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Countryside Stewardship organic management and conversion options: A scoping study to establish a monitoring protocol. Literature review

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Executive summary

This literature review is part of a wider project to determine a monitoring protocol for the organic options within Countryside Stewardship (CS). In 2017, the United Kingdom had a total area of 517,000hectares of land farmed organically (i.e. the fully converted area and area under conversion), (Defra, 2018b). Permanent pasture accounts for the biggest share of the organic area (64%) followed by temporary pasture (18%) and cereals (7%).

Approximately 1.3% of the Rural Development Plan for England is set aside for the organic options of CS. As yet the environmental and public benefits of the organic options have not yet been quantified for the key objectives of CS.

This literature review has studied the evidence from studies of organic and conventional agriculture from Temperate (and some Mediterranean) regions, focussing on England, to determine the costs and benefits of organic agriculture. The following boxes provide summaries of the review by subject.

General

Organic farming has environmental benefits, when expressed on a per unit area basis but the benefits are not so certain or disappear when analysis is carried out using per unit production.

Biodiversity

Organic agriculture is assumed to have benefits for biodiversity, soil and water as well as providing other public benefits. Studies over the last 30 years have observed that biodiversity generally benefits from organic agriculture, with increases in a range of taxa observed in many cases. However some studies observe mixed effects with increases, no change or decreases in different taxa or species. The increases in biodiversity in organic systems are often attributed to the more heterogeneous nature of organic holdings (including crop diversity, boundary features and wooded areas) rather than at an individual field level. Organic farms may not always have higher biodiversity than comparable conventional farms, becuse other factors, especially landscape, do appear to play a large part in influencing biodiversity. Baseline figures for the number of species or habitats in a region or on a farm are therefore required along with regular biodiversity monitoring of organic CS agreements to provide valuable evidence of the maintenance and increase of biodiversity, especially for conversion farms.

Soil

Most literature on organic compared to conventional farming reports greater levels of soil organic matter in organic systems but this is not always the case - organic rotations include a greater proportion of 'fertility building crops' (green manures and leys) that add organic matter to the soil but the higher yields in conventional systems can be associated with greater crop residue additions. Although there are exceptions organically farmed soils usually show greater biological activity and biodiversity.

Soil - continued

Without the possibility of importing readily available nitrogen fertilisers organic farmers must work to minimise its loss and generally the literature has found nitrate leaching to be less on organic farms. However, the incorporation of grass/clover leys is often a 'leaky point' in a rotation. The use of pesticides is extremely restricted on organic farms and so the likelihood of water contamination can only be less than from conventional systems. Organic farms generally make greater use of animal manures than conventional systems which has led to concerns about the risks of disease transmission, but the organic standards encourage treatments such as composting that should minimise this risk.

Management practices associated with organic farming have the potential to prevent soil erosion and several studies have shown this to be the case.

Both higher SOM and less soil erosion in organic farming could make the use of organic land for flood alleviation programmes more effective although there are no studies that prove this.

Water quality

Nitrate leaching is generally less from organic than from conventional farming systems but more modern (lower) fertiliser recommendations for conventional farmers might also make the distinction less clear cut. Phosphorus is usually lost through movement of soil particles rather than by leaching - greater organic matter levels and practices such as winter cover cropping should minimise erosion from organic farms but there has been little comparative study of P loss. Pesticides with the exception of copper (which is in the process of being phased out) should not affect water quality as run-off from organic farms.

Climate Change

A range of meta-analyses and reviews have observed that organic farming tends to score equal or better than conventional farms when GHG emissions are expressed per unit area. When the GHG emissions per output/unit product are considered, some authors observe no differences between organic and conventional.

There are conflicting theories and models on whether nitrogen emissions from organic farms will be higher or lower than from conventional farms.

Organic farming has a lower CH_4 emission potential on a per hectare basis although CH_4 emissions per kg of milk are estimated to be higher in organic dairy farms than in conventional ones.

On a per hectare scale, organic farming has been observed to have positive effects on CO_2 emissions whereas on a per-unit output basis, the CO_2 emissions tend to be higher in organic systems.

The highest mitigation potential of organic agriculture could lie in carbon sequestration in soils although there is no consensus on whether this does, or will happen.

There are not enough studies linking organic farming to climate change adaptation to form a conclusion.

Carbon footprints need to be created on a farm scale rather than a field or option scale to be relevant.

Landscape Character
There have been few studies on the impacts of organic agriculture on landscape pattern, aesthetic and cultural history. The work that has been done shows that organic farms tend to have more landscape elements such as hedgerows, ponds and trees (including agroforestry) and have smaller more complex field systems than conventional farms. In some areas (New Zealand) organic farming is considered 'messy' compared to intensive farms, although this is probably becoming an outdated viewpoint.

The key questions that need to be answered by an evaluation of the organic options of Countryside Stewardship are:

1. How do the biodiversity elements measured for organic maintenance options compare with similar land not in Countryside Stewardship (CS)?
2. How do the biodiversity elements measured for the conventional options in CS compare to organic maintenance options?
3. How does biodiversity on the organic maintenance options of CS compare to the biodiversity of conventional farms with similar environmental settings and/or farm business types?
4. Do the biodiversity elements currently measured for conventional options change at a different rate to conventional farms in CS as farms convert to organic production?
5. How does biodiversity change as a farm converts to organic production compared to a similar farm that is outside of CS over the same time period?
6. How does soil organic matter differ between conventional farms and organic farms in CS?
7. Is there a difference in soil erosion between conventional and organic farms in CS?
8. How do soil biota differ between conventional and organic farms in CS?
9. Is there a difference in the quality of water leaving conventional and organic farms in CS?
10. Do organic farms maintain or change the landscape in a way different from conventional farms in CS?
11. Can the public benefits of organic and conventional farms in CS be quantified and compared: what are the variables (above and beyond those in question 1 to 9) that need to be collected to do this?
12. Are two surveys sufficient: A baseline survey (year 1) and a comparison survey at the end of the CS agreement (year 5)?

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Abbreviations

AES	Agri-environment scheme
ARGOS	A new Zealand Organisation: Agricultural Research Group on Sustainability
CS	Countryside Stewardship
GHG	Greenhouse gas
Defra	Department for the environment and rural affairs
DOK	A Swiss trial: biodynamic (D), organic (O), conventional/konvetionell (K)
HT	Higher-tier
IFM	Integrated Farm Management
IFOAM	International Federation of Organic Agriculture Movements
IPM	Integrated Pest Management
LCA	Life-cycle assessment
LCMP	Land Carbon Management Plan
LFA	Least Favoured Area
MT	Mid-tier
POM	Particulate organic matter
RDPE	Rural Development Programme for England
SOC	Soil organic carbon
SOM	Soil organic matter
VAM	Vesicular arbuscular mycorrhiza

1 Introduction

In 2017, the United Kingdom had a total area of 517 thousand hectares of land farmed organically (i.e. the fully converted area and area under conversion), (Defra, 2018b). Permanent pasture accounts for the biggest share of the organic area (64%) followed by temporary pasture (18%) and cereals (7%).

Approximately £3 billion will be invested in agri-environment schemes (AES) through the 2014-2020 Rural Development Programme for England (RDPE). Of this, around £900m will be for the Countryside Stewardship (CS) Scheme, within which approximately £12m is specifically allocated to supporting organic farming (approximately 1.3%). The remaining £2.1 billion of the RDPE budget is allocated to legacy schemes such as Environmental Stewardship.

Prior to 2015, there were three main environmental schemes in England, being Environmental Stewardship, Catchment Sensitive Farming and the Woodland Grant Scheme. These were combined, in 2015, into CS as one of the main mechanisms for delivery of Defra's Strategic Objective of 'a cleaner, healthier environment, benefiting people and the economy'. CS also contributes to the Defra Single Departmental Plan and should help to address the new 25 year Environment Plan (HM Government, 2018). The five main scheme objectives are:

- Biodiversity
- Resource protection
- Historic environment
- Landscape
- Climate change adaptation

Other CS outcomes include:

- flood and coastal risk management
- landscape character
- genetic conservation

CS (and the earlier schemes) provides support for the management and conversion to organic practices, as a means of delivering the scheme objectives as well as supporting the European Action Plan for Organic Food and Farming. The specific contribution of Organic Management and Conversion options in AES has yet to be systematically monitored and evaluated in England at a national scale, to determine whether the environmental impact of organic management under AES is in line with research data from the UK and across northern Europe and other climatically similar regions worldwide. It is important that this is understood fully because the UK has circa 495,000 ha of land in organic farming, is the 16th largest globally, with organic farming representing 2.9% of agricultural land (Willer & Lernoud, 2016).

The focus of this project is the organic options within CS, as listed below.

Management options
OT1: Organic land management - improved permanent grassland
OT2: Organic land management - unimproved permanent grassland
OT3: Organic land management - rotational land
OT4: Organic land management - horticulture
OT5: Organic land management - top fruit
OT6: Organic land management - enclosed rough grazing

Conversion options
OR1: Organic conversion – improved permanent grassland
OR2: Organic conversion – unimproved permanent grassland
OR3: Organic conversion – rotational land
OR4: Organic conversion - horticulture
OR5: Organic conversion - top fruit

Arable options (already included within the CS baseline project ECM47452[1])
OP1: Overwintered stubble
OP2: Wild bird seed mixture
OP3: Supplementary feeding for farmland birds
OP4: Multi species ley
OP5: Undersown cereal

These organic management and conversion options need to be considered in relation to land in conventional agriculture and where appropriate the matching management options for farms in CS with conventional agricultural management.

The CS guidance notes and manual for the various organic options state that there will be a maintenance or increase in environmental and public benefits from an agreement with that option. For example, OT5 – Organic land management top fruit reads: "Maintains top fruit orchards under organic management, providing a range of environmental and public benefits." However, there is no further information on what those benefits might be.

Many of the desirable goals of reducing the intensity of farming practices such as: increased soil organic matter (SOM), resulting in better soil structure; reduced erosion; and better water infiltration as water holding capacity is increased, are likely to occur on organic farms but not exclusively. This is also true for the use of nitrogen fertilisers and other inputs, although the removal of herbicides, insecticides and fungicides rather than reducing their use (as in Integrated Farm Management) should theoretically be more beneficial on organic farms. With a reduction of inputs and a relaxation of some management practices it has been assumed organic production will subsequently be beneficial to biodiversity in comparison to conventional farming. There has been a large body of research to investigate whether there are the predicted benefits of organic farming and then subsequent meta-analyses to summarise the research. This review will help to bring together the evidence.

2 Project objectives

This review provides the first output from a wider project with the objectives:

Objective 1. Review the literature base to confirm the specific monitoring questions to be tested in relation to the environmental impact of organic conversion and management AES options.

Objective 2. Identify any useable, existing monitoring data, (for example from past agri-environment monitoring databases or from other sources such as Universities, Organic Farming bodies and private individuals), suitable for use as a baseline against which to compare future monitoring.

[1] Current project: The Environmental Effectiveness of the Countryside Stewardship scheme; Establishing a Baseline Agreement Monitoring Sample

Objective 3. Recommend a methodology to test the monitoring questions. This should include an assessment of alternative methodologies and a justification for the recommendation given.

3 Literature review

The focus of this literature review is the environmental impacts of organic farming, relevant to England and to the environmental objectives of the AES support for Organic farming. The review has been designed to not only collect information from systematic reviews, meta-analyses and published accounts concerning the efficacy of organic farming compared to conventional farming in regard to the objectives of CS but also to discover which methods for assessing the environmental and cultural impacts of farming could be used in a future evaluation of CS. The review is split into four key topics and key sectors.

Following discussion with the Project Steering Group it was agreed that the literature review should not be a full systematic review because time and resources were not available.

3.1 Protocols for Literature review, searching and analysis

The search items included synonyms, spelling variations and different combinations of terms as relevant to each topic. The results of the search have been entered into a database, supplied as an output of the project. To ensure that the search was focussed on the CS management and conversion options, key search terms included the relevant sectors, as listed below.

General: This category was used for most meta-analyses or larger studies that covered all crop types or did not specify a crop type.

Grassland. This focused on grassland as a whole including rough grazing, and where sufficient information was available, the grassland was categorised into unimproved or improved, as defined in the OT1, OT2, OR1 and OR2 prescriptions. Where there was a distinction between lowland and upland especially relating to LFAs this was noted.

Rotational land: This included arable land and temporary leys. The crops most commonly grown in UK organic rotational production (Scott, 2017) are winter and spring wheat, barley, oats, and spring beans, in addition to cover crops, green manures and potatoes.

Field vegetable production (as a sub-set of rotational land): Key crops include carrots, onions, leeks, brassicas, salads and legumes picked for fresh consumption.

Fruit. Fruits relevant to the UK organic industry including top fruit orchards (e.g. apples, pears and plums) and permanent bush crops (e.g. gooseberries and raspberries), including polytunnel crops (as they have a landscape impact) such as strawberries.

For all sectors, published research from the UK and research from geographic areas comparable to the UK climate in the Temperate and Mediterranean biomes were considered. The Mediterranean biome studies were relevant as this zone is likely to become more relevant as the climate changes in the coming decades. Academic publication searching was be carried out using the Conservation Evidence website, SCOPUS, the ISIS Web of Science[2], Coventry University 'Locate' and GoogleScholar.

[2] Web of Science: http://wok.mimas.ac.uk. Locate: http://cov-primo.hosted.exlibrisgroup.com/primo_library/libweb/action/search.do

In addition to the standardised interrogations of the highlighted academic databases, searches for grey literature including technical reports and industry publications were carried out using internet search engines (Google, Google Scholar, Defra Science search, Organic Eprints). Moreover key individuals within Natural England, NGOs, charities (such as LEAF and the Soil Association) and the academic community were contacted for the more obscure grey literature reports.

The titles retrieved from these searches were screened, and then abstracts downloaded. These abstracts were subjected to a second round of screening where useful papers were selected. Full copies of the text were obtained for these items. In addition, where sufficient time was available, relevant publications cited in reports obtained during the searches were obtained.

Papers published in other languages were screened out, for example on the www.orgprints.org website there are a wide range of German reports, in addition to some publications in French, Italian Russian, Chinese and Korean.

4 Literature review results

4.1 General

There have been a number of meta-analyses comparing the environmental, economic and cultural differences and impacts of organic and conventional farming systems. The meta-analysis by Seufert and Ramankutty (2017) assessed the costs and benefits of organic and conventional agricultural production globally for production, environmental, producer, and consumer dimensions. They concluded that organic production has many environmental benefits (higher biodiversity, soil and water quality per unit area) but that the benefits were uncertain when relating to lower yields and yield sustainability.

Defra guidance[3] states that organic farming can include:

- avoiding artificial fertilisers and pesticides
- using crop rotation and other forms of husbandry to maintain soil fertility
- controlling weeds, pesticides and diseases using husbandry techniques and where necessary approved materials to control pests and diseases
- using a limited number of approved products and substances where necessary in the processing of organic food

All farms wanting to be considered organic in the UK have to be certified by one of five organic control bodies that conform to standards laid out by the EU[4].

We have also considered the biodynamic branch of agricultural production. The following text comes from the Biodynamic Association of the UK website[5].
"Founded in 1924, Biodynamic farming is the oldest 'green' farming movement, and forerunner of organics. All biodynamic farmers and growers practice organic methods of cultivation, are against genetic modification (GM), and share its ideals, but there are important differences. Biodynamics has metaphysical and spiritual roots that organics does not. Biodynamics thus embraces the mystery of all life processes, including the subtle and energetic realities that are not necessarily easy to measure or justify using current scientific methods. Whereas other forms of sustainable agriculture are

[3] https://www.gov.uk/guidance/organic-farming-how-to-get-certification-and-apply-for-funding#what-counts-as-organic-farming

[4] Commission Regulation (EC) No. 889/2008 of 5 September 2008).(https://ec.europa.eu/agriculture/organic/eu-policy/eu-legislation/brief-overview_en)

[5] https://www.biodynamic.org.uk/discover/#what-is-bd

primarily concerned with producing food sustainably, biodynamic farming aspires to be transformative and seeks to maximize health and vitality. It thus constantly strives to embrace all life's processes, to understand them better, and to improve the way we farm through an ongoing dialogue with Nature. For biodynamics, farming is not a means to maximum production, but an ongoing dialogue with Nature. We consider the land we steward to be an ecological web of biodiversity; our role is to nurture this and help it reach its full potential, whilst balancing the needs of farming and growing with those of the natural world. "

The variation in benefits and costs of organic agriculture is not surprising when the variations of farming systems across the globe are considered. Furthermore the distinction between organic and conventional farming is becoming increasingly blurred as more 'conventional' farm businesses move towards integrated farming practices either through a sense of environmental duty or for the economic benefits from reducing inputs on the farm. Not only are there not such clear distinctions between organic and conventional farms anymore but the term 'Organic farm' includes a wide variety of different types varying from producers that have converted just to the point where their production qualifies for certification to those who are idealists, trying to truly make their farms sustainable and self-reliant in ways that go beyond the standards. There are also farms that use all the organic management techniques but that have not applied for organic certification because they do not feel this is commercially worthwhile; this applies particularly to small scale vegetable producers who market their crops directly.

The literature regarding organic as compared to conventional farming, in many cases, compared systems at the farm level, rather than for individual land use types. To aid us in determining the difference in the effects and impacts between farming system (e.g. organic versus conventional) for each priority heading, and the effects and impacts of farm type (rotational, dairy, mixed etc) within that, and subsequently crop type within that, we created a hierarchy within the database. Reidsma *et al.* (2006) classified farm types (Table 1) assigning each type an ecosystem quality. This is a useful starting point to show examples but because of the complexity outlined by Seufert and Ramankutty (2017) they could be considered over simplistic.

Ecosystem quality[a] (%)	Farm types	Production systems
100	No production	Primary vegetation
40	Extensive grassland management	Medium to high cattle density on natural grassland
35	Extensive organic farming	Low-External-Input and Sustainable Agriculture (LEISA), permaculture
25	Extensive farming	Traditional farming; extensive farming; Low-External-Input Agriculture (LEIA)
20	Intensive organic farming	Rainfed organic farming
20	Intensive grassland management	Grassland production based on ploughing, reseeding and fertilization
15	Highly intensive organic farming	Organic farming in developed countries (where conventional agriculture is based on long-term soil and water investments)
10	Intensive production systems	Intensive agriculture; integrated agriculture; High-External-Input Agriculture (HEIA); conventional agriculture
5	Highly intensive production systems	Irrigation based agriculture; integrated agriculture; drainage based agriculture; additional soil levelling practices; regional specialization; specialization of production at the farm and landscape level

[a] Expressed as percentage of the original pristine situation (see text for further explanation).

Table 1. Summary of ecosystem quality per farm type (Reidsma et al., 2006)

General Summary
Organic farming has environmental benefits, especially when expressed on a per unit area basis but the benefits are not so certain or disappear when analysis is carried out using per unit production.

4.2 Literature review results: Biodiversity

As organic systems do not use synthetic herbicides and fertilisers, and generally include leys in rotations, higher species richness and abundance of non-crop plants would be expected. There are a number of review and meta-analysis papers comparing the biodiversity of organic and conventional systems. These generally focus on the measurement of species richness by taxonomic group, such as birds, butterflies, insect pollinators (hoverflies, bumblebees and solitary bees), epigeal arthropods, earthworms and plants. Soil species are included within the soil section (4.3.1). The reviews all categorise those studies that show positive or negative effects of organic farming. Some reviews have a category for 'mixed' effects (some positive and some negative effects) while others have a fourth category for 'no difference'. Some of the review and meta-analysis papers have combined 'no difference' and 'mixed' into one category, which has prevented a clear distinction between these two potential results and made comparisons complicated.

The reviews we studied generally report that organic farming often increases species richness, but not in all cases (Table 2). For example, when comparing 63 studies published up to 2002, organic farms had on average 30% higher species richness than conventional farming systems, although 16% of studies showed a negative effect on species richness (Bengtsson *et al.*, 2005). A review paper by Letourneau and Bothwell (2008) observed that although results vary among taxonomic groups, biodiversity is enhanced on organic farms compared to conventional farms in most studies. Moreover, Tuck *et al.* (2014) conducted a meta-analysis of 94 studies, and concluded that organic farming has large positive effects on biodiversity compared with conventional farming, but that the size of the effect varies with the organism group and crop studied, and is greater in landscapes with higher land-use intensity. They also observed that plants benefited most from organic farming, probably due to restricted herbicide use.

Tuomisto *et al.* (2012) observed that it is still unclear whether conventional farming with specific practices for biodiversity conservation (i.e. agri-environmental schemes) can provide greater benefits than organic farming.

Parameter reported	**Number of publications reviewed**	**Result**	**Date range**	**Reference**
Effects on taxa	76	66 positive, 25 mixed/no difference, 8 negative	1981-2003	Hole *et al.* (2005)
Species richness	63	84% positive, 16% negative	Up to Dec 2002	Bengtsson *et al.* (2005)
Abundance of organisms	117	82% positive	Up to Dec 2002	Bengtsson *et al.* (2005)
Biodiversity	95	71% positive, 23% no effect, 7% negative	Up to 2010	Pfiffner and Balmer (2011)
Biodiversity	395	327 higher (82%), 56 no difference (14%), 13 lower (3%)	Up to March 2011	Rahmann (2011)
Species abundance/richness	100	100 positive, 39 no difference/mixed, 9 negative	Up to 2009	Tuomisto *et al.* (2012)
Biodiversity	94	Increase by up to 1/3	Up to 2011	Tuck *et al.* (2014)

Table 2. Summary of the main meta-analysis and review papers considering aspects of organic farming as compared to conventional farming on biodiversity

4.2.1 Biodiversity at the landscape scale

The landscape is considered in several ways when assessing the impacts of agriculture. A key objective of CS is to enhance the landscape character of the countryside and to protect historic landscapes (see section 4.6). This is very different to how landscape ecologists and ecologists look at the landscape. They are interested in the complexity of land-use and abundance of elements such as hedgerows, how they are connected and how biodiversity is distributed and dispersed. Indeed, for some taxa, especially birds, studies are often undertaken at the landscape scale, rather than just for individual fields or farms. In recent times the idea of sustainable landscapes for ecosystem services has gained traction and the effects of AES demonstrated (e.g. Baker *et al.* (2012). AES arable options should increase the number of habitats and food provision for a range of taxa. For example the AES winter bird food options increase granivorous bird numbers (Field *et al.*, 2010) and many of the studies cited below are comparing organic farms with intensive non-AES farms. This should be considered when predicting the landscape biodiversity outcomes from the organic options in CS compared to the same options on conventional farms as across Europe they have been demonstrated successful on occasions (Albrecht *et al.*, 2007; Pywell *et al.*, 2011).
In this section the landscape ecology of organic and conventional farming are compared.

Barbieri *et al.* (2017), in a systematic comparison of organic-to-conventional crop rotations at the global scale based on a meta-analysis of the scientific literature, found that organic farming has differences in land-use compared to conventional, with increased complexity of organic crop rotations considered likely to enhance ecosystem service provisioning to agroecosystems. Some key findings when comparing organic with conventional farming were:

- catch crops and undersown cover crops in cereal fields are more frequent in organic systems
- lower proportion of cereals
- higher frequency of cereal intercropping with legumes
- more nitrogen fixing crops, including mixed legume-grass temporary leys
- more diverse crop rotations
- longer crop rotations

Organic studies have for many years considered how the landscape affects biodiversity, with a meta-analysis noting that at a landscape scale (field/farm in matched landscape) farming practice appeared to be less important than the effects of the surrounding landscape onbiodiversity (Bengtsson *et al.*, 2005). The studies summarised below are most relevant to the UK:

- An increase in bird density and number of breeding pairs on organic farms was attributed mainly to the more heterogeneous landscape when compared conventional farms in Poland (Wolnicki *et al.*, 2009).
- In a UK organic/conventional farm level comparison, Gabriel *et al.*(2010) found bird diversity (especially of farmland bird specialists) to be higher on conventional farms, despite the greater food resources (arthropod abundance), seeds of weeds and a higher proportion of winter stubble observed in the organic farms.
- Bird density was significantly higher on English organic farms for six out of 16 species, and none on conventional (Chamberlain *et al.*, 2010). Total abundance of all species combined was higher on organic farms, both habitat extent and farm type were important for starling and greenfinch. However, they concluded organic farming as currently practised may not provide significant benefits to those bird species that are limited by winter seed food resources, in particular, several declining granivores.
- In a Swedish butterfly study (Weibull *et al.*, 2000), each organic farm was paired with one conventional farm so that the farms within pairs were as similar as possible in terms of land-use, or habitats, on the farm. Variation in landscape heterogeneity was observed to be more

important than the farming system for butterfly diversity and abundance, with no difference observed between the 16 conventional and organic farms(Weibull *et al.*, 2000).

- Belfrage *et al.* (2005) compared diversity and abundance of birds and the abundance of butterflies, bumblebees and herbaceous plants between six small farms (<52 ha arable land) and six large farms (>135 ha arable land). Two of the large and four of the small farms were organic. Over twice as many bird species and territories, butterflies, and herbaceous plant species, and five times more bumblebees were found on the small farms. The largest differences in the biodiversity measured were found between small organic and large conventional farms. Differences were also noted between small and large organic farms: 56% more bird species were found on small organic farms, which as none of the farms used any pesticides suggested that area is not the key factor i.e. increasing area is not necessarily going to increase bird abundance proportionately. The authors highlighted that the effects of organic agriculture on biodiversity should include factors that alter with the size of the farm.
- Purtauf *et al.* (2005) found that carabid species richness and activity density within arable fields increased with percent cover of grassland in the surrounding landscape, rather than the management system (organic or conventional). The authors concluded that landscape features were much more important than organic farming management for enhancement of local biodiversity.
- In a German study comparing organic and conventional weed species, organic farming generally promoted species diversity of arable weeds and the surrounding landscape was important for the seed bank (Roschewitz *et al.*, 2005). In conventional fields, species diversity strongly increased with increasing landscape complexity, generating similar diversity levels as in organic fields. They concluded that organic farming contributed most effectively to weed species diversity in simple agricultural landscapes.

4.2.2 Grassland biodiversity

When considering organic system effects on grassland biodiversity, results are less clear then when considering the whole farm. For example, a review paper by Hole *et al.* (2005) observed that within grassland systems differences in vegetation composition between organic and conventional sown pastures tended to be less marked than arable fields, and that the natural colonization of grassland to form a diverse sward is a slow and unreliable process, regardless of farming regime, especially where rarer species are largely absent from the seedbank. Indeed, a meta-data analysis of literature found 19 studies on grassland observing an increase in floral biodiversity on organic farms with five studies showing no change when compared to conventional farms (Rahmann, 2011).

In a lowland permanent grassland study (not ploughed or reseeded for at least seven years) in the Republic of Ireland, ten matched pairs of organic and conventional dairy farms were investigated (Power *et al.*, 2012). Total plant richness was significantly higher on organic farms than conventional and also higher in field edges than the centre of fields.

In a Bavarian permanent grassland comparison study the number of plant species in organic grassland was only slightly higher than extensified grassland, which was in turn slightly higher than intensive grassland; and of the eight organic grassland farms the one that converted three years prior to the study, had a lower number of plant species than the average for intensive farms (Haas *et al.*, 2001).

4.2.3 Biodiversity on rotational land including field vegetable production

A number of review papers and large studies have considered biodiversity in arable and mixed systems:

- A review paper (Hole *et al.*, 2005) found that the majority of studies, floral / weed abundance and species richness of arable and mixed farming systems was greater in organic

farms when compared to conventional farms but that intensive weed control (mechanical weeding or under-sowing) in some organic systems can reduce weed abundance.
- A more recent meta-data analysis of literature found 64 studies on arable land observing an increase in flora biodiversity on arable land with three studies showing no change when compared to conventional farms (Rahmann, 2011).
- A summary of results from 1470 fields on 205 farms observed that average species richness is 10.5% higher on organic farms compared to conventional farms (Schneider *et al.*, 2014), although no increase in rare species occurrence was observed, higher species richness was due to a greater number of common species.
- The change from conventional to organic management is generally thought to increase the activity of predatory invertebrates, but the evidence is not conclusive and, in some cases, contradictory (Hole *et al.* 2005).

In addition to the reviews summarised above, the publications discussed below are most relevant to the UK.

- In Southwest England, ten organic farms were paired with ten conventional farms in a complex landscape. On average, organic farms were three to seven years post conversion. Plant abundance, species richness and diversity were measured in all crop and non-crop landscape elements on each farm. Organic arable fields, on average, contained significantly greater numbers of plant species than their conventional counterparts and had higher plant abundance (Gibson *et al.*, 2007).The authors noted that the organic farms had significantly greater total area of semi-natural (woodlands) and boundary vegetation (field margins and hedges).
- A UK comparison of organic and conventional farms observed that the high floral diversity in organic arable fields may increase the provision of larval host plants and adult nectar resources for flower-visiting insects, and thus contribute to higher densities of butterflies and bumblebees (Gabriel *et al.*, 2010).
- In Northern England the Nafferton Factorial Systems Comparison Experiments consisted of 128 plots (24 x 12 m), half organic and half conventional, with a range of fertiliser and pesticide treatments (Eyre *et al.*, 2008). Beneficial invertebrate activity (13 groups) was assessed in five crop types on a split-plot experimental system using pitfall trapping and suction sampling. In 2005, the plots contained wheat, barley, beans, vegetables (potatoes, cabbage, onions, lettuce, carrots) and grass/clover. They found crop type significantly affects the activity of different groups and that, in general, fertility management had more significant effects than crop protection, with some groups more active on conventional plots and others on organic plots. For example, Staphylinidae and beetle larvae were more active with conventional crop protection in beans and barley, whereas organic management appeared to favour Hemiptera, Lycosidae and Carabidae in beans and vegetables.
- A study in the Netherlands compared ground dwelling and aerial invertebrates on 20 conventional and 20 organic vegetable producing farms (organic for > 5 years), grouped in pairs, with each pair consisting of one organic and one conventional farm (Kragten *et al.*, 2011). Both farms within a pair were surrounded by similar landscape elements, such as woodlots, lines of trees, roads, power lines and wind turbines. At the crop level there was no evidence that organic management led to greater total invertebrate abundance. However, certain individual taxonomic groups were found to be more abundant in organic crops: Carabidae (cereals and potatoes), Araneae (cereals), Staphylinidae (potatoes), Formicidae (carrots) and 'other invertebrates' (carrots).
- The abundance and ecological diversity of selected groups of beneficial arthropods were compared between 16 organic and 17 conventional carrot (*Daucus carota* L.) fields in the North Island and South Island areas of New Zealand (Berry *et al.*, 1996). Organic fields had significantly higher numbers of three taxanomic groups compared with conventional fields:

Parasitic hymenoptera (largest number of all taxa collected), rove beetles (Staphylinidae), and lacewings (Neuroptera), but there was no significant difference for hover flies (Syrphidae). The second most abundant taxa, spiders (Araneae) and also centipedes (Chilopoda) had similar numbers in both organic and conventional carrot fields.
- A German trial comparing conventional and organic wheat fields observed that organic management did not enhance carabid species richness (Purtauf *et al.*, 2005). However, landscape context (i.e., percent cover of surrounding grassland) had an effect on species richness irrespective of management type

4.2.4 Biodiversity and fruit production

Cerutti *et al.* (2011) state in a review: "Although many aspects of environmental accounting methodologies in food production have already been investigated, the application of environmental indicators in the fruit sector is still rare and no consensus can be found on the preferred method. On the contrary, widely diverging approaches have been taken to several aspects of the analyses, such as data collection, handling of scaling issues, and goal and scope definition". Indeed, less literature was available for our literature review from the fruit sector, with a meta-analysis only finding a total of 13 studies on perennial crop land (orchards, vineyards and agroforestry) observing an increase in flora biodiversity in twelve instances, one finding no change and two observing less biodiversity as compared to conventional systems (Rahmann, 2011), with multiple citations of some studies due to different conclusions for different species groups.

4.2.4.1 Understorey biodiversity in orchards

The orchard floor represents a substantial portion of the orchard agroecosystem, but it has generally received less research and management attention than tree horticulture and pest management (Granatstein & Sánchez, 2009). There are a range of methods of managing the understorey in orchards, including maintaining the whole area as grass, grass strips with bare areas, with some orchard grass areas grazed and others mown (Crocker *et al.*, 1998; Lisek & Sas-Paszt, 2015). Weed control tends to be managed via mowing, grazing, use of herbicides or cultivation (tillage), inert mulches, living mulches and flaming (Granatstein & Sánchez, 2009). The studies summarised below focus on the orchard understorey:

- A study of Polish apple and cherry orchards found that the biodiversity of weeds in organic orchards was greater than in conventional orchards, that the repeated shallow cultivation of the soil, without herbicide treatments, resulted in the proliferation of perennial weeds, and that weed species composition was modified by the method of soil cultivation and environmental conditions (Lisek & Sas-Paszt, 2015).
- Understorey vegetation species richness and the species pool were significantly higher in organic apple orchards than in the conventional and integrated managed orchards in the Czech Republic (Lososová *et al.*, 2014). The results showed that a change from conventional to integrated and organic management in apple orchards led to higher plant species diversity and to changes in plant species composition.

4.2.4.2 Invertebrate biodiversity in orchards

A range of studies were found considering invertebrate biodiversity in orchards, including apples, peaches and kiwi fruits, with only orchard systems relevant to the UK discussed below:

- Miñarro *et al.* (2009) conducted a 3-year study to assess the effect of two strategies of fertilizer treatment (organic versus chemical) and three tree-row management systems (straw mulching, tillage and herbicide) on activity-density and biodiversity of epigeic predators in apples. Ground beetles (Carabidae), rove beetles (Staphylinidae), ants (Formicidae) and spiders (Araneae) were sampled monthly with pitfall traps. Tree-row management had a greater influence on predator catches than fertilizer treatment. The mulch had lower total predator catches, reduced carabid abundance, but increased staphylinid catches. Species richness did not significantly differ among treatments for ants, spiders or the total catches, but was higher on herbicide-treated plots for carabids. The fertilizer application treatment only influenced the species richness of rove beetles, being greater in the chemically-treated plots.

- Ant abundance and species richness was higher in organic apple orchards when compared to conventional orchards (Schurr, 2017).
- In a Korean apple orchard study, the abundance of spider communities (total number of individuals) was higher in organic orchards than in conventional orchards, with no significant difference in species richness and species diversity between orchard type (Im *et al.*, 2015).
- In a Spanish apple orchard pollinator study, undertaken in 28 orchards in two provinces, there were no significant interactions between the type of management (organic vs. conventional) and the proportion of cultivated area in the number of flower visits by pollinators, fruit set and number of seeds per fruit (Alins *et al.*, 2016). The flower visits by honey bees were significantly higher in the province with a lower proportion of arable land, and no significant differences were found on the flower visits by the rest of pollinators. The type of management (organic vs. conventional) did not affect the community of pollinators. The lack of influence of organic management in the abundance of insect pollinators may be due to the relative small size of the apple orchards compared to the surrounding conventional agriculture.

4.2.4.3 Bird biodiversity in orchards

Some research was found with a focus on birds in apple orchards, especially great tits, with birds seen as a means of invertebrate control.

- An apple orchard trial in the Netherlands observed greater numbers of caterpillars on organic orchards as compared to Integrated Pest Management (IPM) orchards, even in areas where great tit density was enhanced via the installation of nest boxes (Mols & Visser, 2007).
- In a French apple orchard study, the mean number of blue tit young produced per ha (orchard productivity) was significantly higher in organic orchards than in conventional and IPM orchards (Bouvier *et al.*, 2005). The authors considered that intensive pesticide use under both IPM and conventional managements may have resulted in a substantial reduction in insect prey availability, hence a reduction in blue tit success.
- A three year French study compared the structure (abundance, species richness and diversity) of breeding bird communities in 15 orchards under conventional or organic pest control. Bird abundance, species richness, and diversity were all highest in organic orchards and lowest in conventional orchards. The pest control strategy affected insectivores more than granivores (Bouvier *et al.*, 2011).
- A study of 109 Herefordshire apple orchards compared traditional orchards (small area, grass understorey grazed by livestock, large widely-spaced trees, few or no sprays) with modern orchards (larger, mown understorey often herbicide treated, densely planted trees on strips of bare soil, often frequent pesticide applications), with both sprayed and non-sprayed orchards within the two orchard types (Crocker *et al.*, 1998). There were significantly more birds counted among fruit trees of unsprayed orchards compared with sprayed orchards. The differences between bird numbers and diversity were much greater when comparing the orchard types, with significantly more birds in the traditional orchards as compared to the modern. The authors highlighted the importance of conserving traditional orchards and orchard hedges to enhance bird numbers.
- The total species richness of birds was greater in organic apple orchards than in conventional orchards in Japan (Katayama, 2016). However, among the three dietary guilds surveyed (insectivore, granivore and omnivore), only insectivorous species were more abundant in organic orchards.
- An Italian orchard study (Genghini *et al.*, 2006) compared 26 conventional, 15 organic and 19 integrated farms (where the use of chemicals is limited although not strictly forbidden and

production systems with a low environmental impact are employed) within one province in north Italy. Orchard types were peach, vineyards, kiwi, pear, apricot, cherry, apple, persimmon and plum. Granivorous bird species were the most abundant and unaffected by the farm system. Insectivorous species were less abundant in general, but more frequent on organic and integrated farms. Bird diversity was greater in organic and integrated farms than conventional. The authors attributed these effects, mostly to the different methods of pest management and secondarily to environmental factors (type of orchard, type of farm, age and height of trees, and increased presence of hedgerows and woodland).

			Effect				
Study Parameter	**Farming System**	**Long Term Study / Years**	**Increase**	**Mixed**	**No Effect**	**Decrease**	**Reference**
Weed cover	Orchards (apple)	3				-	Meng *et al.* (2016)
Weed biodiversity	Orchards (apple and pear)	4	+				Lisek and Sas-Paszt (2015)
Species richness	Orchard (apple)	No	+				Lososová *et al.* (2014)
Biodiversity	Vineyards	No		+/-			Puig-Montserrat *et al.* (2017)
Spider community abundance, species richness, species diversity	Orchard (apple)	No		+/-			Im *et al.* (2015)
Ant abundance, species richness, and predation on moth larva	Orchard (apple)	No	+				Schurr (2017)
Ground insect indicator taxa diversity and density	Orchards (apple)	No	+				Popov *et al.* (2017)
Pollinator richness and abundance	Orchard (apple)	No			|		Alins *et al.* (2016)
Spider and carabid biodiversity and abundance	Vineyards	No		+/-			Caprio *et al.* (2015)
Ant abundance & number	Vineyards	No	+				Masoni *et al.* (2017)
Grasshopper, spider and plant abundance, species richness, community composition	Vineyards	No		+/-			Bruggisser *et al.* (2010)
Great tit young produced per ha	Orchards (apple)	3	+				Bouvier *et al.* (2005)
Breeding bird abundance, species richness, diversity	Orchards (apple)	3	+				Bouvier *et al.* (2011)
Bird diversity	Orchards (apple, plum etc)	No	+				Genghini *et al.* (2006)
Bird species richness and abundance	Orchard (apple)	No		+/-			Katayama (2016)
Bird nest density, breeding performance and nest-site selection	Vineyards	No			|		Assandri *et al.* (2017)

Table 3 Fruit biodiversity summary, comparing the effect of organic farming against conventional

4.2.5 Biodiversity monitoring methods

Following extensive research, the BioBio[6] project suggested that for organic and low-input farming systems for all major farm types (field crops and horticulture, grazing, mixed crops with livestock and permanent crops) the species diversity indicators should be vascular plants, bees, spiders and earthworms (Herzog *et al.*, 2012).

A recent landscape scale report included a review of biodiversity survey techniques (Staley *et al.*, 2016). Field survey protocols were designed for nine species groups, in consultation with taxon experts, together with a framework for rapid scoring of AES implementation.

Biodiversity Summary
Organic agriculture is assumed to have benefits for biodiversity, soil and water as well as providing other public benefits. Studies over the last 30 years have observed that biodiversity generally benefits from organic agriculture, with increases in a range of taxa observed in many cases. However some studies observe mixed effects with increases, no change or decreases in different taxa or species. The increases in biodiversity in organic systems are often attributed to the more heterogeneous nature of organic holdings (including crop diversity, boundary features and wooded areas) rather than at an individual field level. Organic farms may not always have higher biodiversity than comparable conventional farms, becuse other factors, especially landscape, do appear to play a large part in influencing biodiversity. Baseline figures for the number of species or habitats in a region or on a farm are therefore required along with regular biodiversity monitoring of organic CS agreements to provide valuable evidence of the maintenance and increase of biodiversity, especially for conversion farms.

4.3 Literature review results: Soils.

This topic includes potential effects of organic farming on soil chemical, physical and biological properties, in addition to soil erosion. The majority of the relevant soil data found was relevant to both rotational land and grassland and so below there is no separation by crop type for these. The soil data for fruit crops were distinct from the other data and so are discussed separately.

4.3.1 Soil biology/biodiversity effects

The soil contains a great diversity or organisms, including bacteria, fungi, protozoa, nematodes, earthworms and arthropods; these all interact in complex food webs. The abundance and activity of each group is affected by land management and this has effects on soil fertility and resources available for non-soil organisms e.g. insectivorous birds.
An important difference between organic and conventional agriculture is the use of pesticides. The main element of concern in organic agriculture is copper, used for many years as a fungicide in various formulations (Lamichhane *et al.*, 2018). It is, however, in the process of being phased out by the organic certification bodies and other regulators throughout Europe. Conventional pesticides have frequently been shown to have detrimental effects on soil biology (Hicks *et al.*, 1990; Tu, 1990; Banerjee & Banerjee, 1991; Banerjee & Dey, 1992; Tu, 1992; Biederbeck *et al.*, 1997; Taiwo & Oso, 1997; Macalady *et al.*, 1998; Martınez-Toledo *et al.*, 1998; Yardirn & Edwards, 1998; Welp & Brümmer, 1999; Sutton *et al.*, 2014).

[6] http://www.biobio-indicator.org/

4.3.1.1 Vesicular Arbuscular Mycorrhiza

Vesicular-arbuscular mycorrhiza (VAM) can form symbiotic associations with most crop species apart from brassicas. VAM can significantly increase yield, particularly on soils low in available phosphorus. They are also effective in binding soil particles together, improving structure and inhibiting erosion (Gosling *et al.*, 2006). However, the use of fungicides to control crop diseases adversely affect VAM; benomyl is particularly detrimental (Johnson & Pfleger, 1992; Scullion *et al.*, 1998). The use of soluble phosphorus fertilisers in conventional agriculture also suppresses VAM (Mårtensson & Carlgren, 1994). Ozaki *et al.*(2004) found that VAM were consistently more abundant in organic soil than in adjacent conventionally managed soil although it was difficult to relate this effect to available phosphorus concentrations or other soil parameters.

- The effects of dimethoate (an insecticide) and benomyl (a fungicide) on soil organisms and plant growth were studied in microcosms containing agricultural soil and indigenous soil fauna together with introduced invertebrates and barley (Martikainen *et al.*, 1998). It can be concluded that although pesticides had transient effects on micro-organisms and, possibly, some microbivorous animals, their influence on nutrient dynamics was negligible and they did not affect plant growth indirectly.
- The effects on soil microbial biomass and the mineralization of soil organic matter of 19 years of cumulative annual field application of five pesticides (benomyl, chlorfenvinphos, aldicarb, triadimefon and glyphosate) applied at, or slightly above, the recommended rates were investigated by Hart and Brookes (1996). The continuous use of these pesticides, either singly or in combination, were found to have no measurable long-term harmful effects on the soil microbial biomass or its activity, as assessed by C or N mineralization.

Fertilisers containing readily available nutrients are much more widely used in conventional agriculture than in organic systems (with the exception of some intensive horticultural production when animal by-products may be important). Although it has long been suggested that high concentrations of water soluble fertilisers may inhibit the microbial biomass through their salt effects (Cooke, 1982) the published evidence for this appears to be scant. Studies at the Broadbalk Continuous Wheat Experiment carried out by Glendining *et al.* (1996) confirmed that different rates of inorganic N-fertiliser (48, 96,144 and 192 kg N/ha since 1852) had no effect on the soil microbial biomass N or C contents, though there was some positive correlation with the specific mineralization rate of the biomass (defined as N- mineralised per unit of biomass). Although the size of the microbial population appears unchanged, its activity was greater in soils receiving long-continued applications of fertiliser N. It was concluded that measurements of soil microbial biomass can reveal changes brought by soil management long before such changes are detected in total organic N or C content.

Most researchers have reported positive effects of organic farming on soil biodiversity or soil biological activity and this has been discussed in several reviews (Stolze *et al.*, 2000; Shepherd *et al.*, 2003; Hole *et al.*, 2005). Experiments have often been used to develop or test indicators of soil quality (e.g. Bending *et al.* (2004)) and so have sometimes arguably chosen extreme rather than typical examples of each type of agriculture. Attention has been focussed on soil microbiology but soil mesofauna has also been considered:

4.3.1.2 Microbial biomass

Microbial biomass has been most commonly measured by chloroform fumigation followed by extraction and analysis of C and N (for example, Fließbach *et al.* (2007)). Direct counting and phospholipid fatty acid (PLFA) analysis is also possible to give an estimate of the bacterial and fungal biomass (Birkhofer *et al.*, 2008).

4.3.1.3 Microbial activity

Microbial activity is usually estimated by measuring the respiration rate of soil, by determining the CO_2 production in incubated samples (for example, Birkhofer *et al.* (2008)). This may be done directly or after the addition of a new substrate such as glucose or an organic material to see how rapidly the microbial activity can respond. The activity of a range of enzymes, released into the soil by microorganism have often been used as an indicator (for example, (García-Ruiz *et al.*, 2008)). Shannon *et al.* (2002) used measurements of ATP and detection of ribosome-rich cells using Fluorescence *in situ* Hybridisation (FISH) analysis, and concluded that changes in soil microbiology may occur as a consequence of converting to organic land management, but these may not be detectable by other methods used frequently to assess soil biomass .

4.3.1.4 Microbial diversity

Microbial diversity has been assessed by evaluating the ability of soil populations to utilise a range of substrates on 'Biolog' plates (Bending *et al.*, 2004). More recently molecular biological approaches have been used; pyrosequencing of bacterial and fungal ribosomal markers revealed differences in the soil microbial community structure in the long term DOK trial (Hartmann *et al.*, 2015).

4.3.1.5 Nematodes

Nematodes are important in nutrient cycling and some can damage crop plants. Scow *et al.*(1998) found that numbers of plant parasitic nematodes were consistently lower in organic and low input systems. A review by Hole *et al.*(2005) reported mixed effects of organic management on nematode abundance and diversity.

4.3.1.6 Earthworms

Earthworms have a crucial role in decomposition and nutrient cycling processes and the modification or soil physical properties. Both numbers and abundance of a range of species have been assessed under different management conditions but an issue is distinguishing seasonal effects from long term changes. Earthworms have usually been found to be more abundant in organic than in conventionally managed soil (Gerhardt, 1997; Siegrist *et al.*, 1998). However, cultivation is detrimental, especially to the larger deep burrowing worm species and ploughing is important in organic arable production to control weeds; Moos *et al.* (2016) found that occasional reduced tillage could be used to restore populations without detrimental effects on yields. Hole *et al.*(2005) concluded that the effect of organic compared to conventional management on earthworms depended very much on the circumstances.

4.3.1.7 Soil Arthropods

Soil arthropods are often responsible for the initial stages of breakdown of crop residues, increasing the surface area available to bacteria and fungi. They are also an important link in the food chain of larger animals. Parisi *et al.* (2005) developed the 'QBS' (Qualità biologica del suolo/ Biological quality of soil) scoring system to assess the types of edaphic microarthropods in soil samples; they found that biodiversity was enhanced in organic farming systems – the highest QBS scores were obtained from grassland and perennial crops.

Examples of refereed papers describing the effects of organic vs conventional farming on soil biology are shown in Table 4.

Study Parameter	Farming System	Long Term Study / Years	Effect: Increase	Mixed	No Effect	Decrease	Reference
Biological activity	Arable	7	+				Marinari *et al.* (2006)
Soil microbial biomass	Field vegetable	No		+/-			Robertson and Morgan (1996)
Soil microbial biomass and activity	Arable	No		+/-			Kirchner *et al.* (1993)
Soil microbial biomass and activity	Arable	20	+				Fließbach *et al.* (2007)
Soil microbial biomass and activity	Arable	27	+				Birkhofer *et al.* (2008)
Soil microbial activity	Arable	No		+/-			Shannon *et al.* (2002)
Soil faunal and microbial diversity	Grassland	No		+/-			Yeates *et al.* (1997)
Soil microbial activity and diversity. Phospholipid fatty acid profiles, microbial biomass	Arable	10	+				Bossio *et al.* (1998)
Soil microbial diversity	Arable and grassland	No		+/-			Elmholt (1996)
Soil microbial abundance and diversity. Bacterial feeding nematodes	Arable	10	+				Gunapala *et al.* (1998)
Micorrhizae spores	Arable	No	+				Ozaki *et al.* (2004)
Microarthropods	Various	No	+				Parisi *et al.* (2005)
Microarthropod diversity	Arable	No	+				Parisi *et al.* (2005)
Collembolan abundance	Arable	No	+				Schrader *et al.* (2006)
Soil microbial composition	Arable and vegetable	5	+				Martini *et al.* (2004)
Microbial and biochemical activity	Arable	5	+				Bending *et al.* (2004)
Soil respiration after rewetting	Arable	10	+				Lundquist *et al.* (1999)
Soil quality	Various	No	+				Schjønning *et al.* (2002)
Soil carbon	Arable	8	+				Clark *et al.* (1998)
Soil carbon	Arable	No	+				Lewis *et al.* (2011)
Soil organic carbon	Various	No	+				Gattinger *et al.* (2012)
Soil organic matter	Arable	No		+/-			Gosling and Shepherd (2005)
Soil organic matter pools	Arable	10	+				Wander *et al.* (1994)
Soil organic matter fractions	Various	5	+				Marriott and Wander (2006)
Soil organic matter fractions	Arable and grassland	No	+				Pulleman *et al.* (2003)
Potentially mineralisable N	Arable	10	+				Gunapala and Scow (1998)
Nitrogen mineralisation potential	Tomatoes	No	+				Drinkwater *et al.* (1995)

Table 4 Some literature regarding the effects of soils in organic rotational and grassland systems compared to conventional

4.3.2 Soils and fruit production

The relevant literature found regarding soils and fruit production is shown Table 5. In general, the soil biodiversity results concur with those of the rotational and grassland studies discussed above.

			Effect				
Study Parameter	**Farming System**	**Long Term Study / Years**	**Increase**	**Mixed**	**No Effect**	**Decrease**	**Reference**
Soil total C and N, microbial biomass and activity	Strawberry fields	No	+				Reganold *et al.* (2010)
Soil organic C, total N, microbial biomass carbon, earthworms	Orchards (apple)	3	+				Meng *et al.* (2016)
Soil chemical and microbial properties	Orchards (apple)	No	+				Lee and Chung (2007)
Soil insect indicator taxa diversity and density	Orchards (apple)	No	+				Popov *et al.* (2017)
Soil nutrient concentration, microbial diversity and density	Orchards (apple and peach)	No		+/-			Pokharel and Zimmerman (2016)
Soil taxa density and diversity	Orchards (apple)	3		+/-			Kostadinova and Popov (2015)
Soil microbiological indices, soil respiration	Vineyards	No		+/-			Probst *et al.* (2008)
Soil microbial biomass and enzyme activity	Vineyards	No	+				Okur *et al.* (2009)
Soil organism activity	Vineyards	No	+				Reinecke *et al.* (2008)
Soil biodiversity	Vineyards	No	+				Wheeler and Crisp (2009)
Soil physical properties	Vineyards	No		+/-			Beni and Rossi (2009)
Soil pH and P	Vineyards	9		+/-			Erdal *et al.* (2016)
Soil physical, chemical and biological parameters	Vineyards	No		+/-			Coll *et al.* (2011)
Soil quality, earthworm abundance	Vineyards	6	+				Penfold *et al.* (2015)
Soil nematode density, microbial biomass	Vineyards	No	+				Coll *et al.* (2012)
Fungal community species and abundance	Vineyards	No		+/-			Morrison-Whittle *et al.* (2017)

Table 5 Summary of fruit references related to soil in organic systems compared to conventional.

4.3.3 Soil organic matter and its effect on soil physical properties

Soil organic matter (SOM) is vital to the functioning of soil ecosystems, providing energy, nutrients and maintaining aggregate stability and soil structure. High organic matter levels are also associated with wider environmental benefits such as reduced soil erosion and better water holding capacity. The management of SOM is central to the maintenance of fertility in organic farming systems; it is built up in the 'fertility building' phase of arable and field vegetable rotations by the inclusion of green manures or leys (Lampkin, 1990; Davies & Lennartsson, 2005; Briggs, 2008). The inclusion of legumes in a rotation, to ensure the provision of nitrogen by fixation from the atmosphere is specified in the organic regulations (Commission Regulation (EC) No. 889/2008 of 5 September 2008).

There is a large body of evidence to indicate that, overall, organic farming practices can result in increased levels of SOM (Stolze *et al.*, 2000). Soil organic matter can be determined in a number of ways – most commonly this is by 'loss on ignition' but organic carbon can also be specifically measured and the organic matter can be chemically or physically separated into stable and labile fractions. Some authors also reported associated changes in soil physical properties:

- Datasets from 74 studies from pairwise comparisons of organic and nonorganic farming systems were subjected to meta-analysis to identify differences in soil organic carbon (SOC) showing that organic farming has the potential to accumulate soil carbon. SOC differences seemed to be mainly influenced by elements of mixed farming (livestock plus crop production), such as organic matter recycling and forage legumes in the crop rotation. It is therefore likely that SOC concentrations and stocks under modern agriculture could be improved if these measures were adopted (Gattinger *et al.*, 2012).
- Marriott and Wander (2006) studied nine established farming systems trials that have comparisons of organic and conventional farming systems. Use of organic farming practices increased the SOC concentrations of surface soils by 14% compared with conventional counterparts. Legume-based and manure legume-based organic management resulted in similar increases in SOM concentrations compared to conventional systems. Of the two labile SOM fractions examined, the particulate organic matter (POM) fraction, which was enriched by 30 to 40% in organic systems, was more sensitive to organic management.
- Within one soil series in the Netherlands, three different farming systems were selected, including a conventional and an organic arable system and permanent pasture without tillage (70 years of different management). Total SOM contents between 0 and 20 cm depth amounted to 15, 24 and 46 g kg^{-1} for the conventional arable, organic arable and permanent pasture fields, respectively (Pulleman *et al.*, 2003).
- Raupp (1995a) described a long-term plot experiment which began in 1980 in Germany to compare conventional (mineral fertiliser only), organic (cattle manure and urine) and biodynamic (as organic but including biodynamic preparations) at three N rates through the rotation; SOM increased in the order conventional (0.79% C) < organic (0.92% C) < biodynamic (1.02% C) after ten years of treatments.
- Armstrong-Brown *et al.* (1995) measured SOM in 30 pairs of organic and conventional farms in the UK; pasture farms had the highest levels of SOM but for this enterprise it was not possible to differentiate between conventional and organic farms. On horticultural holdings, organic farms had the larger SOM levels because of the more frequent manuring. Arable organic farms had more SOM than conventional equivalents because of more manure and the use of leys.
- Clark *et al.* (1998), in the USA, measured more SOM in organic and low-input systems as compared to conventional in a four year plot experiment, which may be in part a result of higher inputs of C due to cover cropping and manure applications.
- Raupp (1995b) described a Swedish long-term experiment (1958-1990) comparing biodynamic treatments (manures and additional preparations) with conventionally fertilised treatments. There were clear benefits to total SOM from the manure applications, but there were no clear differences in soil structure.

  (Fließbach *et al.* (2007) stated that soil organic matter in farming systems of the Swiss DOK trial was positively affected by manure amendment after 21 years of plot management. Microbial biomass and activities were enhanced in organic systems emphasizing the important role of element cycling processes that are supported by an abundant and active soil biological community.

- Reganold (1995) undertook a study in which 16 fields of biodynamic or conventional commercial farms were compared in a paired study in New Zealand. This produced highly significant differences in total topsoil organic carbon and a range of physical parameters (lower bulk density, lower penetration resistance deeper topsoil and a better structural index score in the biodynamic system) (Reganold & Palmer, 1995).
- Reganold (1988) reported a similar paired study on a conventional and organic farm in the USA. Again, the organically managed soil had significantly higher SOM and a significantly lower modulus of rupture, more granular structure, less hard and more friable consistence and 16 cm more topsoil (due to erosion on the conventional farm). The difference in erosion rates was due to different crop rotation systems and different tillage practices.
- Gerhardt (1997) compared two adjacent paired farms in Iowa, USA, one managed according to organic and the other according to conventional methods; there were marked structural differences between the A horizons of the two farms. The A horizon of the organic farm had a noticeably darker colour, significantly greater depth, significantly higher SOM, coarser and better developed granular peds and a greater amount and range of pores and pore sizes. The organic sites had larger and more active earthworm populations, with more castings and burrows.
- Gardner and Clancy (1996) compared four fields (prairie, conventional, organic and no-till) in three contrasting regions of The Great Plains. Depth of topsoil, bulk density and organic matter content were the soil quality parameters tested. On the organic farms these generally scored better than the conventional counterparts, though differences were rarely statistically significant.
- Droogers and Bouma (1996) compared biodynamic and conventional fields in a paired study in the Netherlands. Not only did they compare soil parameters but also simulated yields using long-term weather data to assess the production potential of the respective soils. Organic matter contents were significantly higher in biodynamic fields. The overall impression was that structural differences were relatively small. Compaction appeared to be more pronounced in the conventional fields. It was thought that the relatively small structural differences were due to similar tillage equipment used on both farms.
- Løes and Øgaard (1997) investigated twelve dairy farms across Norway. Significant increases in total-C and total-N concentrations were found in soils with <1.7% total-C, showing that soils with an initially low content of organic matter can be enriched by organic farming.

However, other authors have failed to demonstrate organic matter increases associated with organic farming. This could be because conventional crop yields are higher and so they also leave more residues in the soil. An active microbial population in the organic soil will also encourage rapid mineralisation and so loss of organic matter added from fertility building crops and manure:

- Gosling and Shepherd (2005) examined four paired organic and conventional farm sites but found no overall difference in organic matter levels between organic and conventional management.
- Marinari *et al.* (2006) compared seven years of side by side organic and conventional management in replicated trials but found no effect on organic matter although there was greater microbial activity (in terms of biomass and enzymes).

Although SOM is often implicated when differences are reported in soil physical condition these are really due to a combination of farming practices (cropping, inputs and cultivation). The benefits of minimal tillage are generally acknowledged (Silgram & Shepherd, 1999) but this practice is difficult under organic conditions where ploughing is often relied upon for weed control. Schjønning *et al.*(2002) found, in a long term comparison of organic and conventional systems, that the positive effects of organic manures and diversified crop rotations on soil quality were compromised by heavy machinery resulting in compaction in both management regimes.

Any rise in SOM will have the effect of sequestering atmospheric CO_2, at least in the short term. Shepherd *et al.* (2003) concluded that although organic farming had the potential to increase soil carbon much depended on the balance of individual systems and that any additions would be insignificant on a global scale.

4.3.4 Soil erosion

An EU-focussed report highlighted that organic farming has a high erosion control potential (Stolze *et al.*, 2000), and a more recent review highlighted that wind and water erosion, and runoff, are all reduced in organic farms relative to comparable conventional agriculture (Lotter, 2003).

- In a paired field study of arable systems in Washington (USA) following 30 years of contrasting management there was four times less water erosion of soil in the organic system (Reganold *et al.*, 1987). This was associated with higher soil organic matter and bacterial polysaccharides that bind soil particles together; the difference was ascribed to the greater use of fertility building crops rather than fertilisers in the organic rotation.
- In a long-term field study of arable cropping in Switzerland (the DOK trial) a mixture of field and laboratory methods to assess erosion potential were used 15 years after contrasting management techniques were first employed (Siegrist *et al.*, 1998). Organic soil had the greatest aggregate stability and this was correlated with high earthworm numbers, perhaps resulting from the use of manure rather than mineral fertilisers. However, under conditions of high summer rainfall typical of the area all the soils were still subject to erosion, so additional measures to minimise it may be needed.
- On an experimental farm in Bavaria soil erosion from conventional fields was measured at 2.5t/ha/yr in contrast to only 0.2t/ha/yr from organically managed ones (Siebrecht & Hülsbergen, 2008). The authors believed that this difference was due to higher soil organic matter levels resulting from the greater use of manure and leys and the absence of pesticide that could have a negative effect on microbe-mediated soil aggregation.
- Morvan *et al.* (2018) investigated an arable farming system in France using a paired field study. They showed that three years of organic management had no effect on soil bulk density, soil water retention or hydraulic conductivity. However, aggregate stability was increased in the organic field and the tendency to soil crusting was reduced. This led to a reduction of soil erosion under conditions of simulated rainfall.

There are a range of studies focussing on soil erosion and runoff in vineyards, due to placement on steep slopes, use of heavy machinery and cultivation practices such as keeping inter-rows bare throughout the year.

- In steep vineyards in Germany, use of grass strips and hand hoeing between vine rows in an organic system reduced soil erosion compared to a conventional vineyard which used mechanical weed management (Kirchhoff *et al.*, 2017).
- In a German and Spanish vineyard study, higher erosion rates were observed in conventional vineyards with low vegetation cover and use of heavy machinery as compared to organic vineyards with higher vegetation cover, use of mulches and hand rather than mechanical management (Comino *et al.*, 2016).

4.3.5 Flooding

Agricultural production is currently the dominant land use in most floodplains (Posthumus *et al.*, 2010) and the reinstatement of flooding of meadows has been proposed as a means of climate change adaptation to protect settlements downstream. The question for this review is whether land in organic production will differ from conventional production in terms of water storage and quality. Increased soil organic matter, often linked with organic farming practices, is associated with increased water holding capacity and better water infiltration, reducing water run-off. Both effects are likely to reduce flood risk. There was a dearth of literature specifically comparing the flooding or drought resilience of organic and conventional systems. However, in a review Gomiero *et al.* (2011) noted higher water-holding capacity of soils under organic management. It has been assumed but not demonstrated that water that is held on organic land will gain less pesticide and herbicide residues.

Summary for Soil

Most literature on organic compared to conventional farming reports greater levels of soil organic matter in organic systems but this is not always the case - organic rotations include a greater proportion of 'fertility building crops' (green manures and leys) that add organic matter to the soil but the higher yields in conventional systems can be associated with greater crop residue additions. Although there are exceptions organically farmed soils usually show greater biological activity and biodiversity.

Soil biodiversity is negatively affected by herbicides, insecticides and fungicides and it is assumed that organic farming will be beneficial with many studies showing there are benefits to a wide range of taxa including Vesicular Arbuscular Mycorrhiza.

Copper, used as an 'organic' fungicide has been highlighted as having toxic effect on soil life but its use is in the process of being phased out. Earthworms have been generally found to be more abundant under organic conditions; ploughing is, however, detrimental to them and the increased use of minimal cultivation (difficult to achieve organically) could change this.

Management practices associated with organic farming have the potential to prevent soil erosion and several studies have shown this to be the case.

Both higher SOM and less soil erosion in organic farming could make the use of organic land for flood alleviation programmes more effective although there are no studies that prove this.

4.4 Literature review results: Water quality.

Organic farms generally make greater use of animal manures than conventional ones which has led to concerns about the risks of contamination but the organic standards encourage treatments such as composting that should minimise this.

Most research concerning water quality has been done in arable or mixed farming systems; the effects of agriculture (apart from point source pollution, for example from leaking slurry stores) is usually aggregated across an area and it may take many years for a change in management practice to become evident in water abstracted from the ground. Vincent and Fleury (2015) describe four case studies in which incentives to promote organic farming in France had been promoted as a measure to improve water quality.

Within grassland systems the level of sediment and nutrient leaching can depend on the livestock type. The Agricultural Research Group on Sustainability (ARGOS) in New Zealand has looked at many different conventional, integrated and organic farming cropping and livestock systems (Maegli *et al.*, 2007). Stream health was highly variable for both beef/sheep and dairy farms between farms, clusters (location) and systems. Consequently, very few significant differences were detected in measured parameters between systems (conventional, integrated and organic). The study did show:

- higher levels of nutrients (nitrate and nitrite, ammonium, dissolved reactive phosphorus, and total phosphorus) in waterways on dairy farms than beef/sheep farms
- higher average concentrations of total organic carbon and organic and total sediment, and turbidity levels on sheep/beef farms than dairy farms.

The study highlighted that AES are important tools for minimising impacts on water courses, with measures such as exclusion fencing, riparian planting and crop rotation management, but there were not statistical differences between organic and conventional farms.

4.4.1 Nitrate leaching

Nitrogen in the form of nitrate is readily soluble in water and, being negatively charged, this is not held on cation exchange sites in the soil. Any excess is therefore readily lost by leaching, especially over the winter period when the field capacity of the soil is exceeded. High concentrations of nitrate in ground and surface water is of environmental concern because it can result in eutrophication and contamination of drinking water (The EU Nitrate Directive[7] sets a limit of 50mg nitrate per litre).

A lot of work concerned with nitrate leaching was conducted in the UK and other parts of Europe in the 1990s in order to understand the implications on farming practices of the introduction of Nitrate Sensitive Areas – there was particular concern about the use of animal manures on organic farms (Unwin & Smith, 1995). In the UK Stopes *et al.* (2002) concluded that losses from organic systems are similar to or slightly smaller than those from conventional farms following best practice and this has been the conclusion of a number of reviews (Stolze *et al.*, 2000; Kirchmann & Bergström, 2001; Shepherd *et al.*, 2003). Tuomisto *et al.* (2012) conducted a meta-analysis of 48 studies and found that the median nitrate leaching was 31% lower in organic systems when expressed by area of land although, because of lower yields, it was higher when expressed by unit of product. Organic farming incorporates a number of practices that are known to minimise leaching such as the use of winter cover crops (Farthofer *et al.*, 2004; Olesen *et al.*, 2004; Pandey *et al.*, 2018). However, the ploughing of short term leys, common in organic arable and field vegetable systems, can result in high leaching losses if the mineralisation of the incorporated organic matter is not matched to the uptake of the crops (Torstensson *et al.*, 2006). Loges *et al.* (2006) concluded that a "comprehensive assessment of land use systems at both the regional and farm scale was needed to legitimise incentive payment of the adoption of organic farming standards". High losses associated with ploughing of leys were also found in a UK study (Philipps & Stopes, 1995), but the authors considered that this was offset by low levels of leaching in other phases of the rotation.

Most researchers have used ceramic cups to sample soil nitrate concentrations, a method that works particularly well in sandy soils most prone to leaching (Lord & Shepherd, 1993). Modelling has also been used and this is obviously much less expensive as a monitoring system. Hansen *et al.* (2000) found that modelled nitrogen leaching from organic rotations was always lower than from conventional ones but described how the modelling of leaching has many uncertainties. Several models have been developed to aid nutrient management in organic farming systems, including making estimations of leaching losses. The NDICEA model is described by Van der Burgt *et al.* (2006) and the EU-Rotate_N by Rahn *et al.* (2010).

[7] Council Directive 91/676/EEC of 12 December 1991

Study Parameter	Farming System	Long Term Study / Years	Effect: Increase	Mixed	No Effect	Decrease	Reference
Nitrate leaching	None	No		+/-			Kirchmann and Bergström (2001)
Nitrate leaching	Arable and Dairy	No				-	Philipps and Stopes (1995)
Nitrate leaching	Arable and mixed	5		+/-			Loges *et al.* (2006)
Nitrate leaching	Mixed	10	+				Torstensson *et al.* (2006)
Nitrate leaching	Arable	10			|		Pandey *et al.* (2018)

Table 6 Summary of water quality references (note a decrease in nitrate leaching is desirable)

4.4.2 Losses of other nutrients

Loss of phosphorus from agricultural land is much less than nitrate losses but can still be of concern as it can contribute to eutrophication. Phosphorus is usually lost through movement of soil particles rather than by leaching - greater organic matter levels and practices such as winter cover cropping should minimise soil erosion from organic farms but there has been little comparative study of P loss. In a review Shepherd *et al.* (2003) reported no evidence for a difference between organic and conventional farming systems but believed the risk of losses to be smaller because of lower P inputs. Tuomisto *et al.* (2012) found higher losses from organic farming in only one study out of ten that were reviewed.

4.4.3 Pesticides

Synthetic pesticides are not permitted in organic systems and so this type of agriculture would not be expected to contribute to water pollution (Shepherd *et al.*, 2003). Some pesticides (e.g. atrazine) can persist for a long time after they were last used and Schrack *et al.* (2009) described a long term study set up to follow their fate after conversion to organic farming. Concerns have been expressed about the use of copper compounds, used as an organic fungicide (e.g. against potato blight, in orchards and in vineyards). It is, however, in the process of being phased out from organic standards.

Summary for water quality

Nitrate leaching is generally less from organic than from conventional farming systems but more modern (lower) fertiliser recommendations for conventional farmers might also make the distinction less clear cut. Phosphorus is usually lost through movement of soil particles rather than by leaching - greater organic matter levels and practices such as winter cover cropping should minimise erosion from organic farms but there has been little comparative study of P loss. Pesticides with the exception of copper (which is in the process of being phased out) should not affect water quality as run-off from organic farms.

4.5 Climate change

Countryside Stewardship and previously Environmental Stewardship, have both included climate change as a priority, with a focus on mitigation and adaptation. Mitigation focuses on removing the causes of climate change such as greenhouse gas emissions and improving retention and sequestration of carbon in soils and vegetation (Natural England, 2012). In contrast, adaptation makes changes (e.g. ensuring a variety of habitats) to prepare for, and negate, the effects of climate change, thereby reducing the vulnerability of communities and ecosystems, and hence providing climate change resilience (Figure 1).

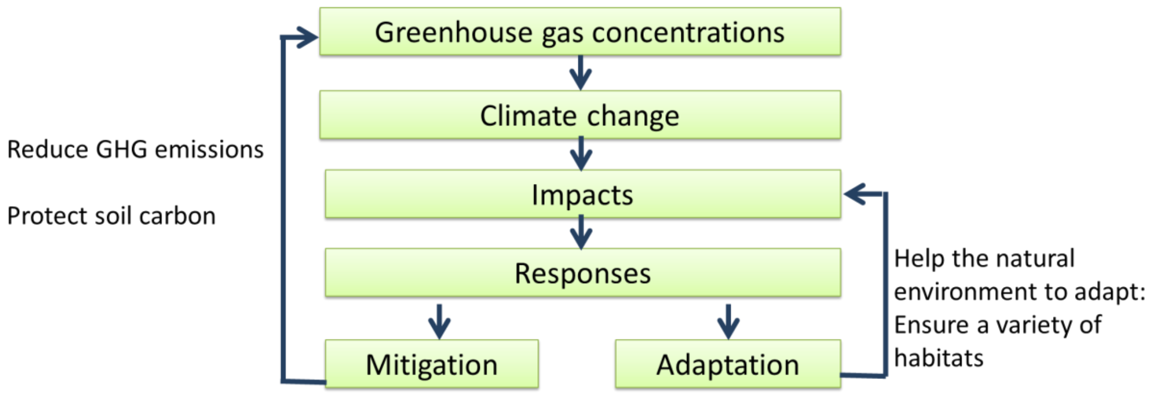

Figure 1. Schematic diagram showing the difference between mitigation and adaptation to climate change. After Locatelli (2011)

4.5.1 Climate change mitigation: Greenhouse gas and ammonia emissions

The three most important greenhouse gases (GHG) related to agricultural activities are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Ammonia (NH_4) is also a gaseous pollutant which causes negative environmental effects through nitrogen release and soil acidification (Stolze *et al.*, 2000). Reduction of the emissions of ammonia is a key priority for Defra (Defra, 2018a) and this will also be considered in this section.

Agriculture is responsible for approximately 10% of greenhouse gas emissions in the EU - 28 countries plus Iceland. Most of this 10% share is generated by methane from enteric fermentation and nitrous oxide emissions from fertiliser use and manure management (Müller *et al.*, 2016). A review (Scialabba & Müller-Lindenlauf, 2010) considers the mitigation potential of organic farming on a global scale (Table 7), highlighting the mitigation potential of avoiding the use of mineral fertilisers and reduction in N_2O from soils.

In many studies, the ratio of organic and conventional farm GHG emissions are considered both per unit area and per unit product. A range of meta-analyses and reviews have observed that organic farming tends to score equal or better than conventional farms when GHG emissions are expressed per unit area (Mondelaers *et al.*, 2009; Skinner *et al.*, 2014; Lee *et al.*, 2015). One of the main influences is the prohibition of chemical fertilizers and pesticides (high levels of GHG emissions during manufacture) in organic farming (Mondelaers *et al.*, 2009), with other factors more prevalent in organic systems including the lower stocking density, use of legumes in rotations (Williams *et al.*, 2006) and returning crop residues to the soil (Goh, 2011).

Source of GHG	Share of total anthropogenic GHG emissions	Impacts of optimized organic management	Remarks
Direct emissions from agriculture	**10–12%**		
N_2O from soils	4.2%	Reduction	Higher nitrogen use efficiency
CH_4 from enteric fermentation	3.5%	Opposed effects	Increased by lower performance and lower energy concentration in the diet but reduced by lower replacement rate and multi-use breeds
Biomass burning	1.3%	Reduction	Burning avoided according to organic standards
Paddy rice	1.2%	Opposed effects	Increased by organic amendments but lowered by drainage and aquatic weeds
Manure handling	0.8%	Equal	Reduced methane emissions but no effect on N_2O emissions
Direct emissions from forest clearing for agriculture	**12%**	Reduction	Clearing of primary ecosystems restricted
Indirect emissions			
Mineral fertilizers	1%	Totally avoided	Prohibited use of mineral fertilizers
Food chain	?	(Reduction)	Inherent energy saving but still inefficient distribution systems
Carbon sequestration			
Arable lands		Enhanced	Increased soil organic matter
Grasslands		Enhanced	Increased soil organic matter

Table 7 Mitigation potential of organic agriculture (Scialabba & Müller-Lindenlauf, 2010)

A summary of GHG emissions for a range of agricultural and natural systems is illustrated in Figure 2, showing that when a specific crop eg winter wheat or grassland for silage is compared on an area basis, the overall GHG emissions in the organic system are lower. A range of relevant studies comparing GHG emissions of organic to conventional farming are summarised below:

- By conversion to organic farming, approximately 20 percent of the agricultural GHG could be reduced by abandoning industrially produced nitrogen fertilizers (Niggli *et al.*, 2009).
- A recent meta-analysis observed that organic farming GHG emissions on an area basis were more likely to be lower than conventional farming for studies where conventional mono-cropping was compared to organic multi-cropping and for crops other than fruits and vegetables (Lee *et al.*, 2015).
- Higher GHG emissions were seen in organic crop rotations with a large proportion of high-value crops, relatively high nutrient inputs and frequent field operations including mechanical weeding (Bos *et al.*, 2014).
- When the GHG emissions per output/unit product are considered, some authors observe no differences between organic and conventional wheat production (Mondelaers *et al.*, 2009; Gomiero *et al.*, 2011).
- Jespersen *et al.* (2017) observed that across a large number of studies, GHG emissions per produced unit are comparable between organic and conventional crops with some studies showing higher emissions in conventional crops and others the reverse.
- Organic wheat for bread production was observed to have higher GHG emissions per unit product than conventional (Chiriacò *et al.*, 2017).
- In a German farm-level GHG emission study which included arable and grassland, the organic farm had reduced emissions per hectare as compared to a conventional farm, but yield-related emissions were not reduced (Flessa *et al.*, 2002).
- In a European meta-analysis Tuotismo *et al.*(2012) observed that in most of cases, organic milk production in Europe had higher GHG emissions compared with conventional systems. Higher GHG emissions in organic systems were due to higher methane and nitrous oxide emissions and lower milk production per animal. In contrast, organic beef production was found to have lower GHG emissions compared to conventional due to lower emissions from industrial inputs.

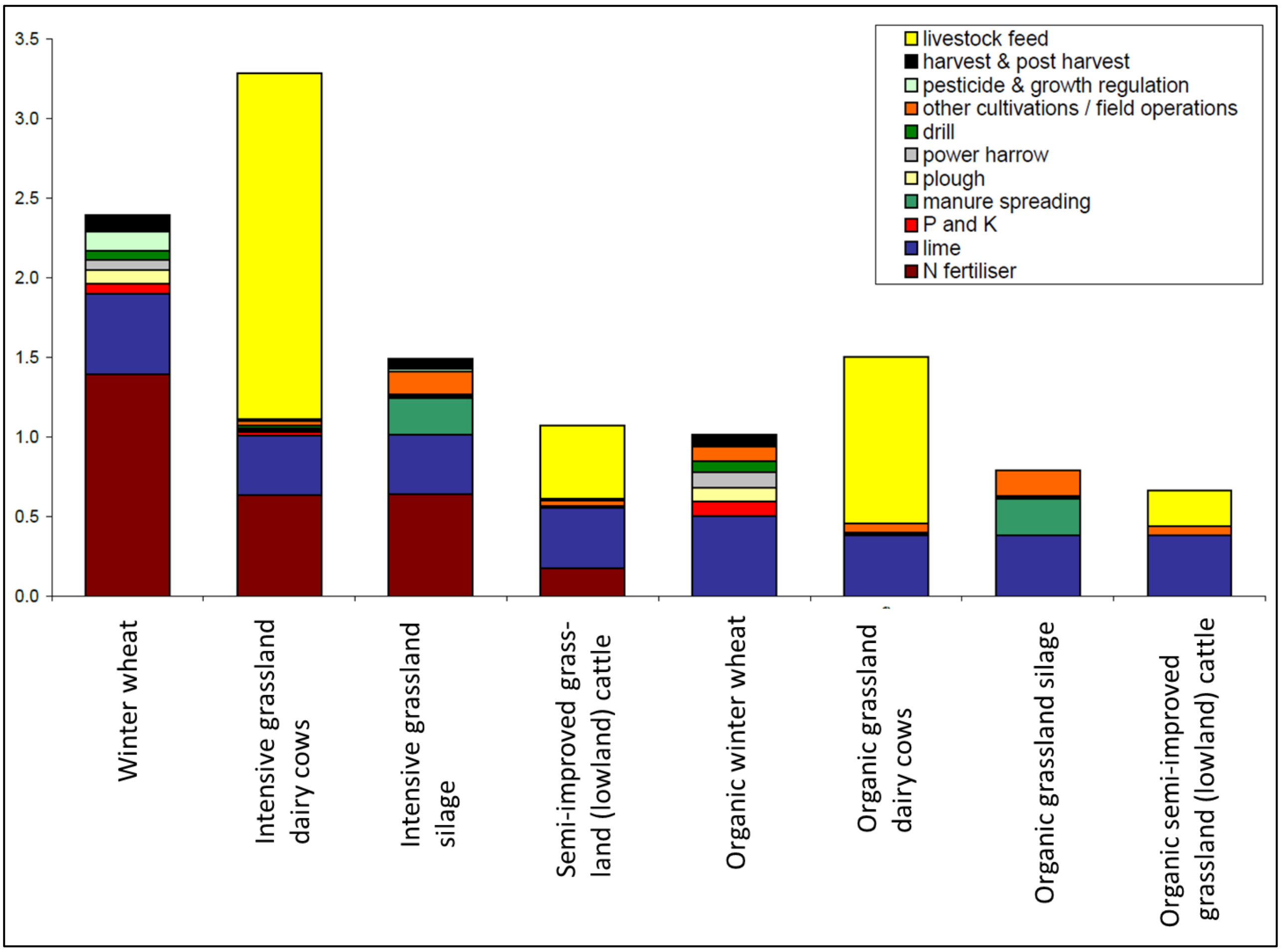

Figure 2 The GHG emissions (t CO_2e ha^{-1} $year^{-1}$) for a range of farm systems including organic (on right hand side) (Defra, 2007)

4.5.1.1 Nitrogen emissions: Ammonia and nitrous oxide

Nitrogen, in the form of ammonia, is lost from agriculture mainly via volatilization and runoff (Müller *et al.*, 2016). For example, ammonia emissions occur from organic manures such as slurry, solid manure and litter, digestate, sludge and compost when they come into contact with air, particularly on warm or windy days, and may also be lost from manufactured fertilisers during spreading (Defra, 2018a). Studies comparing organic to conventional ammonia emissions include:

- Tuomisto *et al.* (2012) reported 18% lower ammonia emissions/ha in organic systems compared to conventional systems, but 11% higher emissions per kg product.
- Jespersen *et al.* (2017) observed that the main environmental consequences of organic livestock production are ammonia loss and risks of eutrophication due to the wider requirements for feeding and housing livestock (outdoor access, larger space requirement, roughage and organic feed).
- Shepherd *et al.* (2003) considered that organic pigs and poultry will have similar ammonia emissions per animal to conventional outdoor units but lower stocking densities will reduce emissions on an area basis.

Within agricultural systems, nitrous oxide (N_2O) emissions arise from soils, manures and during the manufacture of nitrate fertilisers (Defra, 2007). There are a range of factors which influence fertiliser derived N_2O emissions, including management practices and environmental factors, as highlighted in Table 8.

- N_2O emissions from agriculture are estimated from N inputs using emission factors, and little is known about the importance of regional or management-related differences (Petersen *et al.*, 2006).
- In conventional systems mineral fertilizers cause direct N_2O emissions in the range of 10% of agricultural GHG emissions (Scialabba & Müller-Lindenlauf, 2010).
- Within organic farming N_2O emissions are more likely to come from manure and from waterlogging of soils where there is a legume crop (Shepherd *et al.*, 2003).
- N_2O emissions on organic farms tend to be lower on a per hectare basis (Müller *et al.*, 2016).

Management practices	**Environmental factors**
Fertiliser type	Temperature
Application rate	Precipitation
Application technique	Soil moisture content
Timing of application	Oxygen availability
Tillage practices	Porosity
Use of other chemicals	pH
Crop type	Freeze and thaw cycle
Irrigation	Microorganisms
Residual N and C from crops and fertiliser	

Table 8 Key factors affecting fertiliser derived N_2O emissions (Eichner, 1990)

A range of studies consider nitrogen emissions as a whole for the farm, on an area or yield basis:

- A recent IFOAM report (Müller *et al.*, 2016) commented that on organic farms, nitrogen levels per hectare tend to be lower than on conventional farms due to the ban on mineral nitrogen fertilizers, the focus on closed nutrient cycles and the efforts to minimize losses through runoff, volatilization and emissions. Livestock densities also tend to be better adapted to the resources available on the farm itself than is the case with conventional farms.
- Due to the yield gap between organic and conventional agriculture, nitrogen emissions per kilogram tend to be higher in organic than conventional agriculture. Tuomisto *et al.* (2012), report about 30% lower median nitrous oxide emissions from fertilized soils per area in organic systems, while the impact per unit of product was 8% higher than in conventional farming systems.
- Inconsistencies in the modelling underlying many life-cycle assessment (LCA) studies have been highlighted as not adequately capturing nitrogen dynamics in organic systems, with potential to overestimate emissions on a per kg product basis, and by correcting this, the per kg product emissions are not necessarily higher in organic systems (Meier *et al.*, 2015).

4.5.1.2 Methane

About 75% of methane on farms is emitted directly from ruminant animals.

- Organic diets tend to be high in roughage and low in easier to digest concentrates, and this generates higher rates of methane. Methane emission per unit of livestock product decreases as the intensity of animal production increases (two cows producing 5,000 litres of milk will generate more methane than one cow producing 10,000 litres) (Shepherd *et al.*, 2003).
- Organic animal farming has a lower animal stocking rate per hectare, but a higher use of roughage feed per cow, which will influence differences in methane emission (Mondelaers *et al.*, 2009).
- A review of data estimated that organic farming has a lower CH_4 emission potential on a per hectare basis although CH_4 emissions per kg of milk are estimated to be higher in organic dairy farms than in conventional ones (Stolze *et al.*, 2000).

Several authors highlight the potential to process manures via anaerobic digestion to reduce methane emissions (Goh, 2011), which a number of both conventional and organic UK farmers are already undertaking.

4.5.1.3 Carbon dioxide

On a per hectare scale, organic farming has been observed to have positive effects on CO_2 emissions, predominantly due to zero use or lower use of farming inputs produced with high energy consumption as compared to conventional systems such as: no input of mineral N-fertilisers; Lower use of feedstuffs (concentrates); lower input of mineral fertilisers (P, K); and elimination of pesticides (Stolze *et al.*, 2000; Sartaj *et al.*, 2013)

Further publications considering CO_2 emissions:

- Net emissions of CO_2 from agriculture depend upon use of fossil fuel and the amount of carbon sequestration in soil organic matter (Shepherd *et al.*, 2003).
- Stolze *et al.* (2000) reviewed research on CO_2 emissions, and found that, on a per-unit output basis, the CO_2 emissions tended to be higher in organic systems.
- There are little differences in direct input of energy such as ploughing, cultivation, sowing and harvesting which are largely similar for all systems, although mechanical weed control is predominantly an organic practice (Kukreja & Meredith, 2011).

4.5.1.4 Soil carbon storage

- The highest mitigation potential of organic agriculture lies in carbon sequestration in soils and in reduced clearing of primary ecosystems (Scialabba & Müller-Lindenlauf, 2010) although primary ecosystems do not really exist in England. The total amount of mitigation is difficult to quantify, because it is highly dependent on local environmental conditions and management practices.
- The quantity of carbon accumulated in the soil and above ground vegetation are subject to a number of variables characteristic of a particular location such as soil type and annual rainfall (Defra, 2007).
- Seufert and Ramankutty (2017) highlighted that in the literature there are uncertainties regarding the ultimate fate of the stored carbon (that is, for how long this sequestration will continue and whether it will be permanent) and the counterfactual (that is, how the carbon inputs would otherwise have been used), and thus some researchers do not consider soil carbon storage as a climate change mitigation option. Moreover, carbon sequestration in soils is not included in the clean development mechanism agreed to in Kyoto protocol (Sartaj *et al.*, 2013). Hence aspects regarding soil carbon storage are covered in the soil section (23), including soil organic matter.
- Theoretical C storage potential of each habitat within AES and the importance of its continued maintenance or restoration options were calculated (Defra, 2007), updated (Warner *et al.*, 2011), and subsequently developed into a Land Carbon Management Plan (LCMP) creation tool (Dimambro *et al.*, 2011a), as a simple method for farmers to use to understand the C storage potential of AES options on their farm.

4.5.2 Climate change adaptation

There was a dearth of literature specifically comparing climate change adaptation of conventional and organic agriculture. However, some studies considering adaptation options (i.e. autonomous or planned adaptation strategies) were found, to minimize the negative impacts of climate change (increases in temperature and different patterns of precipitation) as highlighted in Table 9. Some examples of potential climate change adaptation strategies and research are as follows:

- Diversification of crop species and cultivars including local varieties, nutrient management, land allocation and farming system (Scialabba & Müller-Lindenlauf, 2010; Azadi *et al.*, 2011; Bindi & Olesen, 2011).
- A number of studies have shown that, under drought conditions, crops in organically managed systems produce higher yields than comparable crops managed conventionally (Lotter, 2003; Lotter *et al.*, 2003).
- The selection of crop varieties with eco-stable yields has been highlighted as a key tool for climate change adaptation (Macholdt & Honermeier, 2017).
- In recent years, studies have been comparing the yields of a range of crop varieties in conventional and organic systems, and in some cases finding the highest yielding conventional cultivars were not the same as for organic systems e.g. in wheat (Murphy *et al.*, 2007) and pakchoi (Han *et al.*, 2017). The researchers highlighted that breeding varieties specifically for relevant organic traits could result in higher-yielding varieties adapted to organic cultivation.

Objectives	Means	Impacts
Alternative to industrial production inputs (i.e., mineral fertilizers and agrochemicals) to decrease pollution	Improvement of natural resources processes and environmental services (e.g., soil formation, predation)	Reliance on local resources and independence from volatile prices of agricultural inputs (e.g., mineral fertilizers) that accompany fossil fuel hikes
In situ conservation and development of agrobiodiversity	Farm diversification (e.g., polycropping, agroforestry and integrated crop/livestock) and use of local varieties and breeds	Risk splitting (e.g., pests and diseases), enhanced use of nutrient and energy flows, resilience to climate variability and savings on capital-intensive seeds and breeds
Landscaping	Creation of micro-habitats (e.g., hedges), permanent vegetative cover and wildlife corridors	Enhanced ecosystem balance (e.g., pest prevention), protection of wild biodiversity and better resistance to wind and heat waves
Soil fertility	Nutrient management (e.g., rotations, coralling, cover crops and manuring)	Increased yields, enhanced soil water retention/drainage (better response to droughts and floods), decreased irrigation needs and avoided land degradation

Table 9 Adaptation potential of organic agriculture (Scialabba & Müller-Lindenlauf, 2010)

4.5.3 Climate change. Monitoring methods

4.5.3.1 *Greenhouse gas emissions*

Static chambers (which can be automatic or manual) followed by gas chromatography have been used in a number of comparison studies between organic and conventional systems to assess nitrous oxide emissions and in some cases also carbon dioxide over time (Burger *et al.*, 2005; Chirinda *et al.*, 2010; Ball *et al.*, 2014; Benoit *et al.*, 2015). The gas is either analysed with gas chromatography or for ammonia, photoacoustic infrared spectroscopy (Rees *et al.*, 2013).

4.5.3.2 *Carbon footprinting*

Although many ELS and HLS options, and subsequently comparable CS options do offer benefits to the farm's carbon footprint by maintaining or enhancing soil carbon (Defra, 2007; Dimambro *et al.*, 2011b), carbon stewardship is not the main focus of AES. However, once monitoring the GHG emissions and carbon sequestration associated with an organic farm's business is commonplace this would be a more holistic approach, than considering field or option-level climate change assessments in isolation. A wide range of carbon footprint calculators are already available on-line[8]. An alternative

[8] www.farmcarbontoolkit.org.uk/carbon-calculator, www.cffcarboncalculator.org.uk, www.farmcarboncalculator.org.uk, /www.fwi.co.uk/business/free-farm-carbon-footprint-tool etc

approach would be to utilise the Land Carbon Management Plan (LCMP) creation tool which was developed for the National Trust in partnership with Natural England (Dimambro *et al.*, 2011a), originally as a tool for farmers to consider which AES options to select when planning a new scheme. The LCMP could also be used to provide a whole-farm summary of the maintenance and enhancement of carbon storage achieved by the AES options already in place.

Summary for Climate Change

A range of meta-analyses and reviews have observed that organic farming tends to score equal or better than conventional farms when GHG emissions are expressed per unit area. When the GHG emissions per output/unit product are considered, some authors observe no differences between organic and conventional.

There are conflicting theories and models on whether nitrogen emissions from organic farms will be higher or lower than from conventional farms.

Organic farming has a lower CH_4 emission potential on a per hectare basis although CH_4 emissions per kg of milk are estimated to be higher in organic dairy farms than in conventional ones.

On a per hectare scale, organic farming has been observed to have positive effects on CO_2 emissions whereas on a per-unit output basis, the CO_2 emissions tend to be higher in organic systems.

The highest mitigation potential of organic agriculture could lie in carbon sequestration in soils although there is no consensus on whether this does, or will happen.

There are not enough studies linking organic farming to climate change adaptation to form a conclusion.

Carbon footprints need to be created on a farm scale rather than a field or option scale to be relevant.

4.6 Literature review results: Landscape

The literature regarding organic farming within a landscape scale context is an important aspect to consider, with landscape character being one of the key priorities of CS. Literature in this area tends to vary greatly depending on the type of landscape being considered (Seufert *et al.*, 2014); there is a contrast between the vast field sizes in the USA as compared to more heterogeneous landscapes within the UK. Hence our literature searching focused on landscapes within the UK and other countries with comparable landscapes. Almost all of the literature relating to how organic farming has an impact at the landscape scale relate to how biodiversity uses the landscape (covered in the biodiversity section) rather than landscape character which is the focus here.

There is little doubt that the intensification of agriculture in the 1950s to the 1980s altered the landscape. The introduction of AES and environmental legislation in the 1980s and beyond has moderated the change but a 33 year study of the English landscape shows it continues (Countryside Agency, 2006). Most people would consider the changes such as increased field sizes, the removal of hedgerows and the introduction of techniques such as ‘Spanish polytunnels’ (Evans, 2013) to be negative for the landscape and the wildlife that inhabits it. It might be expected that the principles of organic farming should halt the decline and possibly reverse it.

The first concept to consider is what we mean by landscape and landscape sustainability. Stobbelaar and van Mansvelt (2000) define three realms for landscape sustainability: the β realm that is the physical environment; the γ realm that is the management of the landscape; and the α realm that is

the cultural history of the landscape. The authors summarise the results of an EU concerted action on sustainable landscapes, producing a table of the criteria that should be considered when assessing landscapes. This type of evaluation, that includes all three realms, is beyond what we are considering here. However, Section 6 of their list of criteria is what we will focus on. There are three elements in the section:
6.1 Diversity of landscape components;
6.2 Coherence amongst landscape elements; and
6.3 Continuity of land-use and spatial arrangement

The criteria were tested in various European countries and, although the samples were strictly limited in size, they did indicate that organic farms provided more to sustainable farming goals than conventional farms in the same region (Hendriks *et al.*, 2000; Kuiper, 2000; Stobbelaar & van Mansvelt, 2000). However, in most cases other factors had more of an influence than farm system. In Denmark , there was no link found between farm type and measures of landscape complexity (habitat types, hedgerows, field margins, watercourses, infrastructure, productive area, buildings, small biotopes) but there were differences between regions and crop types (Westergaard, 2006). The statistical methods employed in the Danish study could be useful for future studies in England. An earlier study in Denmark had shown at a national scale organic farms were found in more complex landscapes but at a regional scale it was shown that this relationship disappeared as other factors could explain the differences (Levin, 2007).

- A study of paired organic and conventional farms in England in the early years of this century showed that organic farms tend to be found in more heterogeneous landscapes and the organic farms have more complex landscape structure (Norton *et al.*, 2009). The study analysed the land parcels surrounding the 1km squares around target fields on organic farms by utilising the Landcover Map 2000. The farmers were interviewed and surveyors noted landscape features when undertaking other research within the project. There was considerably more variation in the crop types grown on organic farms compared to conventional farms.
- Organic farms in the Bristol area of England had greater total areas of semi-natural habitat (woodland, field margins and hedgerows combined) than their paired conventional counterparts (Gibson *et al.*, 2007). Woodland area on its own was also significantly greater. Organic mixed farms had more continuous blocks of woodland (with simpler perimeters than similarly sized patches on conventional farms), whereas woodland on conventional farms often consisted of more linear patches. Semi-natural habitats on organic farms did not have higher plant abundance, richness or diversity than their conventional counterparts. The only landscape element that showed a significant increase in plant abundance, richness or diversity was arable fields. This study, although well carried out, used now outdated mapping techniques and would no longer be recommended.

All of the studies cited above describe how the landscape related to organic farming compares to that of conventional farming. None of the studies describe how organic farming maintains or changes the landscape in comparison with conventional farming over time. There is a connection between the creation of more sustainable landscapes (more hedges, trees, wild flower areas, ponds etc.) and organic farming but this has been linked more to farm size than farming system *per se* (Pedroli *et al.*, 2007). Furthermore, the development of sustainable landscapes is confounded with the motivations of the farmer. There is no evidence to suggest that organic farmers will generally produce more diverse landscapes in terms of their character or cultural aesthetic than well motivated conventional farmers in AES(Mills *et al.*, 2013). It would seem perverse if Countryside Stewardship organic options for horticulture supported Spanish polytunnels when they have an adverse effect on landscape character (Evans, 2013).

Table 10 summarises the literature found regarding landscape effects of organic farming. There is not enough evidence to state whether the organic options in Countryside Stewardship will either maintain or benefit the landscape character of the areas where they are applied. There are survey techniques that have been developed that could be adapted to compare conventional and organic farms in Countryside Stewardship. Notably, the use of remotely sensed data (landcover, LIDAR and aerial photographs) could be of use to determine landscape structure and identify linear features and small elements such as individual trees and ponds.

			Effect				
Study Parameter	**Farming System**	**Long Term Study / Years**	**Increase**	**Mixed**	**No Effect**	**Decrease**	**Reference**
Landscape	All	No			|		Stobbelaar and van Mansvelt (2000)
Habitat types/ hedgerows/field margins/ watercourses/ infrastructure/productive area/buildings/small biotopes	Dairy and rotational on morraine and outwash	No			|		Westergaard (2006)
Landscape elements	Mixed	No	+				Gibson *et al.* (2007)
Landscape elements	Mixed	No		+/-			Levin (2007)

Table 10 Summary of landscape effects of organic farming as compared to conventional farming

Summary for Landscape Character
There have been few studies on the impacts of organic agriculture on landscape pattern, aesthetic and cultural history. The work that has been done shows that organic farms tend to have more landscape elements such as hedgerows, ponds and trees (including agroforestry) and have smaller more complex field systems than conventional farms. In some areas (New Zealand) organic farming is considered 'messy' compared to intensive farms, although this is probably becoming an outdated viewpoint.

4.7 Literature review results: Other CS priorities

Historic environment and genetic conservation are also priorities within CS. Small scale horticultural producers are more likely to grow 'heritage' varieties and the proportion of these that are organic will need to be considered. There is potentially a positive correlation between rare breeds of livestock and organic production related to the attitudes of the farmers and only a carefully conceived project could determine if there are benefits of organic options to the maintenance of rare breeds.

4.8 Literature review summary

Comparative studies tend to focus on specific crops, over a short period of time. Simplifying the focus of the farming system analysis, through single commodity versus whole farm productivity analysis, entails the risk of compromising the understanding of its complex reality and supplying incomplete information (Gomiero *et al.*, 2011). The diagram below (Figure 3)provides a summary of the effects of organic farming (Jespersen *et al.*, 2017), illustrating how complex the interactions are. Indeed, the high level of heterogeneity among studies emphasises the importance of local aspects such as soil type, climate, surrounding habitats etc. While organic standards are process oriented, i.e. they describe and limit the conditions under which production is allowed, there is no specific focus on the potential environmental outputs created during production. The complexity will have a bearing on the sample size required for any evaluation of the CS organic options in comparison with conventional CS options and farms not in CS.

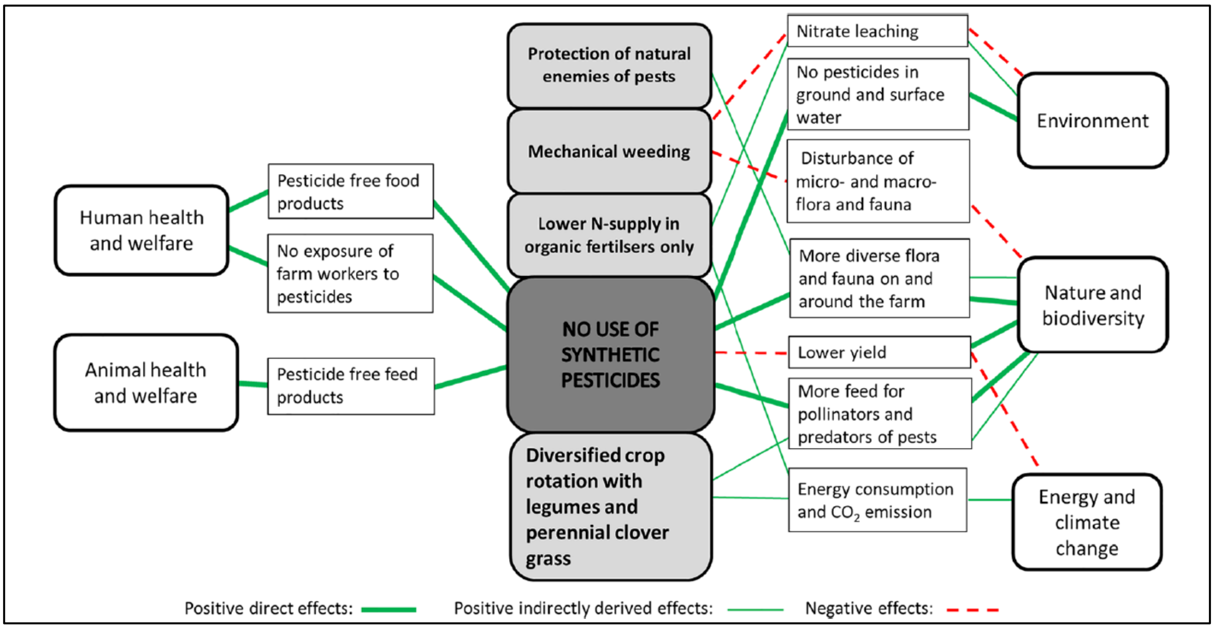

Figure 3 The direct and indirect contribution of organic farming to public goods due to ban of synthetic pesticides plus compensated cropping (Jespersen et al., 2017).

5 Monitoring projects

In 2005, high priority areas for future related research identified include the potential biodiversity benefits of organic livestock farming, long-term controlled studies on responses to conversion, and the effect of extent of organic management at larger scales (Anon, 2005). A range of methods have been identified in research where organic farming has been compared to conventional farming.

The Research Project BioBio – Biodiversity indicators for organic and low-input farming systems (KBBE-227161) identified scientifically sound and practicable farmland biodiversity indicators, based on a literature review, iterative interaction with a stakeholder advisory board and testing on 195 farms in 12 case-study regions across Europe (Herzog *et al.*, 2012). The result was a set of eight indicators for habitat diversity, four indicators for species diversity, three indicators for genetic diversity and eight indicators for farm-management practices, applicable across Europe and for major farm types (**Error! Reference source not found.**). Guidelines for applying the BioBio indicator were ummarised as follows:

- Random selection of farms from the "farm population" to be evaluated / monitored;
- Obtain agreement and farm boundaries from farmer;

- Farm-habitat mapping and random selection of plots from among habitat types for species recording;
- Recording of vascular plants, bees, spiders and earthworms via standard methods;
- Farm interview to determine genetic diversity of crops and livestock, and for management practices as these cannot be obtained from field survey.

Small sample sizes have made evaluation of the organic elements of past schemes difficult. The ELS monitoring study NECR113 (Food and Environment Research Agency, 2013) had a limited number of farms in OELS to compare with farms in ELS. Moreover, the HLS monitoring study NECR114 (Mountford *et al.*, 2013) had very few organic farms in the sample, as it was specifically designed to look at the HLS where management options were not specified, and any organic options that occurred were combined with the OELS management prescriptions.

6 Questions to be addressed by the evaluation protocol

From the literature studied in this review there is no consensus on the degree to which organic farming is providing environmental and/or public benfits above those of conventional farms in AES, if at all.

The key questions that need to be answered by an evaluation of the organic options of Countryside Stewardship are:

1. How do the biodiversity elements measured for organic maintenance options compare with similar land not in Countryside Stewardship (CS)?
2. How do the biodiversity elements measured for the conventional options in CS compare to organic maintenance options?
3. How does biodiversity on the organic maintenance options of CS compare to the biodiversity of conventional farms with similar environmental settings and/or farm business types?
4. Do the biodiversity elements currently measured for conventional options change at a different rate to conventional farms in CS as farms convert to organic production?
5. How does biodiversity change as a farm converts to organic production compared to a similar farm that is outside of CS over the same time period?
6. How does soil organic matter differ between conventional farms and organic farms in CS?
7. Is there a difference in soil erosion between conventional and organic farms in CS?
8. How do soil biota differ between conventional and organic farms in CS?
9. Is there a difference in the quality of water leaving conventional and organic farms in CS?
10. Do organic farms maintain or change the landscape in a way different from conventional farms in CS?
11. Can the public benefits of organic and conventional farms in CS be quantified and compared: what are the variables (above and beyond those in question 1 to 9) that need to be collected to do this?
12. Are two surveys sufficient: A baseline survey (year 1) and a comparison survey at the end of the CS agreement (year 5)?

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