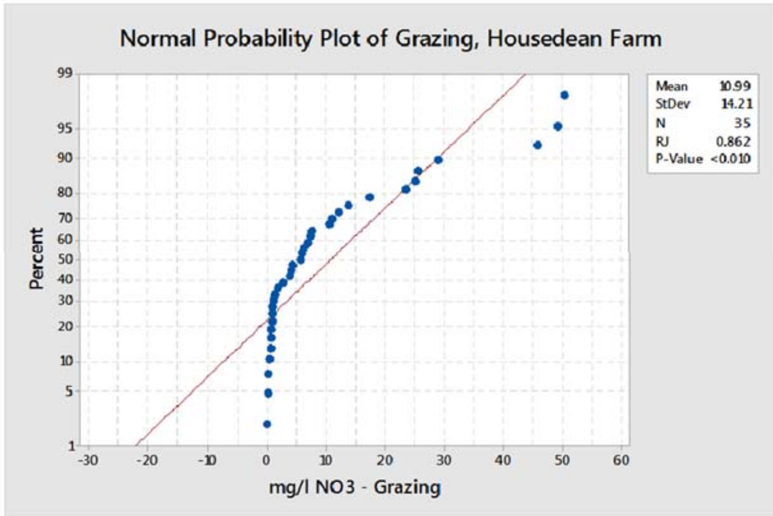
7.03.18	PLOTS	SEED MIX	TRAPS	SLUGS		TOTAL SLUGS	OBSERVATIONS
				derocerus reticulatum	arion hortensis		
	1	Simple EFA	1S	0	0	0	
		Simple EFA	2S	0	0	0	
		Simple EFA	3S	1	0	1	
	2	Complex EFA	4S	0	0	0	
		Complex EFA	5S	0	0	0	
		Complex EFA	6S	0	0	0	
	3	Short catch	7S	3	0	3	all in trap, 1 worm
		Short catch	8S	0	0	0	
		Short catch	9S	0	0	0	
	4	Control (bare)	10S	8	0	8	
		Control (bare)	11S	8	0	8	
		Control (bare)	12S	23	2	25	1 spanish, 1 worm
	5	Long cover	13S	1	0	1	
		Long cover	14S	2	1	3	
		Long cover	15S	0	0	0	
	6	Grazing	16S	1	0	1	
		Grazing	17S	4	1	5	
		Grazing	18S	2	0	2	
	7	Multi mix	19S	3	2	5	
		Multi mix	20S	8	6	14	
		Multi mix	21S	1	0	1	
total:				**65**	**12**	**77**	

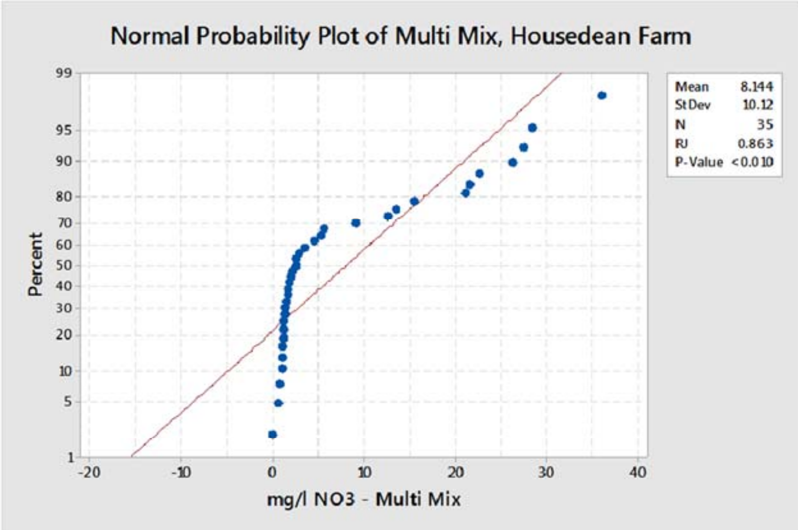
Appendix 3: Normality Test Results.

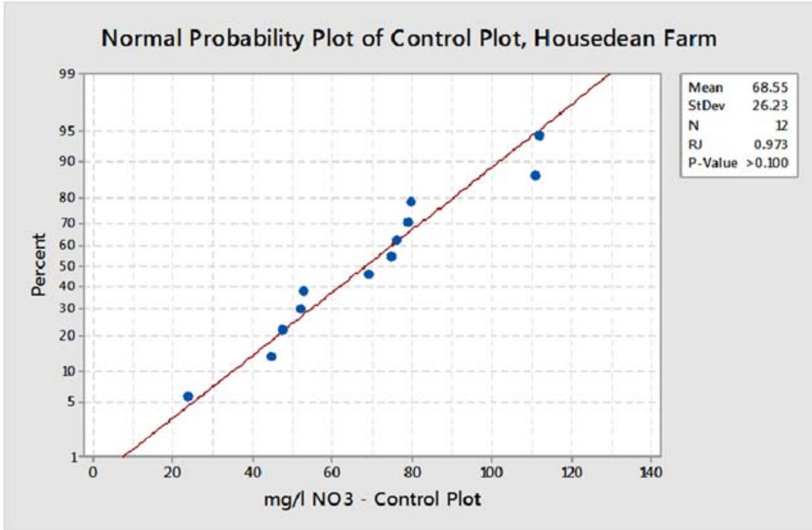


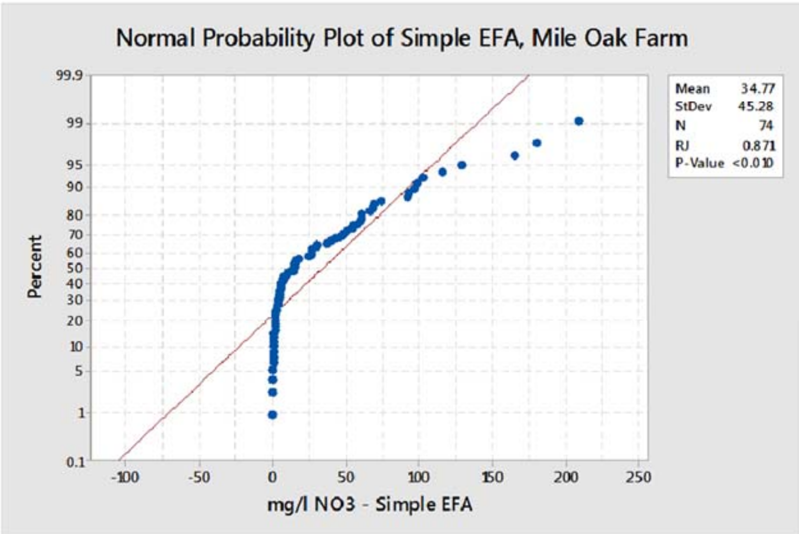


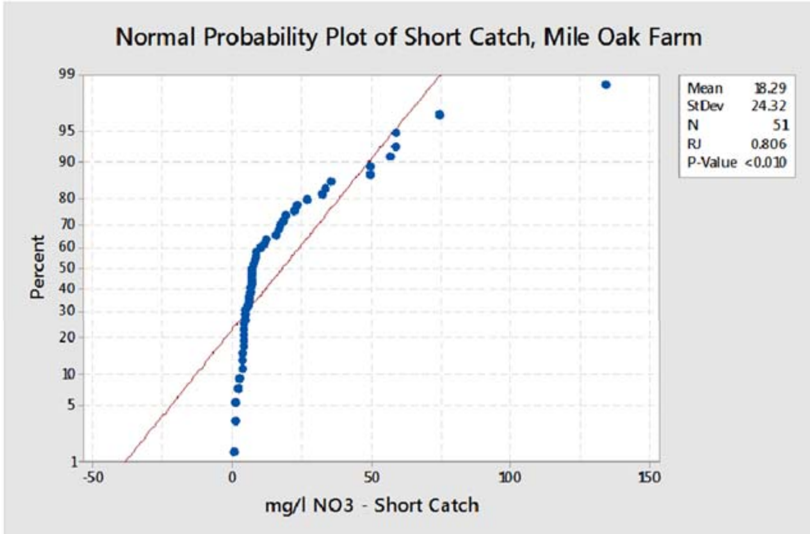


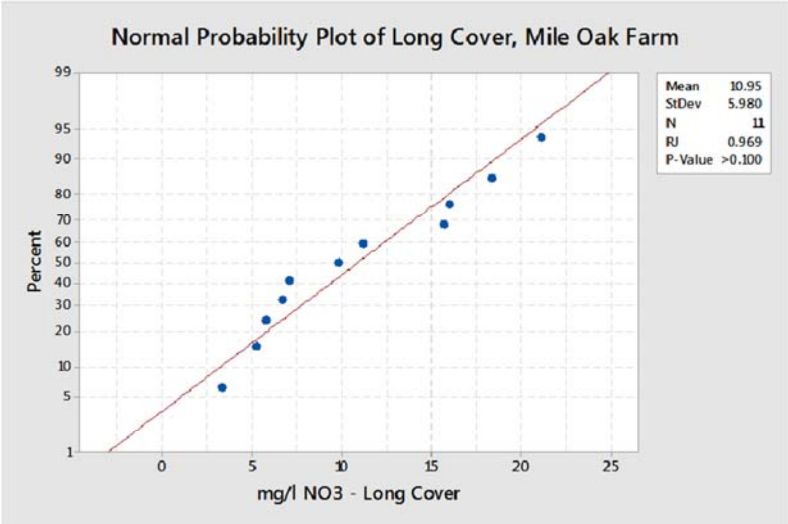


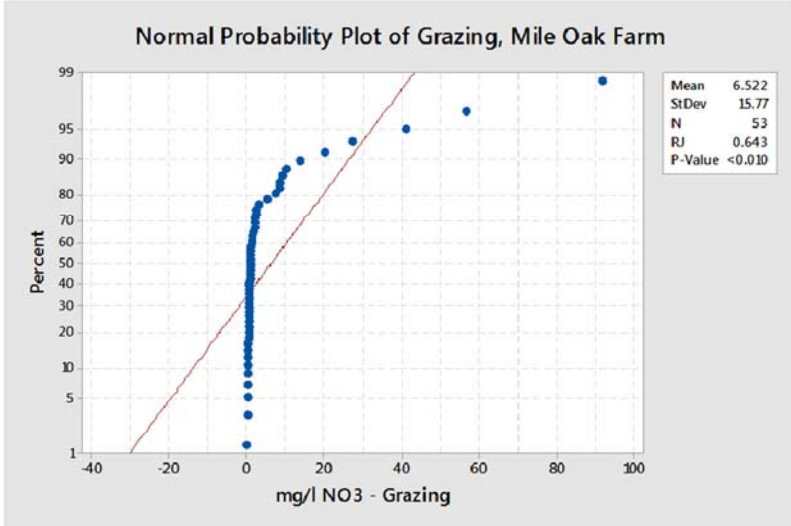

Normal Probability Plot of Multi Mix, Housedean Farm
Mean 8.144
StDev 10.12
N 35
RJ 0.863
P-Value <0.010
Percent
mg/l NO3 - Multi Mix

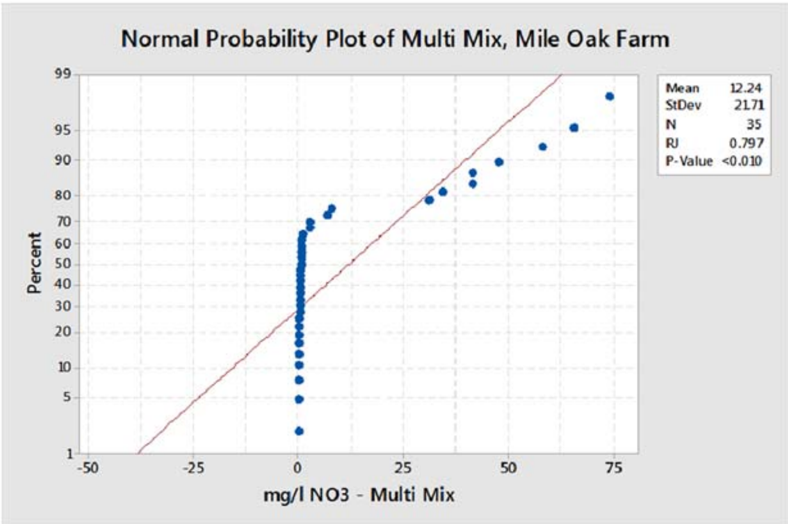

Normal Probability Plot of Control Plot, Housedean Farm
Mean 68.55
StDev 26.23
N 12
RJ 0.973
P-Value >0.100
Percent
mg/l NO3 - Control Plot

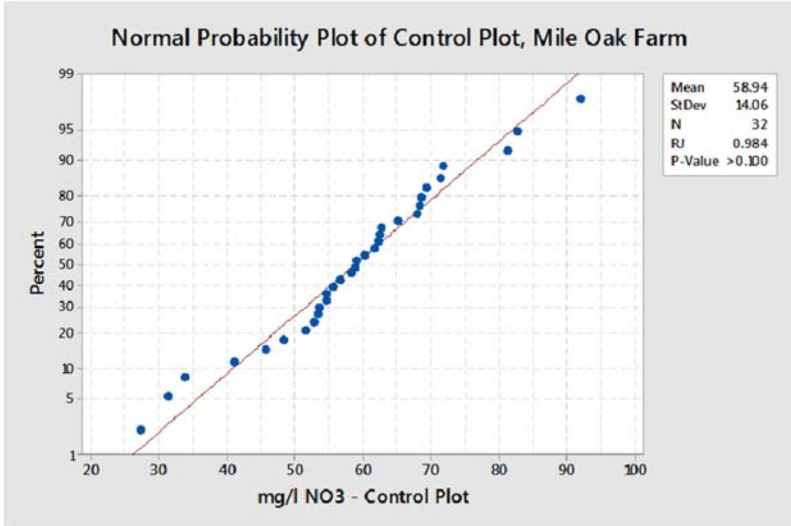

Normal Probability Plot of Simple EFA, Mile Oak Farm
Mean 34.77
StDev 45.28
N 74
RJ 0.871
P-Value <0.010
Percent
mg/l NO3 - Simple EFA


Normal Probability Plot of Short Catch, Mile Oak Farm
Mean 18.29
StDev 24.32
N 51
RJ 0.806
P-Value <0.010
Percent
mg/l NO3 - Short Catch


Normal Probability Plot of Long Cover, Mile Oak Farm
Mean 10.95
StDev 5.980
N 11
RJ 0.969
P-Value >0.100
Percent
mg/l NO3 - Long Cover

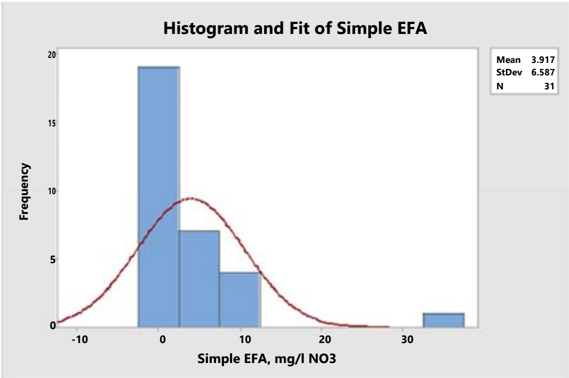

Normal Probability Plot of Grazing, Mile Oak Farm
Mean 6.522
StDev 15.77
N 53
RJ 0.643
P-Value <0.010
Percent
mg/l NO3 - Grazing

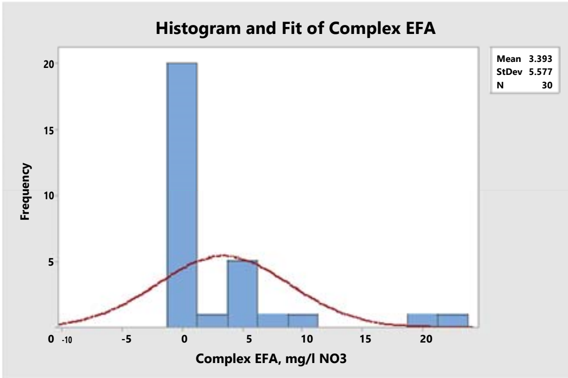

Normal Probability Plot of Multi Mix, Mile Oak Farm
Mean 12.24
StDev 21.71
N 35
RJ 0.797
P-Value <0.010
Percent
mg/l NO3 - Multi Mix

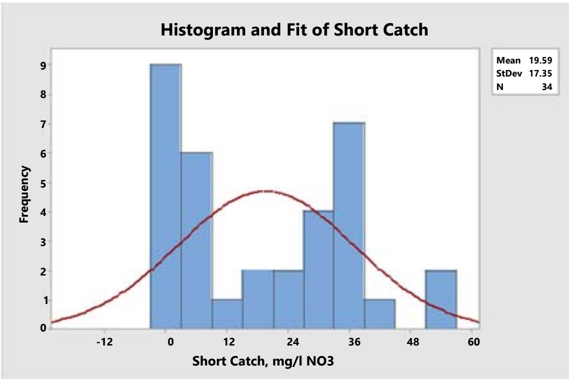

Normal Probability Plot of Control Plot, Mile Oak Farm
Mean 58.94
StDev 14.06
N 32
RJ 0.984
P-Value >0.100
Percent
mg/l NO3 - Control Plot

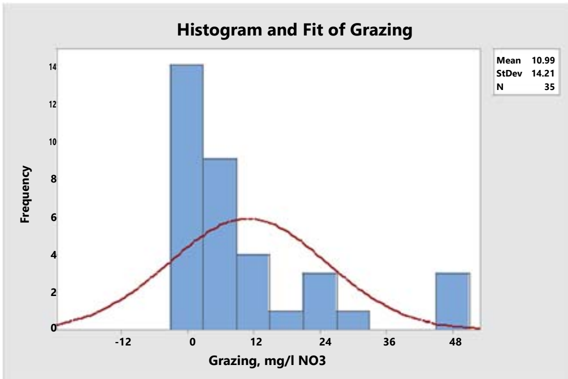
Appendix 4: Distribution Comparisons for the Mann-Whitney U test.

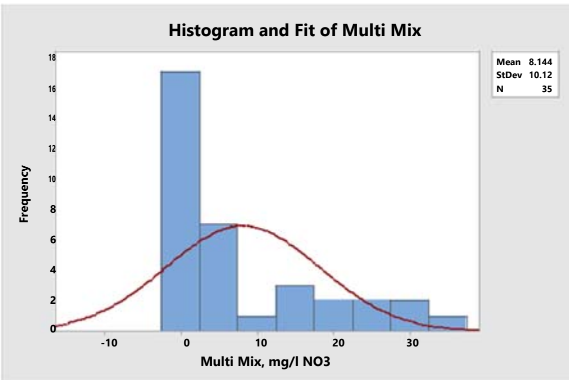
Histograms comparing distribution of the Housedean Farm data.

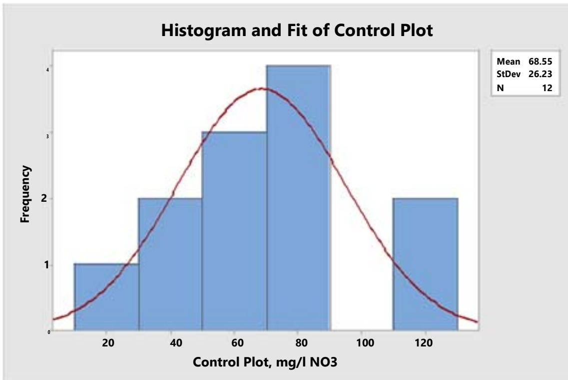




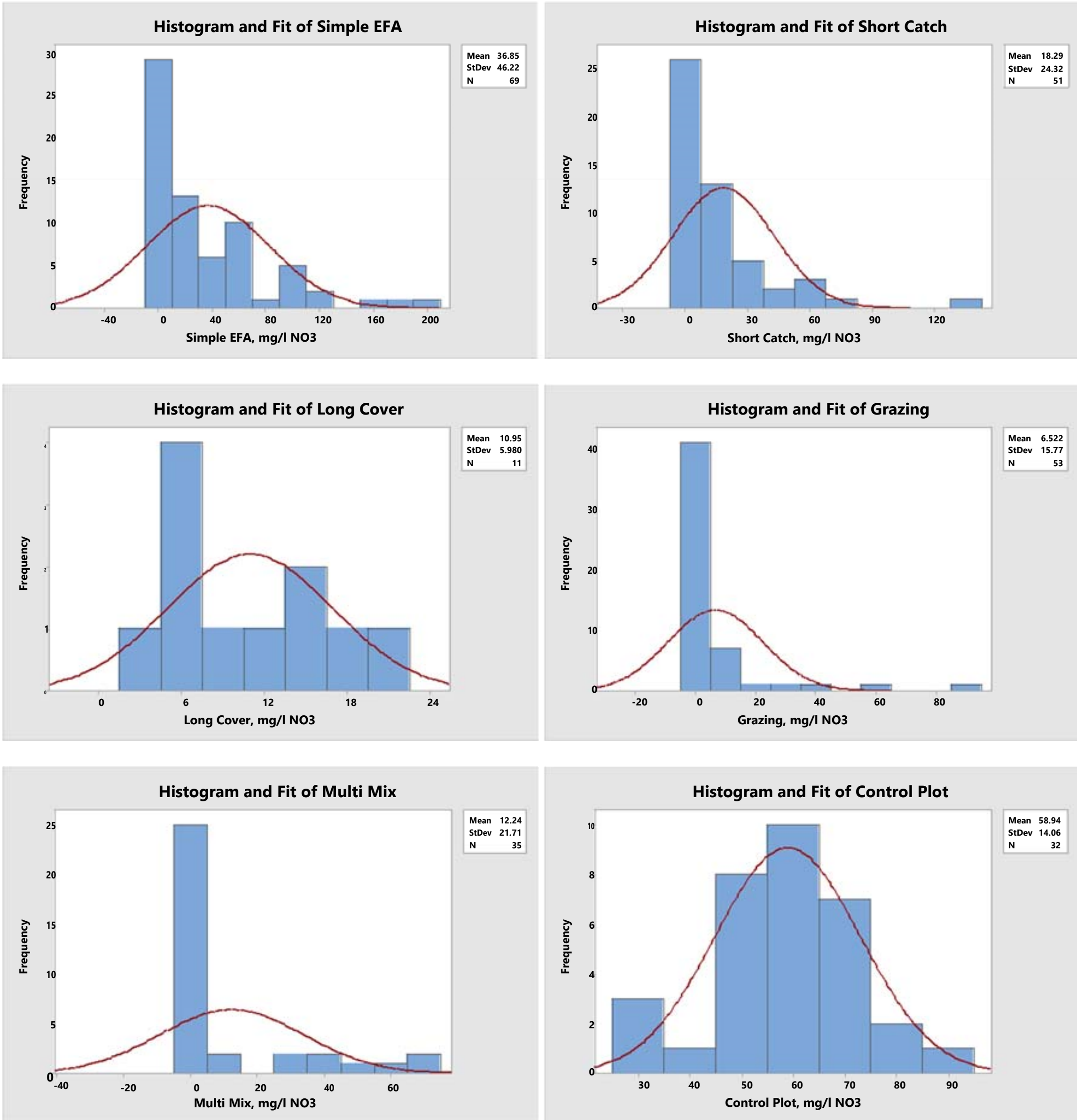








Histograms comparing distribution of the Mile Oak Farm data.



Appendix 5: Environment Agency Rainfall Data

	Housedean Farm	Applesham Farm	Ditchling Rd tbr
01/10/2017	3.1	1.1	1.2
02/10/2017	1.7	1.1	2
03/10/2017	0	0	0
04/10/2017	0	0	0.2
05/10/2017	0	0.5	0
06/10/2017	0	0.6	2.2
07/10/2017	2	0.4	0.2
08/10/2017	0.5	0	0
09/10/2017	0	0.3	0.6
10/10/2017	0	0.1	1.6
11/10/2017	6.5	1.5	3
12/10/2017	0	0	0
13/10/2017	0	0	0
14/10/2017	0	0	0.2
15/10/2017	0	0	0
16/10/2017	0	0	0
17/10/2017	0	1.2	1
18/10/2017	2.2	2.3	1.2
19/10/2017	10.6	11.1	9
20/10/2017	6	5.7	9.2
21/10/2017	8.2	5.3	3.2
22/10/2017	0	0.5	0.6
23/10/2017	6.4	4.7	5
24/10/2017	0	0.7	0.4
25/10/2017	0	0.7	0.8
26/10/2017	0	0	0
27/10/2017	0	0	0
28/10/2017	0	0	0.6
29/10/2017	0	0	0
30/10/2017	0	0	0
31/10/2017	0	0	0
01/11/2017	0	0	0
02/11/2017	0	0.5	0.2
03/11/2017	3.6	1.9	1.4
04/11/2017	0.4	3.2	1
05/11/2017	0	0	0
06/11/2017	0	0	0
07/11/2017	11.4	8.9	7
08/11/2017	0	0.1	0.2
09/11/2017	0	0	0.2
10/11/2017	7.3	6.1	6.6
11/11/2017	6.2	7.1	6.8

	Housedean Farm	Applesham Farm	Ditchling Rd tbr
12/11/2017	0	0	0
13/11/2017	0	0	0
14/11/2017	0	0.2	0.2
15/11/2017	0	0.5	0
16/11/2017	0	0	0
17/11/2017	0	0	0
18/11/2017	2.1	2.2	2.2
19/11/2017	2.1	0.7	1
20/11/2017	2.6	1	1.4
21/11/2017	0	0	0
22/11/2017	3.6	8.1	3.6
23/11/2017	2.1	2.1	2
24/11/2017	0	0	0
25/11/2017	0	0	0
26/11/2017	3.1	1.4	1.2
27/11/2017	0	1.7	1
28/11/2017	0	0	0
29/11/2017	0	0	0.2
30/11/2017	0	0	0
01/12/2017	0	1.8	0
02/12/2017	0.8	0.3	0.6
03/12/2017	0	0	0
04/12/2017	0	0	0
05/12/2017	0	0	0
06/12/2017	2.4	0.9	0.8
07/12/2017	4.6	5	3.6
08/12/2017	0	0	0
09/12/2017	28.3	23.7	26.2
10/12/2017	15.6	8.3	9.4
11/12/2017	1.6	6	5.8
12/12/2017	4.9	5.4	3.4
13/12/2017	3	4.5	2.4
14/12/2017	1.5	1.4	1.4
15/12/2017	0	0.4	0.6
16/12/2017	0	0	0
17/12/2017	6.7	3	5.2
18/12/2017	0	1.5	0
19/12/2017	0	0	0.2
20/12/2017	0	0	0.2
21/12/2017	0	0	0.4
22/12/2017	1.6	0.7	1.2
23/12/2017	0	0.2	0.2

	Housedean Farm	Applesham Farm	Ditchling Rd tbr
24/12/2017	1.4	2.4	1
25/12/2017	1	1.4	1
26/12/2017	23.2	22.7	16.8
27/12/2017	3.2	2	2.8
28/12/2017	5.5	5.1	5.2
29/12/2017	9.6	9.3	5
30/12/2017	14.1	12.7	9.6
31/12/2017	12	5.8	7
01/01/2018	4.1	3.6	3.6
02/01/2018	12.3	10.5	8
03/01/2018	7.3	6	6.4
04/01/2018	1.1	3	0.6
05/01/2018	4.5	6.3	4.6
06/01/2018	0	0	0
07/01/2018	0	0	0
08/01/2018	0	0	0
09/01/2018	1.6	0.2	1.2
10/01/2018	0	0.1	0
11/01/2018	0	1.8	0.2
12/01/2018	0	0	0
13/01/2018	0	0	0
14/01/2018	4.1	5.3	2.8
15/01/2018	7.2	9.1	5.4
16/01/2018	0	0	0
17/01/2018	8	5.7	4.6
18/01/2018	0	0	0
19/01/2018	4.1	5.5	5
20/01/2018	2.4	2.5	2.8
21/01/2018	13	9.9	10
22/01/2018	1.5	1.8	1
23/01/2018	1.9	2.2	1.2
24/01/2018	9.8	7.6	8.2
25/01/2018	2.1	1.1	1.2
26/01/2018	10.4	0.5	0
27/01/2018	0	8	6.4
28/01/2018	0.2	0.5	0
29/01/2018	0	0	0.2
30/01/2018	5.5	8	3.8
31/01/2018	3.5	1.2	1.6
01/02/2018	0	0	0
02/02/2018	0	0.2	0.6
03/02/2018	3.7	1.8	2.2
04/02/2018	0	0.5	0
05/02/2018	0	0	0
06/02/2018	0	0.5	0
07/02/2018	0	0	0
08/02/2018	15.5	8.8	7.8
09/02/2018	0	0.4	0
10/02/2018	6.2	4.8	2.4

	Housedean Farm	Applesham Farm	Ditchling Rd tbr
11/02/2018	0	0.5	0
12/02/2018	0	3.3	0.6
13/02/2018	0	4.9	3.8
14/02/2018	38.9	20.2	22.4
15/02/2018	0	0.3	0.2
16/02/2018	0	0	0
17/02/2018	0	0.9	0
18/02/2018	1.7	1.7	1
19/02/2018	2.1	0.3	1.8
20/02/2018	0	0.2	0.6
21/02/2018	0	0	0.2
22/02/2018	0	0	0
23/02/2018	0	0	0
24/02/2018	0	0	0
25/02/2018	0	1	0
26/02/2018	0	1	0
27/02/2018	0	0	2.2
28/02/2018	0	0	0.4
01/03/2018	0	0.5	0
02/03/2018	6.4	1.7	1.2
03/03/2018	2.5	4.9	2.8
04/03/2018	1.4	0.8	1.4
05/03/2018	0.7	0.4	0
06/03/2018	8.4	8	8.4
07/03/2018	6.1	7.4	4.2
08/03/2018	0	0	0
09/03/2018	8.6	9.2	7.6
10/03/2018	1.4	2.3	2
11/03/2018	7.8	5.1	7.6
12/03/2018	5.4	6.5	5.4
13/03/2018	0	0	0
14/03/2018	15.5	11	10.8
15/03/2018	3.5	2.6	3.2
16/03/2018	0	0	0
17/03/2018	2.6	3.9	0
18/03/2018	0	0.7	0.6
19/03/2018	0.8	0	0.2
20/03/2018	0	0	0
21/03/2018	0	0	0
22/03/2018	3	2.5	1.2
23/03/2018	1.7	2.5	2.2
24/03/2018	0	0	0
25/03/2018	0	0.5	0
26/03/2018	0	3.9	4.2
27/03/2018	6.2	2.8	7.6
28/03/2018	1.7	6.8	2.8
29/03/2018	6.3	3.9	4.8
30/03/2018	14.7	8.5	10.4

Appendix 6: FWAG Soil Results.

Soil testing results for Housedean Farm. Samples taken from a core depth of 0 – 30 cm.

Date received	Plot	NO_3-N (Kg/ha)	NH_4-N (kg/ha)	SMN (kg/ha)	pH	Phosphorus (mg/l)	Potassium (mg/l)	Magnesium (mg/l)	OM (%)	N (%)	Dry Matter (%)	Total N (kg/ha)	FW (t/ha)	N (%)	C (%)	C:N ratio
06.09.17	1- Simple EFA	36.8	3.8	40.6												
06.09.17	2 - Complex EFA	38.7	2.8	41.5												
06.09.17	3- Short catch	40.7	4.5	45.1												
06.09.17	4- Long cover	27.4	3.7	31.1												
06.09.17	5- Grazing	30.7	3.3	34												
06.09.17	6- Multi mix	38.4	4	42.5												
06.09.17	7- Control (bare)	39.6	3.1	42.8												
06.09.17	Not specified				8.07	33	159	19	4.22							
24.01.18	1- Simple EFA	19.1	5.2	24.3						2.16	22.5	49.2	10.13	2.16	38.7	17.9
24.01.18	2 - Complex EFA	18.7	8.5	27.2						3.32	12.1	93.4	23.17	3.32	37.4	11.3
24.01.18	3- Short catch	19.2	6.6	25.8						2.04	23.2	109.4	23.1	2.04	38.2	18.7
24.01.18	4- Long cover	18.8	6.9	25.7						3.01	14	163.2	38.71	3.01	36.7	12.2
24.01.18	5- Grazing	17.6	8.2	25.7						2.39	16.9	95.8	23.74	2.39	37.5	15.7
24.01.18	6- Multi mix	23.8	5.1	28.9						2.72	16.8	106.1	23.27	2.72	37.9	13.9
24.01.18	7- Control (bare)	19.8	7.5	27.3												
24.01.18	Not specified															

Soil testing results for Mile Oak Farm. Samples taken from a core depth of 0 – 30 cm.

Date received	Plot	NO_3-N (Kg/ha)	NH_4-N (kg/ha)	SMN (kg/ha)	pH	Phosphorus (mg/l)	Potassium (mg/l)	Magnesium (mg/l)	OM (%)	N (%)	Dry Matter (%)	Total N (kg/ha)	FW (t/ha)	N (%)	C (%)	C:N ratio
06.09.17	1- Simple EFA	48.8	3.3	52												
06.09.17	2 - Complex EFA	41.4	4.3	45.7												
06.09.17	3- Short catch	47.4	4.2	51.7												
06.09.17	4- Control (bare)	54.8	4.3	59.1												
06.09.17	5 - Long cover	46.4	6.8	53.2												
06.09.17	6- Grazing	46.3	5.3	51.6												
06.09.17	7- Multi mix	32.5	3.5	36												
06.09.17	Not specified				8	24	312	77	9.47							
24.01.18	1- Simple EFA	34.7	10	44.8						2.23	23	66.6	12.97	2.23	41.2	18.5
24.01.18	2 - Complex EFA	28.5	9.2	37.7						3.69	17	61	9.71	3.69	41.2	11.2
24.01.18	3- Short catch	36.9	23.5	60.5						3.47	15.4	75.7	14.13	3.47	40.6	11.7
24.01.18	4- Control (bare)	29.8	8.3	38.1												
24.01.18	5 - Long cover	27.6	11.8	39.4						3.5	16.1	91.3	16.16	3.5	43.1	12.3
24.01.18	6- Grazing	25.1	9.2	34.2						3.5	16.3	87.7	15.36	3.5	42.9	12.3
24.01.18	7- Multi mix	25.5	5.6	31.1						2.33	15.7	47.7	13.06	2.33	41.9	18
24.01.18	Not specified															