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The relationship between best practice for managing soils to protect the environment with that for increased productivity

Sub-project B of Defra Project SP1605: Studies to support future Soil Policy

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1. Introduction

Recent UK food security assessments have identified increased food production as one of three main priorities for sustainable farming systems. These assessments are in response to decreasing levels of food self-sufficiency in recent decades, an increasing global population and the potential threats of climate change both at a local and global scale.

In January 2010, the UK government released a sustainable food strategy called ‘Food 2030’, which calls for an increase in food production while ensuring sustainability of production. The Strategy is designed to meet UK needs in terms of food security, as well as ensuring that the UK plays an important role in the United Nations target to increase food production by 70% by 2050. The Council of Food Policy Advisers also recognizes the importance of increasing UK food self-sufficiency from the current level of 61% and highlights the importance of increasing the consumption and domestic production of fruit and vegetables. UK agriculture therefore faces a number of challenges in the next few decades, including increasing productivity, while maintaining (and enhancing) natural resources – soils, water and biodiversity – on which food production depends, and reducing emissions of greenhouse gases and other potentially harmful pollutants to air. These challenges highlight the multi-functional nature of soils and the eco-system services that society is increasingly looking for soils to deliver.

Government Departments and Agencies, including Defra and the EA, have produced guidance documents that advise on sustainable soil management. However, this guidance is generally perceived to be about managing soil for environmental protection and there is a contention in some sectors that there is a need for advice to assist farmers to manage soils for increased production. The aim of this discussion paper is to address the question of whether best practice for managing soils to protect the environment is different from best practice for maintaining the productivity of soils.

‘Best practice’ for environmental protection – principles and sources of information

‘Best practices’ for environmental protection can be split into four main categories based on whether they aim to:

1. Preserve good soil structural conditions in the field – maintaining aggregate stability and soil porosity (e.g. cultivating compacted tillage soils); maintaining soil biological activity; and maintaining or enhancing soil organic matter
2. Protect the soil surface within the field during periods of high erosion risk (e.g. cover crops, arable reversion etc.)
3. Provide a barrier to overland flow and reduce the transport of pollutants to surface waters (e.g. beetle banks, hedges, buffer strips etc.)

There are a number of guidance documents that provide valuable information on soil management to protect the environment. These range from documents produced by Government Departments and Agencies, such as the Defra ‘Code of Good Practice for Farmers’ to the Soil Management Initiative ‘Guide to Managing Crop Establishment’. Section 2 of this discussion paper summarises current guidance on best practices for managing soils to protect the environment. An inventory of soil management practices is provided in section 4 and in Annexe I.
‘Best practice’ for increased food and fibre production – changing priorities, principles and sources of information

In ‘Food 2030’, the first major UK food strategy for around 60 years, Defra describes a number of priorities and key challenges, including increasing food production sustainably. There is, therefore, a need to provide clear guidance that allows farmers to maintain or increase yields, while sustaining the productivity of soils and reducing the food system’s impact on the environment. The principles of sustainable crop production are outlined in a number of previous ADAS and Rothamsted/NW Res research (e.g. Nicholson et al. 1997; Jenkyn et al. 2001; Turley et al. 2003) and farming industry publications/reviews e.g. ADAS (1983), Davies (1988), EFMA (2000) and SMI (2005). There are a number of soil management principles that are recognised within the farming community as being important for weed and pest control, such as the creation of a fine and firm seedbed to maximise herbicide activity and control slugs in oilseed rape crops. It is important to acknowledge that such practices can increase soil erosion risk on sloping land so that the need for environmental protection can be balanced against the need to maintain or increase food production.

Section 3 of this discussion paper considers best practice for managing soils for increased production across the main farming systems.

2. Summary of best practice for managing soils to protect the environment

In the following sections we set out current best practice for managing soils to protect the environment focusing on methods to reduce erosion risk, alleviate compaction and enhance or maintain organic matter. The sections are also split between arable and grassland situations.

Arable – soil management best practice for environmental protection

Erosion control

Soil management best practice for soil erosion control begins with an assessment of soil erosion risk (Defra 2005a; Defra 2009a; Defra 2009b). This involves identifying soil types and sloping land on farm, as well as identifying combinations of high risk soil-slope combinations and high risk land uses, such as the late harvesting of potatoes or forage maize. Sloping land with ‘sandy or light silty’ soils is of highest risk, while gently sloping or flat land with ‘calcareous’, ‘medium’ or ‘heavy’ soils is of lowest risk.

Once the soil erosion risk categories in each field have been identified, it is important to note any additional soil issues that occur in each field (EA 2006; Defra 2005a; Defra 2009b). These issues may be ‘runoff or erosion’ features and ‘compaction due to cultivations’ (Defra 2009b) or ‘platy soil structure’ in the topsoil (EA 2006a). The next step is to consider actions (or ‘soil protection measures’ – Defra 2009b) to reduce soil erosion risk. These can be split into methods that:

1. Preserve good soil structural conditions in the field – maintaining good soil structure and porosity (e.g. cultivating compacted tillage soils)
2. Protect the soil surface within the field during periods of high erosion risk (e.g. establishing autumn crops early or establishing cover crops)
3. Provide a barrier to overland flow and reduce the transport of soil particles and pollutants to local water courses (e.g. beetle banks and buffer strips)

The first set of methods are covered in the below sections on ‘compaction avoidance or alleviation’ and enhancing or maintaining soil organic matter. The remaining methods focus on protecting the soil surface and either breaking up the landscape (reducing slope length and landscape connectivity) or creating barriers to flow and opportunities for
sediment deposition (i.e. cultivations to increase surface roughness and the establishment of beetle banks and buffer strips).

In most arable crops, improved protection of the soil surface can only be achieved through early crop establishment (Chambers et al. 1992; Chambers et al. 2000; Defra 2009b), leaving the seedbed as coarse as possible (Deasy et al. 2009; Defra 2009a and b), under-sown spring crops (Buchner 1988; Natural England 2008) and establishing a cover crop (Cuttle et al. 2006; Defra 2009b). An important management practice for reducing soil erosion risk in winter cereals is to drill early (by mid October) and avoid a fine, smooth seedbed such that a vegetation cover of 25 to 30% is in place before heavy rain falls on ‘wet’ soils in late autumn/winter (Chambers et al. 2000; Evans 1990). A cover crop reduces the risk of soil erosion by water and wind (Kwaad & van Mulligen 1991). Cover crops can be grown in mid summer following the early harvest of crops such as summer brassicas or vining peas (typically in June/July), and in the autumn during the break between a summer/autumn harvested crop and a following spring crop. The most effective way to reduce soil erosion risk on high risk areas in arable or horticultural production is to revert the land to grassland (Cuttle et al. 2006; Natural England 2008).

There are a number of methods that can increase surface roughness and reduce the risk of soil erosion and run-off. Defra guidance on controlling erosion (Defra 2005b) suggested that the following land surfaces present a progressively increased soil erosion risk (least vulnerable to most vulnerable):

- Land with good crop/vegetation cover
- Cereal stubble
- Rough ploughed/cultivated land
- Bare land after root crop harvesting
- Fine seedbeds

Any practice that can move the land up the scale of stability can potentially reduce soil erosion risk. It therefore makes sense to cultivate (to some degree) sloping land with erodible soils (particularly ‘sandy and light silty’ soils) after root crop or maize harvesting, if conditions allow (Withers & Bailey 2003). However, where soils are not compacted and there is a 25 to 30% cover of vegetation and/or residue, soil erosion risk is reduced if cereal stubble can be retained over winter (Natural England 2008).

Other methods serve to reduce landscape connectivity and create both a barrier to run-off and opportunities for sediment deposition (the barrier approach). These include establishing new hedges, establishing beetle banks and establishing riparian buffer strips (Cuttle et al. 2006; Natural England 2008; Defra 2009b). These methods are most effective on sloping land with ‘sandy and light silty’ soils. On sloping lower erosion risk land with drained ‘medium’ and ‘heavy’ soils not only is the risk of surface run-off and soil erosion lower, but a good proportion of the eroded soil is transported via the field drains (Russell 2001). Therefore, on these ‘medium’ and ‘heavy’ soils with drainage, the above ‘barrier’ methods are less effective in reducing total soil losses. ‘Barrier’ methods occupy a small proportion of the land surface, but represent approximately two thirds of the soil management methods available under Entry Level Stewardship (Natural England 2008).

Compaction alleviation or avoidance

Guidance suggests that soils should not be trafficked by heavy machinery or livestock when ‘wet’ (Defra 2009c; NSRI 2002). Timeliness is crucial in that cultivations are only really effective over a narrow range of soil water contents. If the soil is too ‘wet’ (soil water content is over the plastic limit in ‘medium’ and ‘heavy’ soils) cultivations can result in deformation and smearing of the soil. If the soil is too dry cultivations are less effective; for example, clod size reduction is less effective and draught requirements for sub-soiling become excessive (ADAS 1983; NSRI 2002; SMI 2005). Dexter and Bird (2001) suggest that the soil plastic limit is the upper limit to the moisture content for tillage; and the
inflection point on the moisture release curve for the optimum water content. However, NSRI (2002) and Defra (2009c) guidance also recognises that on occasions working soils when ‘wet’ is unavoidable and that “when damage is caused, it is important to recognise it and put it right as soon as possible”. This also forms the basis of the reasoning behind allowing access to waterlogged land in the latest Cross Compliance Guidance for Soil Management (Defra 2009a; Defra 2009b) where the date and reason for accessing waterlogged land must be recorded as well as the action taken to remediate the damage caused.

Each soil cultivation should only be carried out if it is absolutely necessary. Once soil has been loosened it is vulnerable to compaction, so additional or ‘recreational’ (i.e. unnecessary) cultivations should be avoided at all costs (SMI 2005). The minimum number of cultivations should be carried out to produce satisfactory soil structure to allow the passage of roots, water and air from topsoil to subsoil and a seedbed that is loose enough above and below the seed to encourage rapid germination and promote drainage and rapid root development, but firm enough around the seed to promote water absorption and herbicide activity (NSRI 2002). These are the principles that support the adoption of minimal tillage and direct drilling. However, reduced cultivation systems should only be adopted once any sub-surface compaction has been alleviated and the systems are not suitable in all circumstances (SMI 2005). For example, reduced cultivation techniques are more difficult on ‘sandy and light silty’ or stony soils (ADAS 1983; NSRI 2002).

Most arable and field vegetable crops are grown using a bed or tramline system to concentrate any compaction from agricultural machinery. However, compaction can also occur at harvest, particularly when maize, root crops and vegetables are harvested from soils at or wetter than field capacity (Batey 2009). Compaction can be avoided or minimised through the use of low ground pressure tyres or cage wheels (Davies et al. 1973) and by minimising indiscriminate trafficking at harvest (Defra 2009a; NSRI 2002). Maintaining field drains is essential on many ‘heavy’ and ‘medium’ soils (Defra 2009c) and it may also be necessary to re-install field drainage.

Other methods focus on alleviating compaction once it has occurred. Alleviation can be carried out across the whole field, where necessary, or in specific areas, such as tramlines or headlands where most of the compaction occurs (Deasy et al. 2009). The alleviation of compaction is incorporated into a number of Entry Level Stewardship options (i.e. EF2 Wild bird seed mixture; EF4 Nectar flower mixture; EF6 Overwintered stubbles; EF10 Unharvested cereal headlands within arable fields; EG2 Wild bird seed mixture in temporary grassland areas; EG3 Nectar flower mixtures in grassland areas; EG4 Cereals for whole-crop silage followed by over-wintered stubbles; EJ2 Management of maize crops to reduce soil erosion) (Natural England 2008).

The first step in alleviating compaction is determining its depth and nature (NSRI 2002; SMI 2005; EA 2006a; Defra 2009b). Small pits (about a spade in width) should be dug in the spring or early summer to determine the extent, depth and nature of any compaction. As with cultivations for seedbed preparation, timeliness is critical for compaction alleviation. Implement size, geometry and depth of operation are also critical for the success of any tillage operation to remove compaction. To break up a tillage pan or compacted layer in the topsoil, a suitable implement (e.g. a chisel plough) should be used just below the zone that needs to be broken up (Spoor 2006). Alternatively, the next tillage operation may be all that is needed to break up a tillage pan (Birkas 2008).

For sub-soiling, wider tines are needed to ensure that tillage is carried out at or above the critical depth for the implement. This critical depth is approximately six times the individual loosening tine’s width. Operations undertaken above this critical depth result in a loosening action through brittle failure, while operations carried out below critical depth result in compaction due to the sideways resistance of the surrounding soil. The effectiveness of each tillage operation can be checked through soil pit inspections (Spoor 2006). After sub-soiling, further compaction can be avoided by leaving as long as
possible before subsequent cultivation operations are carried out (NSRI 2002; Spoor 2006).

Routine sub-soiling carried out without determining the presence, depth and extent of compaction is likely to be a waste of time and energy and could be detrimental to soil structure and function, since loosened soil can be readily compacted if the correct management strategies post-loosening are not implemented (Soane et al. 1987; Spoor et al. 2003).

*Enhance or maintain soil organic matter*

Maintaining or enhancing soil organic matter is a key target area for the Cross Compliance Soil Protection Review (SPR) (Defra 2009b). Within the SPR, a number of soil protection measures can be selected. These include:

- Where organic matter is low, apply bulky organic manure, compost or digestate.
- Where organic matter is low, introduce grass leys into the rotation.
- Where organic matter is low, introduce cover crops/green manures into the rotation.
- Minimum tillage and direct drilling techniques used.

To maintain organic matter, minimum tillage or direct drilling techniques would have to be regarded as a more or less permanent system. Ploughing every few years to control weeds could potentially result in as much oxidation (loss) of organic matter as annual ploughing.

The need to maintain or enhance organic matter in arable soils is also prominent in the Defra Code of Good Practice for farmers, growers and land managers, including the incorporation of crop residues (Defra 2009c).

**Grassland – soil management best practice for environmental protection**

*Erosion control*

The Cross compliance Soil Protection Review (SPR) requires farmers to assess the soil erosion risk in grassland fields as they do for arable fields, although the risks are normally lower due to the presence of a permanent vegetative cover (Boardman & Evans 1994). Farmers are then asked to note the soil issues that occur in each field (EA 2006a; Defra 2005a; Defra 2009b). This might include evidence of ‘poaching of soil by livestock’, ‘run-off or water erosion’ features, ‘waterlogging’ or ‘compaction due to cultivations and mechanical damage’. The next step is to consider actions (or ‘soil protection measures’ – Defra 2009b) to reduce soil erosion risk. In grassland fields most methods focus on preserving good soil structural conditions in the field (e.g. loosen compacted soil layers in grassland fields). The SPR methods for improved grassland are:

- Maintain land drainage systems.
- Use well drained tracks for vehicles and livestock.
- Minimise damage to riverbanks by providing managed access to water for livestock.
- Remove sward compaction using a grass sub-soiler, tines or spikes.
- Regularly move ring feeders or place feeders and troughs onto a stone base.
- Re-seed grass early to achieve a good cover before winter. Aim to create a coarse seedbed that is less likely to form a cap that will lead to runoff.
- Remove grazing livestock from grassland when the soil is too wet.
- Locate out-wintered stock on fields with freely drained soils and not on fields that will lead to erosion. Cultivate and reseed in the spring to remove any compaction.
Most of the above methods focus on maintaining a vegetative cover and avoiding or alleviating compaction. Other methods include consideration of the livestock system to ensure that it is appropriate for the soil types on farm (Defra 2009c).

Measures in addition to the SPR can include buffer strip options as part of Entry Level Stewardship (Natural England 2008). In addition, the following ELS grassland options include an element of soil management:

- **ED5** Management of archaeological features on grassland
- **EG2** Wild bird seed mixture in temporary grassland areas
- **EG3** Nectar flower mixtures in grassland areas
- **EK1** & **EL1** Take (grassland) field corners out of management
- **EK2** & **EL2** Permanent grassland with low inputs
- **EK3** & **EL3** Permanent grassland with very low inputs and **EK4** & **EL4** Management of rush pastures
- **EK5** Mixed stocking
- **EL5** Enclosed rough grazing (SDA land within the LFA and Moorland Line parcels under 15 ha) - includes instruction not to plough, cultivate or reseed; not to install any new land drainage or modify any existing land drainage, or remove any peat or sediment; not to increase existing stocking levels; and not to supplementary feed

EG2 and EG3 include the requirement to remove compaction (except on sites of archaeological interest) and several options do not allow supplementary feeding (ED5, EK1, EL1, EK3, EL3 and EL5).

**Compaction alleviation or avoidance**

Soil bulk densities are generally lower in grassland soils than in arable soils (Environment Agency 2006b). However, over-compaction and damage to the grass sward can occur through compressive forces from the hooves of livestock and the wheels of agricultural machinery when the soil is ‘moist’ or ‘wet’ (Mulholland & Fullen 1991; Davies et al. 1973; Frost 1988). Over-compaction can, therefore, be avoided if intense grazing and traffic by tractors, slurry spreaders and forage harvesters is limited to when the soil is at or below field capacity. The degree of compaction can also be reduced through the use of low ground pressure tyres (NSRI 2002). However, the real solution is good management and sustainable stocking rates appropriate for the soil types on farm.

Compaction can be alleviated through shallow loosening when the soil is ‘moist’ or ‘dry’ (ADAS 1984; NSRI 2002), but it is important to investigate the compaction and be sure it is present before loosening is carried out. Topsoil loosening should be carried out in the autumn when growth is declining (ADAS 1984). If it is carried out in the spring or summer, when grass is often under water stress, the unavoidable damage to the root systems will almost certainly reduce yields and can potentially lead to sward death (ADAS 1984; Frost 1988). In wetter areas, shallow moling below the depth of the compaction may be possible (NSRI 2002). Topsoil loosening is not recommended in poorly drained soils if no under drainage is present or in poorly drained soils that are unresponsive to drainage (ADAS 1984). In severe cases of over-compaction, ploughing and re-seeding may be necessary. Plough sub-soiling (using a small tine that extends 7.5 to 15 cm below the furrow bottom) may be an option to alleviate subsoil compaction (NSRI 2002).

**Enhance or maintain soil organic matter**

Grassland soils tend to have higher organic matter contents than arable soils. Indeed, including grass leys into an arable rotation is one of the soil protection measures that farmers can adopt as part of their SPR (Defra 2009b). Perhaps the key management practice here is to prevent the ploughing out of permanent grassland that would lead to the loss of stored carbon and increased risk of sediment loss on sloping land.
An inventory of methods

An outline of the principal soil management guidance available in England and Wales is provided in Annexe I. This covers the following soil management guidance documents:

- Environment Agency (2006): Think Soils
- Defra "Diffuse Pollution User Manual" (Cuttle et al., 2006)

An inventory of potential best practices, focussed on soil management methods, was collated from the above documents and from Defra projects ES0203 (Cost-effectiveness of integrated diffuse pollution mitigation measures), WQ0106 (Development of a database of suitable mitigation options to reduce nutrient oversupply for use in guidance to farmers, and in the development of regulation) and SP08016 (Best practice for managing Soil Organic Matter in agriculture). This inventory was used to develop a matrix of potential best practices for environmental protection and to structure the discussion in section 4.

3. Summary of best practice for managing soils for increased production

In this section we have summarized best soil management practice for maintaining or increasing the production of the major UK crops in England and Wales; namely, cereals, oilseed rape, potatoes and grass.

Cereals

Maximising cereal grain yields and quality requires timely sowing and establishment of the crop and the provision of growing conditions that allow development of an optimum canopy of green tissue to intercept energy from sunlight. Studies have shown that the optimum Green Area Index (GAI, the ratio between the total green area of all tissues and the ground area) is between 5 and 6 (HGCA 2008). Development and support of this above-ground crop structure requires a range of management inputs which commonly vary significantly from field to field. The soil type and soil condition in individual fields has a very strong influence on the most appropriate management practices that are needed. There is a very wide range of soil types used for cereal production including deep sandy soils, shallow soils (e.g. over sandstone, chalk or limestone), heavy clay soils and peaty soils.

There are several objectives of practical soil management as follows:

1. To provide optimum soil seedbed conditions for crop establishment. Seedbed conditions for cereals are less demanding than for other small seeded crops and a relatively coarse seeded can be acceptable. However, if the seedbed is too coarse, this can increase the risk of slow establishment under dry weather conditions, slug damage and weed development. A well structured soil with adequate organic matter
content will usually minimise the time and effort needed for seedbed preparation. Finer seedbeds are more important for spring sown than autumn sown cereals.

2. **To provide good soil structural conditions for deep root penetration (alleviating compaction).** An extensive root system is needed for water and nutrients uptake into the crop. Dry summer weather and a limited supply of soil water is one of the main yield-limiting factors, especially on drought prone deep sandy or shallow soils. Roots are also the main way that nutrients are taken up from soil reserves and applications of manufactured fertilisers/organic manures. Soil compaction can significantly reduce the ability of roots to take up soil nutrient reserves.

3. **To provide good soil structural conditions through maintaining or enhancing soil organic matter content.** Retaining crop residues and applying organic manures contribute towards maintaining and enhancing organic matter levels. Regular additions over a number of years (compared with no manure or residue applications) can result in increased crop yields, particularly for spring sown crops that need to develop a sufficiently large root system quickly to acquire nutrients and water (Johnston and Poulton 2009). Increasing soil organic matter content as a result of repeated livestock manure additions has been shown to increase crop available water supply (Bhogal et al. 2009).

4. **To provide artificial drainage to remove surplus water from the soil.** On poorly drained soils (e.g. heavy clay soils, soils with groundwater), artificial drainage systems (pipes, often with gravel backfill and periodic provision of mole channels) are usually needed to remove excess rain and avoid waterlogging of the soil. Root development and crop yields can be severely restricted under waterlogged soil conditions.

5. **To bury crop debris or applications of organic manures.** Previous cropping (e.g. root or vegetable crops) can leave large amounts of crop debris. Applications of bulky organic manures (e.g. FYM, green composts, straw) need to be incorporated into the soil to allow a soil surface suitable for seedbed preparation for the next crop. Research on straw incorporation has shown that yields can be lower following reduced cultivation compared to ploughing systems (Davies and Finney 2002). Under some circumstances, incorporation of organic manures is a regulatory condition under the current Nitrate Vulnerable Zones (NVZ) Action Programme measures (Defra 2009d).

6. **To remove any soil structural damage (e.g. compaction) resulting from previous cropping and/or natural processes.** Farm operations, notably from wheeled machines (e.g. application or harvesting equipment, field tramlines), commonly cause soil compaction. Compaction can result in restricted and/or diseased rooting and associated crop yield reductions, especially for spring crops grown on light soils (Marks and Soane 1987).

7. **To reduce the impact of high weed seed populations.** Weed control, notably grass weeds such as black grass and sterile brome, is a major management requirement in cereal production especially on heavy clay soils. Crop rotations, herbicides and soil cultivations are the main techniques used by farmers for weed control. Since weed seed populations accumulate in the soil surface, ploughing is more effective for controlling weeds than shallow minimum cultivation methods.

8. **To provide a supply of essential plant nutrients and lime (for controlling soil pH) that are optimal for crop growth.** Nitrogen, phosphate, potash and sulphur are the main nutrients that commonly need to be applied as manufactured fertiliser and/or organic manure, but amounts depend on the supply of these nutrients in individual fields. Good soil structure increases the ability of roots to explore the soil and obtain nutrients, thereby optimising nutrient use efficiency. Current Defra nutrient recommendations are given in The Fertiliser Manual (RB209) (Defra 2010, in press).

9. **To develop a farm system that is cost-effective.** Machinery, fuel and labour costs are major elements of farm expenditure and need to be minimised.
potential problem but can be controlled by rolling. Single pass combination systems are being used increasingly to minimise cost, speed up operations and to minimise soil compaction resulting from the wheelings of multiple passes. Soil compaction is a particular concern in sandy soils since the low clay content means that little ‘shrink-swell’ and natural re-structuring occurs during the cropping cycle. Soil compaction in sandy soils can therefore have a significant impact on crop yields, particularly for spring sown crops (Soane et al. 1987).

Heavy clay soils are the dominant soil type for cereal production and present significant soil management challenges to optimise crop yields and cost-effective production. Reduced cultivation systems (i.e. cultivating the surface 10-15 cm of soil), often using combination equipment in one pass, are becoming more common but with tactical ploughing where needed (e.g. due to weed pressures). The main advantages of non-ploughing are easier seedbed preparation, due to retention of the weathered soil tillth at the soil surface, reduced cost and faster operation. Farm experience and long term research experiments (200 site years) indicates that well managed non-ploughing systems usually gave as good or better yields of winter cereals as ploughing. Where reduced cultivation gave lower yields, it was usually due to weed pressure, topsoil compaction or loss of surface structure. However, reduced cultivation techniques were less successful for spring cereals (Davies and Finney 2002; HGCA 1988). Moling is commonly carried out every few years on suitable soil types, and is necessary and effective to maintain soil drainage. Sub-soiling is also commonly carried out to alleviate soil compaction but increasingly this is on a tactical basis only in tramlines and/or headland areas where a problem has been identified.

Oilseed rape

UK farm yields of oilseed rape have remained static since the mid 1980s (Defra Statistics). This has occurred despite plant breeders increasing the yield potential of new oilseed rape varieties. It has been concluded that sub-optimal crop management is an important factor explaining the static farm yields (Berry & Spink 2006) and management of the soil through soil cultivation methods have been identified as one of the possible sub-optimal management practices (Spink & Berry 2004). Cultivation methods are of great importance for oilseed rape for two reasons; 1) oilseed rape seed is small and therefore good seed to soil contact is essential for achieving good plant establishment (Stokes et al. 2000), 2) oilseed rape has been shown to have insufficient roots, particularly at depth, to capture the majority of plant available water and nutrients (Barraclough 1989). Greater oilseed rape rooting has been correlated with heavier yields in dry years (Blake et al. 2006). Therefore achieving a soil structure which maximises root exploration is of great importance.

Several different types of cultivation methods are used to establish oilseed rape including; 1) ploughing to around 20 cm then breaking the soil down to produce a seed bed, 2) minimal cultivations usually to less than 15 cm depth, 3) spreading seed behind the legs of a sub-soiler and 4) direct drilling or autocasting seed directly onto the soil immediately following harvest of the preceding cereal crop. Methods 1 and 2 are often preceded by sub-soiling. All of the methods of establishment usually culminate with rolling to maximise seed to soil contact and to minimise cavities in the soil which allow free movement of slugs.

Autocasting and direct drilling have been shown to result in lower yields compared with ploughing, but yields from crops established using minimal cultivations have been found to be similar to those established with ploughing (Sauzet et al. 2003; Bowerman et al. 1995). Conversely, Christensen et al. (2003) found no detrimental effect of direct drilling on yield. It appears that autocasting is less effective when there are large amounts of poorly chopped straw from the previous crop, wet conditions or wet and poor soil structure. Non-burial of the residues of the previous crop has also been shown to increase lodging and phoma fungal infection and associated crop lodging (Sauzet et al. 2003) and increase slug damage, which may cause sub-optimal plant populations to be
established. Spreading seed directly behind the legs of a sub-soiler has only recently begun to be used on farms. Anecdotal evidence is that it generally results in good plant establishment, often as a result of conserving soil moisture, and there is no evidence of lower yields compared with other methods of establishment.

A study of oilseed rape rooting by Blake et al. (2006) showed that ploughing resulted in slightly more roots in the top 20 cm of soil compared with minimum tillage, but there were no statistically significant effects deeper than 20 cm depth. It should be recognised that there were generally more than sufficient roots in the top 20 cm to extract all available water and nutrient within this zone of soil, so small reductions in rooting at shallow depths are unlikely to be of significance for crop productivity. It was clear from this study that any soil compaction, e.g. resulting from a plough pan, significantly reduced the root length density within this zone of soil.

Oilseed rape has a high demand for nutrients especially nitrogen (Berry & Spink 1999) and sulphur (McGrath & Zhao 1996). Potassium and phosphorus are also important nutrients, and ADAS soil indices of 2 (satisfactory levels) should be maintained to allow yield potential to be achieved (Defra 2010). The soil must be managed to maximise the availability of these nutrients during the phases of crop growth when they are required. Berry & Spink (2009) have shown that significant amounts of nitrogen must be available for uptake from stem extension onwards and that ability to take up N during and after flowering is likely to be important for achieving high yields. It may, therefore, be expected that soils with high organic matter may help to achieve high yields as more N will be mineralised from these soils during late spring and early summer. However, we can find no published evidence that organic matter content of soil is linked to greater yields in oilseed rape. Sulphur deficiency has been linked to restricted root growth in glasshouse experiments (Helal & Schnug 1995), demonstrating that adequate sulphur levels are essential to maintain root integrity, prevent root mortality, and improve root efficiency.

**Potatoes**

Potato crop productivity is sensitive to soil degradation (wind erosion, water erosion, capping, slumping and compaction) and due to the nature of the land and soil types on which some potato crops are grown and the numerous cultivations often carried out to establish the crop, there are many factors that threaten to reduce soil quality below the optimal condition for crop growth.

**Consolidation and compaction**

Some degree of consolidation is needed for potato crop growth – good contact with soil helps root anchorage and allows water uptake. Also, crop emergence is delayed if there is not enough soil consolidation around the tuber at planting time and without sufficient consolidation the ridge can slump with a potential increase in some tuber skin diseases such as Powdery scab and Black dot. It is only when the degree of soil compaction prevents optimum crop growth that it becomes a problem (Hatley et al. 2005). Stalham et al. (2005) observed that since 1990 there has been a major change in the methods of cultivation for potatoes which has increased rather than decreased the risk of creating poor soil conditions, including compaction. A survey by Stalham et al. (2005) of 602 commercial potato fields in the UK between 1992 and 2004 revealed that two thirds of fields had a serious impediment to rooting within the potential root profile.

**Moisture stress**

Potatoes extract less water than cereals and have about half the effective rooting depth. Despite this, the crop’s leaf growth rate and canopy development is very sensitive to low soil moisture, so where compaction reduces the number of pores that hold water for crop uptake and the volume of soil available for root exploration this can impact significantly on yield (Hatley et al. 2005). However, where rainfall or irrigation is sufficient to meet crop
water requirements (i.e. generally cooler or wetter areas where the summer moisture deficit is moderate or low) yields are often not affected (Batey 1988; Towers et al. 2006), even where compaction has been shown to exist.

Waterlogging

Potatoes are also highly sensitive to waterlogging. Roots can be affected after even a short time, leading to premature root death and crop senescence. A number of potato diseases are also induced by waterlogging. These include Blackleg (Pectobacterium carotovorum subsp. Atroscepticum); Rubbery rot (Geotrichum candidum); and Powdery scab (Spongospora subterranea). Crop total and marketable yields can be significantly affected (Pierce & Burpee 1995).

Soil compaction and yield

There is evidence, both from sub-soiling experiments and from experiments with compaction treatments, that compaction decreases tuber yield. A number of unpublished experiments on effects of deep cultivations were done in the 1980s at ADAS Terrington. Some of these showed effects on potato yield, but many did not. One such experiment showed that a compaction alleviation treatment along the row (and below the tubers) increased total yield in 1981 (from 37.3 to 42.4 t ha⁻¹), but did not in 1982 when yields were greater (up to 60 t ha⁻¹). These results suggest that compaction caused yield loss in 1981 when water was limited, but not in 1982. O’Sullivan (1992) reported that sub-soiling increased yield (5.2–11.5%) in zero-traffic conditions, but not when there was normal trafficking. Ross (1986) found that sub-soiling increased yields (by around 100%) when water was limiting, but not at near optimum rates of irrigation. Rosenfeld (1997, cited by Allen & Scott, 2001) reported that yields of Maris Piper were decreased by compaction at 0.1 m and 0.4 m depth, both with and without irrigation.

Cultivations

The potato crop performs best on free draining soil and so is often grown on ‘sandy and light silty’ soils. These soils are not only erodible, but are also susceptible to severe over-compaction and will not recover with time as they do not shrink and crack when drying out (Marks and Soane 1987; BPC 2007). Furthermore, land often undergoes numerous cultivations in preparation for potato production. These can include ploughing, sub-soiling, a pre-ridging cultivation, deep ridging, deep-bed tilling, stone separation, planting and sub-soiling post planting. Over-working a soil can damage its structure and over-worked soils are more prone to slumping, compaction and capping, particularly if the soil has a high silt content.

There is, therefore, a delicate balance between carrying out the minimum number of cultivations to establish an adequate plant growth medium with sufficient consolidation, and over-working the soil, resulting in capping, slumping, compaction and increased soil erosion risk. Dickson et al. (1992) found that over three seasons, potatoes grown under a controlled traffic system gave mean increases of 14% and 18% in total and marketable yield, respectively, when compared with a conventional system, as a result of greater soil air-filled porosity in wet years and lower soil strength in dry years.

Surface run-off and erosion

In addition to the risks associated with compaction, surface run-off can also result in green or diseased potatoes, while soil erosion can result in the loss of soil resource and expensive remediation operations (soil replacement). Wind erosion on sandy and light silty soils can result in damage to young foliage and exposure of tubers. Methods that reduce the risk of water and wind erosion will therefore benefit potato crop productivity in the short and longer term (BPC 2007).
Best practice

Best soil management practice for potato production begins with the regular inspection of the soil down to 500 mm. Compaction beyond 700 mm may affect growth, but is difficult to alleviate (Batey 2009), but identification of compaction to 500 mm and appropriate alleviation through sub-soiling or pre-ridging cultivation (deep soil loosening in the row) can have a significant effect on yield (Pierce & Burpee 1995).

As with other crops, severe over-compaction can be avoided through timing cultivations when soils are at or below field capacity. However, the greater the number of cultivations the higher the risk that compaction will result at some level within the final beds. Indeed, compaction can occur (at various points in the bed and soil profile):

- Below plough depth from ploughing when the soil is ‘wet’ or from previous cropping operations
- Just above plough depth caused by the bed tiller or separator
- Under the bed and/or at the base of the ridge, where wheelings have extended beyond wheel width. Compaction under the bed reduces water availability to the crop. Compaction at the base of the ridge prevents water shed by capped ridges entering the soil
- Below the tuber caused by the blade/sharp-edged disc coulter cutting into the soil ahead of the potato planter

To keep compaction to a minimum, soils should be drier than the plastic limit when cultivated or travelled upon. According to the British Potato Council (2007) the risk of compaction can be reduced by:

- Reducing the weight of machines
- Spreading the load over a wider area, but without increasing wheel slip
- Selecting radial tyres that have a larger footprint than cross-ply tyres
- Using reduced tyre pressures

‘Best practice’ guidance (BPC 2007) recommends ploughing in the autumn to allow natural drainage channels and wormholes to form, which means the soil is quicker to dry out in the spring. If compaction is present and conditions allow, sub-soiling should be carried out at right angles to the direction of proposed drill lines.

In the spring, soil conditions should be checked by digging down to 300-350 mm and if required, pre-ridging cultivation can be used to loosen compacted soil at around 250-300 mm. This will allow the deeper ridger to work consistently. Timeliness is crucial, since using the deep ridger in unsuitable conditions can result in smearing at the base of the furrow and on the side of the ridge. Also, excessive tilth can produce fine soil particles that can lead to increased capping and ridge slumping, particularly in silty soils. Using the deep bed-tiller in unsuitable conditions can also create a pan at the base of the cultivation depth.

Stone separators should only be used if the soil has a high stone content. Routine use risks damaging soils and operating too deeply can result in smearing and wet material discharged to the wheeling. If tyres are not correctly aligned or if travelling across slope, the use of a separator can also result in compaction at the side of the bed. This can inhibit root development and increase soil erosion risk.

When planting, timeliness and tyre settings are important considerations. In addition, it is worth checking for compaction at the base of the drill edge and at the sides of the wheelings and alleviation should be carried out if conditions allow (Stalham et al. 2005). BPC guidance recommends the use of a tied ridger system on sloping land with sandy or light silty soils to reduce run-off in wheelings. Sub-soiling after planting is not
recommended, unless conditions are suitable, as sub-soiling the centre of wheelings can lift or push buried stones back into the ridges (BPC 2007).

At harvesting, the weight of the harvester is historically the greatest soil compaction threat, but in more recent times, the size of trailers has been such that they often have the highest ground pressure. The use of low ground pressure tyres is, therefore, recommended for all harvesting machinery. Minimising the number of passes on headlands can also reduce over-compaction in these areas.

There are opportunities to reduce damage at harvest through the use of appropriate machinery. However, the fact that maincrop potatoes are harvested later in the year when the soil is at or wetter than field capacity; they have to be lifted from the ground; and the weight of produce is in the range of 30-50 t/ha means that a degree of compaction is almost inevitable (Batey 2009). Cultivation to break up compaction of rutted surfaces immediately after harvest can reduce the risk of further serious compaction. Deeper cultivation (sub-soiling) can have adverse effects and should only be carried out where examination of the soil has shown that a layer of compaction is present in the subsoil, and that the soil is dry enough for fracturing to take place (Batey 1990). The same principle applies to other late harvested crops, such as forage maize and sugar beet.

Soil removal at harvest is also a significant issue, particularly for sugar beet and potato crops (British Sugar 2002; Ruysschaert et al. 2006). Soil removal at harvest is still regarded as the main process of soil loss associated with root crops (British Sugar, 2002) and it is estimated that 350,000 to 450,000 t of soil are removed with sugar beet at a rate equivalent to 6% of the beet yield. There is less evidence in the scientific literature on soil loss associated with potato harvest. Nevertheless, there is agreement that soil losses are much lower than those associated with sugar beet. For example, Ruysschaert et al. (2006) found mean rates of soil loss of 3.2 t/ha per harvest for potatoes as compared to 8.7 t/ha per harvest for sugar beet. A soil loss rate of 3 t/ha per harvest equates to a mean local annual rate of 1 t/ha for land used permanently for potato production in a three year rotation.

Poesen et al. (2001) report that erosion rates associated with sugar beet harvest in Belgium varied between 5 and 20 t/ha per harvest during the period between 1968 and 1995 and that most of this variability could be explained by differences in soil moisture content. Soil loss at harvest can therefore be reduced by avoiding harvesting in ‘wet’ conditions. However, root crop producers are restricted by contractual agreements and some years cannot easily avoid harvesting when the soil is ‘wet’.

Although potential yield benefits may be possible as a result of improved soil management in potatoes, there is probably greater potential in developing new varieties with improved resistance to pests and diseases and more efficient use of water and nutrients, through variety selection and breeding programmes (Dale et al. 2010).

Grass

Much of livestock production in England is based in the western regions where the combination of temperature, rainfall, soil and topography are optimal for high grass production and consequently the livestock that it supports. In these areas the rainfall is well distributed and the soils have a good water-holding capacity and grass-growth is not limited by extreme conditions. However, grassland with poor drainage may pose problems with the utilization of the sward, including grazing and machinery access and also be susceptible to compaction and poaching by animals (Frame et al. 1995). Grazing by both dairy and beef cattle can damage the soils under grassland by poaching. This can be a problem when the numbers of cattle are above the carrying capacity of the land or where cattle are over-wintered on grassland, particularly around gateways, feeding areas and watering points. This can lead to risks of soil erosion and compaction. Poaching can occur where the land is ‘cut-up’ through cattle moving or tramping on wet soils. This removes the vegetative cover, leaving the soil open to the elements and prone
to being washed away via surface water run-off. Soil erosion can not only remove fertile top soil and clog up drains etc., but can also lead to water pollution if the sediment is washed into watercourses.

The effects of compaction manifest themselves in decreased water infiltration or disrupted soil structure. The resultant losses in herbage production were first investigated in NW Europe with the rapid expansion of silage making. One of the threats to the soil in grassland systems has come from the increasing use of heavy machinery on swards which can cause compaction and other sward damaging effects. This is a problem particularly in swards that are cut for conservation. The losses in herbage production from compaction have been estimated to be broadly in the range 10 – 20% relative to zero or minimal traffic. This is in addition to the associated reductions in N and mineral components or offtake in the harvested herbage (Douglas 1994). Although, Tyson et al. (1992) found that the effect of drainage on both herbage production and liveweight gain were relatively small. The main benefit of drainage was in spring when herbage dry-matter was 11% greater on the drained plots. However, this was reduced to 3% when annualised due to the larger soil water deficit on the drained plots in the summer. Rarely is all the grassland on a farm poorly drained, and better use may be made of the well draining fields to carry the livestock during wet periods (Hopkins 2000).

Compaction may be relieved in grassland soils through spiking, sub-soiling or lifting the soil according to the prevailing conditions, but taking care not to exacerbate the problem with excessive trafficking. Mytton et al. (1993) showed that the introduction and maintenance of *Trifolium repens* in grasslands can have a significant benefit for soil structural amelioration. Reducing stocking density is one management tool available to farmers to reduce the risk of degrading soils on the farm. This, however, could conflict with production goals or targets. If it is necessary to out winter animals then woodchip pads may be considered (Chadwick 2009). These not only reduce compaction and poaching problems in the winter, but also may alleviate potential welfare and foot disease problems.

_Grazing systems and soil_

**Continuous stocking**: Animals have access to the entire grazing area for a large part of the grazing season. This is particularly appropriate in upland and rangeland systems where the level of production is low relative to available area and grass production. Modifications of this system are common in sheep and beef production. In these systems poaching may be a problem around gateways, feeding areas and water troughs.

**Rotational grazing**: The sward is grazed at intervals following a period of regrowth, with animals usually restricted to a number of paddocks. These systems are more common with dairy production, but are used in some lowland sheep and beef farms. In these systems the soil is more prone to compaction and poaching due to the risks from overstocking and particularly overgrazing when the soil is vulnerable in wet periods.

**Zero-grazing**: The sward is only subjected to cutting, with no grazing, the animals held in housing. There are some operational draw-backs to these systems in terms of energy and labour costs and hence are not widely used in the UK.

**Grass / clover systems**: Important in the provision of N to soils and have shown significant increases in milk yield. They may become more important as the cost of fertiliser N increases. Clovers have been shown to have a role in alleviation of compaction (Mytton et al. 1993).
4. Discussion of the similarities, differences and inter-relationships of the
two differently focused sets of ‘best practice’

To structure our discussion we have developed a matrix of potential soil management
best practices for environmental protection (see Table 1). This was based on the
inventory of guidance documents detailed at the end of section 2. For each ‘best
practice’, we have summarised its effect on soil, air and water (across a wide range of
pollutants) and identified whether or not there is a conflict between the ‘best practice’ and
the objective of maintaining or increasing production. Where a conflict exists, we have
described it in the matrix. Methane is excluded from the list of agricultural pollutants, since
emissions of methane from most agricultural soils are not significant. Methane emissions
from agriculture are dominated by enteric fermentation and manure storage. The
dominant greenhouse gas in the context of soil management is nitrous oxide (N₂O).
Emissions are affected by the degree of soil compaction and the proportion of water-filled
pores.

Bio-chemical oxygen demand (BOD), ammonia and faecal indicator organisms are also
excluded from the matrix as they are little affected by soil management methods.
Table 1. Matrix of soil management practices for environmental protection.

\[\text{↓ = a decrease; ↑ = an increase; ~ = no change; ? = direction of change unknown}\]

<table>
<thead>
<tr>
<th>No</th>
<th>Method Name</th>
<th>IMPACTS ON SOIL</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
<th>Nitrous Oxide</th>
<th>Carbon Dioxide (energy)</th>
<th>Conflict with increased production Y/N [and comments]</th>
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<td>Adopt reduced cultivation systems, minimum or non-inversion</td>
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<td>Cultivate compacted tillage soils</td>
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<td>Cultivate and drill across the slope</td>
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<td>Cultivate according to wind direction</td>
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<td>6</td>
<td>Leave autumn seedbeds rough</td>
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<td>Manage over-winter tramlines</td>
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<td>8</td>
<td>Maintain and enhance soil organic matter levels</td>
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<td>9</td>
<td>Loosen compacted soil layers in grassland fields</td>
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<td>Introduce rotational grass; include grass leys in arable rotation on susceptible land.</td>
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<td>Establish grass buffer strips</td>
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<td>Establish cover crops or green manures in the autumn</td>
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<td>Phosphorus Particulate</td>
<td>Nitrous Oxide (for nurse crops)</td>
<td>Carbon Dioxide (energy)</td>
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<td>Use nurse crops to limit wind blow</td>
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<td>Apply mulch to surface of seedbed</td>
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<td>15</td>
<td>Cultivate land for crops in spring rather than autumn</td>
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<td>17</td>
<td>Adjust irrigation application rates to suit field and soil conditions</td>
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<td></td>
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<td>21</td>
<td>Move feeders at regular intervals</td>
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<td>22</td>
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<td>~</td>
<td>↓</td>
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<td>~</td>
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<td>25</td>
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<td>↓</td>
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<td>26</td>
<td>Re-site gateways away from high-risk areas</td>
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<tr>
<td>29</td>
<td>Remove land from arable rotation and revert to permanent grass</td>
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<td>31</td>
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<td>32</td>
<td>Grow biomass crops (i.e. willow, poplar, miscanthus)</td>
<td>User Guide SOM Best Practice</td>
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**Similarities**

For the most part, soil management practices that help protect the environment also help maintain or increase production. The principles set out in the Defra Soil Protection Review (Defra 2009c) will both conserve soils and enable them to perform to their full potential in terms of food production. These principles include:

- Assessing the risks and presence of soil erosion, soil compaction and low soil organic matter contents
- Inspecting soils to determine the extent of soil capping and compaction (including nature and extent) (Defra 2009c, EA 2006a)
- Selecting soil protection measures to reduce threats from erosion and compaction processes and alleviate compaction
- Maintaining or enhancing soil organic matter contents

The above principles are inherent in the adoption of a ‘soil cultivation plan’ and underpin the management of soils for increased production. A cultivation plan is used to ensure that land is worked at the right time with the right machinery and that unstable soils are not overworked. The risks of causing compaction can be minimized by avoiding working or trafficking the land in wet conditions. However, guidance for environmental protection also acknowledges the fact that it is not always possible to avoid working soils when wet (e.g. NSRI 2002). In some years, soils are ‘wet’ for much of the autumn and the only alternative to avoid working the soil in sub-optimal condition is to wait until the spring when conditions may not be any better and a reduction in yield is highly likely in most years. Thus soil management guidance for environmental protection acknowledges that when soil damage is caused it is important to recognize it and put it right as soon as possible, which would also be of benefit to food and fibre production. This forms part of the Defra Soil Protection Review (Defra 2009c).

Soil compaction can increase the risk of soil erosion and reduce soil functions (and the ability of soil to deliver ecosystem services such as water regulation). Soil compaction can also reduce crop yield potential (Allen and Scott 2001; ADAS 1984; Blake et al. 2006), particularly in dry years. Sub-soil compaction has greatest impact on spring crops grown on light soils (Marks & Soane 1987) as these soils do not shrink and crack through the season. Johnston and Poulton (2009) assert that good soil structure (and soil organic matter) is important to maximise crop yield, especially for spring crops that need to develop a root system quickly to meet the rapid development of the above ground parts. This is supported by evidence from experiments they report from Rothamsted and Woburn.

**Alleviating compaction**

There is detailed guidance on the alleviation of compaction in arable situations (NSRI 2002; Spoor 2006). A number of studies have shown that sub-soiling can increase yields where the soil is over-compacted below the topsoil, but guidance recommends and research has found that it is very important to check for the presence and depth of compaction before alleviation is carried out. Sub-soiling when there is no compaction present can reduce yields (Spoor et al. 2003). Equally, timeliness and depth of operation is crucial in that sub-soiling too deep or when the soil is too ‘wet’ can cause smearing and additional compaction and sub-soiling when too dry will require additional draught power. There is some concern that with the use of larger and heavier machines for tillage and harvest the depth and extent of compaction has increased in recent times (Hakansson & Reeder 1994; Batey 2009). However, in the UK this is largely based on circumstantial evidence. Over-compaction at depths below 40 cm is difficult to alleviate and may be permanent in soils that do not crack naturally, resulting in possible permanent reductions in yield (Hakansson & Reeder 1994). There appears, therefore, to be a need to develop cost-effective techniques for the alleviation of deep-seated compaction in an agricultural context.
Alleviating compaction in grassland reduces the risk of run-off and erosion and improves water holding capacity and the ability of soil to store and regulate water. Loosening compacted soil layers in grassland can also increase grass yield (ADAS 1984). However, if the loosening is carried out in the wrong conditions or at the wrong time of year yield reductions can result (ADAS 1984; Frost 1988). Loosening in the spring can give rise to sward and root damage resulting in lower yields (compared with no loosening) for the first cut of grass. If the loosening is carried out when the soil is ‘wet’ the damage to the sward and to the soil can result in more persistent reductions in yield. So, as in the arable context, careful assessment of the need for loosening as well as timeliness, implement size, geometry and depth (of operation) are crucial to the success of any soil loosening operation.

Maintaining or enhancing soil organic matter contents

The importance of soil organic matter in improving crop yields is illustrated by examples from experiments at Gleadthorpe, Rothamsted and Woburn (Bhogal et al. 2009; Johnston and Poulton 2009). For example, on the Barnfield experiment at Rothamsted yields of root crops and spring barley between 1968 and 1973 were always larger on the soils with more soil organic matter, irrespective of the amount of N applied. Similar patterns were observed for spring-sown crops at Woburn between 1973 and 1980, but yields of the autumn/winter sown crops were independent of the level of soil organic matter (Johnston and Poulton 2009). This suggests that spring crops are more susceptible to poor structure and low SOM contents than autumn-sown crops as they need to develop a sufficiently large root system quickly to acquire nutrients and water. Autumn-sown crops have a long period to develop an adequate root system.

Nevertheless, soil organic matter content appears to be important in maximising crop yields, particularly for high value crops such as potatoes for which there is potential to increase domestic production and reduce dependence on imports.

Reduced cultivation systems

There are a variety of zero/reduced cultivation systems available to farmers, ranging from direct drilling of cereals or spreading seed directly behind the legs of a sub-soiler for oilseed rape to the use of a disc and tine combination to a depth of less than 15 cm that still leaves 30% cover of residue at the surface (SMI 2005). Environmental benefits include greater residue cover, improved soil structure and reduced soil erosion risk. Field experiments have shown that reduced cultivations do not necessarily reduce yields (Bowerman et al. 1995; Christensen et al. 2003; NSRI 2002; Sauzet et al., 2003; SMI 2005) and that yields of cereals can even be increased (HGCA 1988; Davies and Finney 2002). The emphasis in the Soil Management Initiative (SMI) literature is on reduced cultivation providing potential to save establishment costs and improve profit/loss margins rather than increasing yields.

In two reviews (HGCA 1988; Davies and Finney 2002) of long-term field experiments on more than 200 sites throughout the UK, it was noted that well managed shallow cultivation or direct drilling usually gave as good or better yields of winter cereals as ploughing. Straw was either burnt or bailed and grass weeds were either controlled by overall applications of herbicides or individual applications on affected plots. Establishment of spring cereals by reduced tillage or direct drilling tended to be less successful than winter crops except where soil conditions were particularly good. In those experiments where reduced tillage or direct drilling gave lower yields, greater populations grass weeds and topsoil compaction and/or loss of structure were the major causes. Risks from slug damage have been found less on drier finer well consolidated seed beds associated with reduced tillage. Coarse cloddy and poorly consolidated seedbeds particularly in wet years and in the presence of straw are thought to favour greater slug activity and increase lodging and phoma infection in oilseed rape (Sauzet et al. 2003). Improved timeliness benefits of cultivation (not working the soil when it is too wet or too dry) are particularly associated with reduced tillage systems. It is also very important to
make sure any sub-surface compaction has been removed before adopting a reduced cultivation system.

It would seem, therefore, that there is great potential to adopt reduced cultivation systems to improve economic margins on farm and for environmental benefit without compromising yields. However, these techniques are more difficult on sandy soils and light loams and where topsoils contain many stones, and reduced cultivation does require greater attention to details of timeliness and soil assessment than plough based systems (SMI 2005). Reduced cultivation systems are also less successful for spring cereals (Davies and Finney, 2002).

Leaving seedbeds rough

Little evidence could be found as to the effectiveness of rough seedbeds in reducing soil erosion from agricultural land. However, it is known that a coarse seedbed reduces the rate and incidence of soil surface capping and that capping can significantly reduce water infiltration rates and the risk of run-off and soil erosion. The guidance (Defra 2009a and 2009c) is quite clear that a rough seedbed is encouraged in cereal crops, but not for small-seeded crops, such as oilseed rape that need good seed to soil contact to achieve good plant establishment (Stokes et al. 2000). However, it is important to establish whether a coarse seedbed in itself is likely to have any impact on the yield of cereal crops.

It is difficult to determine the effect of tilth on crop yield in isolation. For example a number of researchers have measured the effects of tillage energy and wheel traffic on subsequent tilth. Patterson et al. (1980) showed that different specific energies associated with different primary tillage equipment resulted in a range of different tilths. In essence deeper cultivation resulted in coarser tilth which then required more energy to produce a seedbed which under dry conditions was often far more coarse. These experiments were carried out over four years and on three sites (Boxworth, Rothamsted and Silsoe). Clay soils often resulted in coarser tilth. However, with the exception of direct drilling in wet years there was no significant difference in the yields of winter wheat. Using powered and draught secondary cultivation following ploughing Chamen et al (1996) produced a range of different tilths, with fine tilth associated with high energy powered cultivation and coarse tilth linked to lower energy draught implements. Again tilth appeared to have no significant influence on winter wheat yields.

In conclusion, there appears to be no reason why a coarse tilth in cereals should result in reduced yields. Provided that cultivation does not result in the compression or deformation of clods or peds and that herbicide activity is not compromised by a coarser tilth, cereal yields should not be compromised.

Early establishment of crops in the autumn

Early establishment of crops in the autumn reduces soil erosion risk during the late autumn and winter months (Chambers et al. 2000; Evans 1990). Research in the 1980’s and 90’s has shown that early establishment can increase winter cereals yields. Green et al. (1985) found a 0.35% reduction in wheat yield and a 0.43% reduction in barley yield for every day of sowing later than mid September. In a three year study, Thorne et al. (1988) found that sowing winter wheat early (before mid September) increased grain yields by 0.4 to 0.7 t/ha on a clay soil, but increased yields in only one year (1.6 t/ha) on a sandy soil. Widdowson et al. (1986) observed grain yield increases of 0.6, 1.7 and 0.2 t/ha when winter barley was sown early at Rothamsted between 1980 and 1983. However, there were interactions with other treatments. Tinker et al. (1984) reported a 0.45 t/ha benefit from sowing winter wheat early.
The above studies confirm that environmental protection and increases in production are possible from the early establishment of winter cereals in most years. However, early establishment may also give rise to the following issues:

- An increase in the need for agro-chemicals, particularly in areas where ‘black grass’ is a problem
- Increased lodging risk if seed rates are not reduced and soil nitrogen supply is high
- Increased ‘take-all’ risk in second and third wheats

**Other methods**

There are a number of soil management methods for environmental protection that do not conflict with food and fibre production. These include:

- Cultivate and drill across the slope
- Cultivate according to wind direction
- Manage over-winter tramlines
- Maintain field drainage systems
- Reduce the length of the grazing day/grazing season
- Adjust irrigation application rates to suit field and soil conditions so that the risk of surface run-off and wind erosion is minimised
- Move feeders at regular intervals
- Construct troughs with permeable base
- Fence off rivers and streams from livestock
- Construct bridges for livestock crossing rivers/streams
- Re-site gateways away from high-risk areas
- Farm track management
- Establish new hedges

**Conflicts**

Most conflicts arise between food and fibre production and environmental protection, either due to measures that reduce the area of food production (i.e. arable crops or livestock), or due to operations on the cropped area that result in sub-optimal conditions for crop establishment and growth. Some conflicts arise where practical considerations limit uptake of environmental protection methods. For example, cultivating and drilling crops across the slope can reduce soil erosion risk (Deasy et al. 2008), but farmers are reluctant to adopt the practice due to health and safety considerations, and in some fields it would result in machinery having to turn more frequently and cause more headland compaction.

The conflict between food production and environmental protection that results from taking targeted areas out of production is recognised in Environmental Stewardship schemes through payment to farmers for income foregone. Nevertheless, the introduction of such measures still results in a loss of food or fibre production.

A number of soil management methods that can help reduce soil erosion or increase soil organic matter levels conflict directly with the production of arable crops and/or grassland. These include:

- Methods that result in the conversion of arable land to (permanent) grassland, either as buffer strips or larger areas (e.g. field corners) – which reduce the area of arable crop production, but in some circumstances (e.g. when applied to whole fields) can increase the area for livestock production.
• Not growing high risk crops, such as potatoes, maize and sugar beet on high erosion risk land. This method reduces the area of production for these crops, but not all crops.
• Growing cover crops, while very effective in reducing soil erosion can have negative effects on the yield of following crops.
• Delaying cultivations over the summer to autumn or from autumn to spring is recommended as an environmental protection measure to reduce soil erosion risk. However, this can significantly reduce the yield of following crops, especially when wet weather coincides with the delayed cultivation. Cultivating land in spring rather than autumn is not ideal for many ‘medium’ and all ‘heavy’ soils that need over winter frosts to help break-down the structure of ploughed soils.
• Early harvesting of maize and potato crops in the autumn reduces the risk of soil compaction and subsequent problems with increased surface run-off and soil erosion from sloping land. However, the use of early maturing varieties can also impact on yields due to a shorter growing season.
• Introducing grass leys (of two or more years duration) into an arable rotation will increase soil organic matter levels, reduce soil erosion risks and often increases yields of the following arable crop (Johnston et al. 2009), but will reduce the overall production of arable crops over the rotation.
• In grassland systems, over-stocking can significantly increase the soil erosion and compaction risks. However, any reduction in livestock numbers will inevitably have an impact on food production from grassland.
• Reducing stocking rates when soils are wet helps avoid soil compaction and reduces run-off and soil erosion. However, it is common practice on many farms to out winter livestock on fields. This will inevitably increase soil compaction and increase surface run-off and soil erosion from sloping land.

Cover crops can have both positive and negative effects on nitrogen dynamics in the following crop (most commonly a cereal) (Thorup-Kristensen et al. 2003) and the late incorporation of the cover crop can result in a reduced window of opportunity for cultivations to establish the following crop, especially if weather conditions are not favourable, resulting in a coarse seedbed with deformed and compressed soil clods as well as difficulties with burying the cover crop residue.

Delaying cultivation can move operations to a time when other field activities are competing for a farmer’s time. For example, delaying cultivation after pea harvest moves the operation from June/July when there is little on-farm activity and soils are often in a good condition for cultivation to September/October when farmers need to harvest and establish crops across large areas of many arable farms and the weather may not be suitable for primary cultivations.
5. Conclusions – commonalities and conflicting interests

Commonalities

There are a number of best management practices where environmental protection is in line with maintaining or increasing production (i.e. ‘win-win’ situations). For example, increased crop yields will return more organic matter to soils and organic material additions will increase soil organic matter/carbon storage and long-term crop yields etc. (Johnston & Poulton 2009).

Best management practice for both environmental protection and maintaining production encourage the following activities:

- Assessing soil erosion risk
- Assessing soil compaction risk
- Regular soil inspections
- Producing a cultivation plan (avoid cultivation when the soil is ‘wet’)
- When soil damage is caused alleviating it as soon as conditions allow
- Managing grasslands to minimise poaching
- Maintaining or enhancing soil organic matter levels

Maintaining or enhancing organic matter levels could be an important part of increasing crop production, particularly for spring crops that need good soil structure to rapidly develop an adequate root system (Bhogal et al. 2009; Johnston & Poulton 2005). In addition, the following methods should not impact on production in most circumstances and in some cases can increase it:

- Early establishment and harvesting of crops in the autumn
- Reduced cultivation systems
- Leaving cereal seedbeds rough
- Cultivate and drill across the slope
- Manage over-winter tramlines
- Maintain field drainage systems

Conflicts

Conflict exists where the nature or timing of soil management operations for environmental protection result in competition with other farm activities or the potential for reduced yields. For example, growing a cover crop on medium/heavy soils to protect soils from erosion can result in loss of yield in the following crop due to changes in nitrogen dynamics (Thorup-Kristensen et al. 2003) and/or late cultivation and incorporation of the cover crop resulting in a poor seedbed and poor establishment.

Other methods reduce the area for arable food production through the reversion of arable land to (permanent) grassland, energy crops or woodland (in some circumstances this can increase the area for livestock production or fibre production). These include any methods that result in the conversion of arable land to grassland, either on buffer strips or larger areas (e.g. field corners) as part of targeted Environmental Stewardship schemes or due to not growing high risk crops, such as potatoes, maize and sugar beet, on high risk land.

Early establishment of crops in the autumn has the potential to reduce soil erosion on sloping land and increase yields, but if not managed correctly, early establishment can also increase agro-chemical use and increase the risk of ‘take-all’ and lodging later in the season. The main methods where a conflict between production and environmental protection can exist are:
• Establish grass buffer strips – thereby reducing the arable cropping area
• Establish cover crops in the autumn
• Cultivate land for crops in spring rather than autumn
• Delay cultivation in the autumn
• Reduce field stocking rates when soils are wet
• Reduce overall stocking rates on livestock farms
• Remove land from arable rotation and revert to permanent amenity grass/heathland in targeted areas – this reduces food production
• Arable reversion to low fertiliser input extensive grazing – this is distinct from the above method in that the reverted grassland is used for livestock production
• Establish permanent woodlands
• Grow biomass crops (i.e. willow, poplar, miscanthus) – this reduces food production but increases fibre production

6. References


ADAS 1983 To Plough or Not to Plough? Her Majesty’s Stationery Office. ISBN 0 11 2425542.


Defra 2005a *Controlling Soil Erosion – Incorporating Former Advisory Leaflets on Grazing Livestock, Wind, Outdoor Pigs and the Uplands*. Published by the Department for Environment, Food and Rural Affairs. 44pp.


Defra 2009b *Cross Compliance Soil Protection Review 2010*. Published by the Department for Environment, Food and Rural Affairs. 50pp.


Defra 2009d *NVZ Guidance leaflets*. Defra publications.


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Annex I - Soil Management Guidance Documents

This annex provides an outline of the principal soil management guidance available in England and Wales, including an inventory of best soil management practice methods available to farmers.


Best management practices

The Code describes key actions that farmers can take to protect and enhance the quality of soil. The key soil management practices mentioned in the Code are:

- Establish cover crops or green manures in the autumn
- Early harvesting and establishment of crops in the autumn
- Cultivate land for crops in spring rather than autumn (overwintered stubbles)
- Maintain and enhance soil organic matter levels (including the incorporation of crop residues)
- Cultivate compacted tillage soils
- Consider direct drilling or reduced tillage systems
- Drill across the slope where possible
- Consider delaying establishment of tramlines
- Prepare as coarse a seed bed as you can that will still produce a good germination and ensure the effectiveness of any pre-emergence herbicides
- Do not leave a fine seedbed unplanted after combinable crops
- Adopt livestock systems that are appropriate for your soil
- Move livestock to other fields/paddocks (or indoors) when problems of run-off and erosion occur
- Fence off rivers and streams from livestock
- Consider providing hard standing around permanent feeders, water troughs and in gateways
- Move feeders at regular intervals to avoid poaching in all situations where it will lead to run-off or erosion (a legal and cross-compliance requirement on natural or semi-natural vegetation)
- Consider relieving compaction in grassland soils to improve infiltration and drainage
- Produce and follow a manure management plan
- Produce and follow a soil management plan (including matching crops and rotations to soil capability, protecting archaeological remains, timeliness of operations, inspecting soils and producing a risk map for run-off and erosion)
- Maintain field drainage systems
- Establish buffer strips alongside surface waters at the bottom of slopes (but do not rely on such areas at the expense of good soil management in the rest of the field)
- Do not plough permanent grass for arable production in places where the risk of erosion is high, such as on slopes or in river valleys that flood
- Relocate gateways away from high risk areas

The aim of a manure management plan is to ensure that manure is applied in suitable conditions, using suitable techniques and at suitable application rates to reduce the risk of causing soil compaction and the risk of environmental pollution (soil, air and water) from manures. Through considering slope, soil type and the position of surface waters and water supplies, a manure management plan can help identify fields or parts of fields where and when livestock manures and dirty water can be spread and where they should never be spread.
The aim of the soil management plan is to maintain optimum conditions for crop growth while minimising the risk of run-off and erosion. Readers are referred to the ‘Cross Compliance Guidance for Soil Management’ (Defra 2006) and ‘A guide to better soil structure’ (NSRI 2002).

The Code has a 24 page section on ‘Field Work’, which includes sections on ‘soil management and cultivations’; ‘management of peat soils’; ‘application of livestock manures and dirty water’; ‘application of organic wastes’; and ‘managing livestock’. The soil management and cultivations section is based on ‘Cross Compliance Guidance for Soil Management’ (Defra 2006) and ‘A guide to managing crop establishment’ (SMI, 2005). It includes guidance on how to implement, follow and review a soil management plan; and the selection of riparian buffer strips or larger areas of arable reversion grassland. There is also guidance on enhancing or maintaining soil organic matter contents, primary cultivations (particularly timeliness and appropriate cultivation depth), reduced tillage systems and avoiding compaction at harvest.

The ‘Field Work’ section of the Code also suggests that farmers ‘manage the crop’ by:

- Cultivating wheelings (in row crops or bed systems) and tramlines (in combinable crops) to loosen any compaction if it is causing run-off and erosion.
- Using a tined weeder or similar implement within the crop to break up capped soils that are causing run-off.
- Ensuring irrigation is applied evenly and that droplet size is not too big to prevent sealing or capping of the soil surface and to reduce run-off.

On light or other blowing soils prone to wind erosion, the Code suggests that farmers should:

- avoid high risk crops, such as sugar beet and some vegetables, on the most exposed fields;
- establish windbreaks;
- direct drill or drill in to a ‘ploughed and pressed’ surface;
- plant straw to protect emerging seedlings;
- apply a surface mulch such as farmyard manure;
- sow nurse crops such as barley to stabilise the soil and protect seedlings.

The section on ‘management of peat soils’ focuses on the protection of the peat resource by avoiding erosion (controlling stocking rates and public access), drainage, lowering of the water table, spray drift or nutrient enrichment of peat. It is suggested that farmers “fence off areas of eroding soil to help the vegetation to re-establish”. The Code also suggests that “blocking grips and surface drains can also reduce erosion”, but that the Environment Agency should be consulted to ensure these practices work correctly and do not lead to more serious flooding downstream. Bare soil should not be left during bracken management and vegetation should not be burned if it will leave a bare surface that is at risk of erosion.

For lowland peat, it is stated that growers should “minimise the oxidation (shrinkage) of the peat by keeping the water-table as close to the surface for as long as possible consistent with the need to manage such land for food production...(and)...consider reinstating natural peat mire conditions”.

The section on ‘managing livestock’ emphasises the fact that the impact of livestock systems on farm should be incorporated into the farm ‘soil management plan’, including being prepared to move livestock from a field if soil problems (e.g. poaching, run-off, erosion) occur. The Code recognises that extended grazing can be a cost-effective system, but that such a system (e.g. the New Zealand Grazing System) “should only be considered on suitable sites where the risk of poaching, erosion and run-off can be
managed to maintain the productivity of the sward and prevent water pollution." Similar principles are described for outdoor pigs and poultry.

The Code also includes sections on 'soil handling' and 'turf production'. Farmers should ensure that these practices are carried out in line with regulations and best management practice in relation to storage, movement/handling and after care of soils. Best management practice includes assessing the soil resource prior to movement, planning storage and re-instatement and avoiding the movement/handling of soils when they are 'wet' and are prone to deformation (i.e. soil water content is above the plastic limit). This is in line with the principles of timeliness for cultivations, stocking and other land management practices on farm.

Farming systems

The Code covers good practice applicable to all farming systems.

Soil types

Guidance is not split by soil type, although there is a short section in the Code specific to the management of peat soils. When applicable the Code also highlights where there are soil type specific management risks.


Best management practices

The Manual describes key actions that farmers can take to assess the risk of erosion and management practices that can be used to prevent or minimize soil erosion. The key soil management practices mentioned in the Manual are, in brief:

• Targeted removal of land from arable rotation and revert to permanent amenity grass/heathland
• Arable reversion to low fertiliser input extensive grazing
• Introduce rotational grass; include grass leys in arable rotation on susceptible land.
• Plant hedges or build new ditches to restrict run off, or direct run off water away from areas prone to erosion
• Grow rows of trees or hedges to provide protection for soil and crops grown on the sheltered side
• Targeted establishment of permanent woodlands
• Establish cover crops (e.g. rye, mustard or grass) or green manures in the autumn
• Use nurse crops to limit wind blow
• Early harvesting and establishment of crops in the autumn
• Cultivate land for crops in spring rather than autumn
• Adopt reduced cultivation systems, minimum or non-inversion techniques and direct drilling
• Include periodic ploughing or subsoiling in minimum tillage systems
• Cultivate and drill across the slope
• Leave autumn seedbeds rough and press lighter soils when moist, preferably just before you sow the crop
• Maintain and enhance soil organic matter levels
• Use appropriate machinery to avoid soil damage
• Adjust irrigation application rates to suit field and soil conditions so that the risk of surface run-off is minimised
• Avoid compaction, particularly on the surface, and correct any problems before sowing
• Set up tramlines after the crops have emerged and do not use them until the spring. If this is not practical, a shallow tine behind the wheel can break up compacted soil
• Select sites for outdoor pigs which minimise the risk of erosion. Take account of slope, soil type and rainfall. Maintain grass cover on any sites where this is necessary to prevent run off
• Apply mulches to the surface of seedbeds on sandy soils at 5-15 t/ha after drilling

Farming systems

The Manual covers good practice applicable to all farming systems but includes chapters focusing on management practices particularly targeted at lowland grazing livestock, outdoor pig and upland farming systems.

Soil types

The manual highlights the soil types most at risk from:

a) water erosion - sandy soils in southwest and southeast England, East Anglia, the Midlands and South Wales, as well as chalky soils on the South Downs, Wolds and in East Anglia and for

b) wind erosion – bare sandy and peaty soils between March and June in East Midlands, Vale of York and East Anglia.

The importance of soil type for identifying on-farm erosion risk is recognised. Some management practices are differentiated by soil type, where the practice is only suitable for use on a particular soil type.


Best management practices


The Guidance includes a section on ‘Managing soils on your farm’, which is split into sections on specific soil-related problems:

• Compaction
• Run-off and erosion
• Poaching
• Waterlogging
• Wind erosion
• Maintaining soil organic matter

‘Managing soils on your farm’ focuses on recognizing these soil-related problems and preventing soil eroding from fields, maintaining soil organic matter and maintaining good soil structure.

The Guidance lists twelve general principles of good husbandry:
i) Prepare and follow a soil management plan and, for cross compliance, complete a Soil Protection Review.

ii) Prepare and follow a nutrient management plan.

iii) Wet soils are more easily damaged by cultivation, harvesting, trafficking and livestock. Timeliness of activities and not overworking soils are critical to maintaining soils in good condition.

iv) Drainage extends the season for field operations and grazing, especially in autumn and spring periods.

v) Soil organic matter improves soil stability and increases workability.

vi) Look at soils during and after rain to identify areas of poor drainage and surface soil stability.

vii) If you have to travel on or work wet soils, reduce the load with low ground pressure set-ups, or set tyre pressures at the lowest pressure that is compatible with the load and tyre type.

viii) Regular use of a spade to look for any compaction in the topsoil or subsoil helps you make decisions on cultivations, loosening and subsoiling. Deeper cultivation is often needed on tramlines, headlands and gateways to remove soil compaction.

ix) Grow crops that match the capability of the land. When growing crops that require late harvesting, be prepared to correct any compaction or structural problems if they occur. Out-wintering of stock should be carried out on land that has good drainage. Stocking rates should be adjusted to minimise compaction and any runoff to watercourses caused by poaching.

x) Operating machines on sloping ground increases the possibility of overturn and likely injury. When carrying out your soil management planning, it is good practice to consider the limitations of the equipment you have available and avoid unnecessary risks to your safety.

xi) Consider the risks of runoff and erosion when planning what to grow or your stocking on sloping land and which management practices to adopt.

xii) Where severe erosion occurs, earth banks or other physical barriers may be used as a last resort to check the flow of water.

It then provides guidance on management requirements, good husbandry and the main problems associated with the five different cross-compliance soil types, which are:

- sandy and light silty soils;
- medium soils;
- heavy soils;
- chalk and limestone soils; and
- peaty soils.

Definitions for each cross-compliance soil type are given in the relevant soil type section and in the Appendix. Section 4 of the Guidance outlines the risks to soils and the soil protection measures that can be adopted when carrying out the following ten farm activities:

A. Cereals, combinable crops, grass seed
B. Potatoes, sugar beet, salad crops, vegetables and bulbs
C. Maize and forage crops
D. Fruit crops (not under poly tunnels); hops; vines
E. Polytunnels (field)
F. Turf production
G. Outdoor pigs & poultry
H. Short Rotation Coppice, Miscanthus and Rhizome Production
I. Improved Grassland (including equine)
J. Natural and Semi-Natural Grassland and Vegetation
K. Other Land Use Types e.g. Flowers (not bulbs), Herbs, Nurseries, Pharmaceutical Crops, etc.
L. Agricultural Land not in agricultural production or used for non-agricultural activities

These same ten farm activities are used to structure the ‘Farm Soil Plan’ within the ‘Soil Protection Review’. The SPR involves a risk based approach whereby the soil issues on farm are first identified and then a ‘Soil Risk Record’ (map or table) is completed according to the soil types found on the farm. Finally, a ‘Farm Soil Plan’ is completed, which involves the selection of soil protection measures from a list of 6-17 measures per farm activity/land use (see A to L above). In all, there are 55 distinct soil protection measures to choose from across all ten farm activities.

Farming systems

See A-L above

Soil types

See the five cross-compliance soil types above.

Environmental Stewardship Scheme – Stewardship Handbooks - 2008 Edition

The agri-environment schemes in England and Wales (Entry Level, Organic Entry Level and Higher Level Stewardship in England; Tir Cynnal, Organic Farming Scheme and Tir Gofal in Wales) aim to encourage farmers and land managers to deliver simple yet effective environmental management that goes beyond the requirement to maintain land in Good Agricultural and Environmental Condition (GAEC). The primary objectives of the stewardship schemes are to:

- Conserve wildlife (biodiversity) – including birds, mammals, butterflies and bees
- Maintain and enhance landscape quality and character
- Protect the historic environment – including archaeological features and artefacts
- Promote public access and understanding of the countryside
- Improve water quality and reduce soil erosion and surface run-off

Therefore while the principal aim of environmental stewardship schemes has been to improve biodiversity and enhance landscape character many of the options contribute towards soil protection and reducing the risk of soil erosion and surface surface run-off. The Entry Level Stewardship options that relate to soil management are:

- **EC1 Protection of in-field trees on arable land**
  (“Do not carry out any cultivations under the canopy of the tree.”)
- **EC4 Management of woodland edges**
  (“Do not cultivate within 6 m of the woodland edge.”)
- **ED2 Take out of cultivation archaeological features that are currently on cultivated land** (effectively arable reversion)
- **ED3 Reduced-depth, non-inversion cultivation on archaeological features**
  (minimum till) – maize, root and tuber crops (excluding non-harvestable root crops such as grazed fodder beet and forage turnips) cannot be grown.
- **ED5 Management of archaeological features on grassland**
  (“Maintain a continuous grass sward; do not supplementary feed on or next to the archaeological feature; minimise the use of heavy vehicles on the feature; do not locate water troughs, mineral licks, etc, in such a way as to cause poaching on or next to the archaeological feature.”)
- **EE1 – EE8 Options for buffer strips at field margins and round in-field ponds**
- **EF1 Management of field corners** (arable reversion to grass)
• **EF2 Wild bird seed mixture**
  (Farmers have to ensure that any areas of soil compaction are removed prior to establishment. On sandy soils, strips must be sown along contours.)

• **EF4 Nectar flower mixture**
  ("Remove any compaction in the topsoil if you need to prepare a seedbed").

• **EF6 Overwintered stubbles (Cultivate land for crops in spring rather than autumn) — ("…a light surface cultivation can be made before the end of September or within the first month following harvest if later, to encourage weed germination and loosen any surface compaction or capping. If the stubble is already weedy, do not cultivate. On sloping fields, tramlines and other areas of severe compaction should always be subsoiled following harvest (except where there are archaeological features or when conditions are wet), to reduce the risk of run-off and erosion").

• **EF7 Beetle banks**
  (Creation of an earth ridge reverted to grass across an arable field)

• **EF10 Unharvested cereal headlands within arable fields**
  (Includes instruction to “take action to remove any surface compaction in tramlines within the headland, if they are causing run-off").

• **EG1 Undersown spring cereals**
  ("Do not destroy the grass ley before 15 July of the following year").

• **EG2 Wild bird seed mixture in temporary grassland areas**
  ("Ensure that any areas of soil compaction are removed prior to establishment, except on sites of archaeological interest. On sandy soils, strips must be sown along contours.")

• **EG3 Nectar flower mixtures in grassland areas**
  (Includes an instruction to “remove any compaction in the topsoil if you need to establish a seedbed, except on archaeological features").

• **EG4 Cereals for whole-crop silage followed by over-wintered stubbles**
  ("Where soils are capped, undertake a light surface cultivation within the first month after harvest. On sloping fields, remove tramline compaction.")

• **EJ2 Management of maize crops to reduce soil erosion**
  ("Harvest by 1 October and plough or cultivate to leave a rough surface, ideally within two weeks of harvest, to reduce subsequent soil erosion; or harvest by 1 October and establish an autumn-sown crop; or undersow the maize with a grass- or clover-based mixture and after harvest (ideally within two weeks) remove any areas of soil compaction. Do not subsoil areas on sites of archaeological interest.")

• **EK1 & EL1 Take (grassland) field corners out of management**
  (Includes instruction to “cut no more than once every 5 years”; and “do not graze").

• **EK2 & EL2 Permanent grassland with low inputs**
  (Includes instruction to “move feeders as often as required to avoid poaching”; and “do not feed on or next to archaeological sites, steep slopes, footpaths or watercourses").

• **EK3 & EL3 Permanent grassland with very low inputs and EK4 & EL4 Management of rush pastures**
  (Include an instruction not to supplementary feed livestock.)

• **EK5 Mixed stocking**
  ("Supplementary feeding is allowed, but move feeders as often as required to avoid poaching. Do not feed on or next to archaeological sites, steep slopes, footpaths or watercourses.")

• **EL5 Enclosed rough grazing (SDA land within the LFA and Moorland Line parcels under 15 ha)**
  (Includes instruction not to plough, cultivate or reseed; not to install any new land drainage or modify any existing land drainage, or remove any peat or sediment; not to increase existing stocking levels; and not to supplementary feed.)

• **EL6 Unenclosed moorland rough grazing (Moorland Line land only)**
  (Includes the following instructions: “do not plough, cultivate or reseed;…do not install any new land drainage or modify any existing land drainage, or remove any peat or sediment from drainage channels;…do not supplementary feed using silage or other forage wrapped in plastic; do not use ring feeders or troughs; move all feeding sites
regularly to minimise damage to vegetation and soils; and take care to avoid damage by vehicles."

Under options for Severely Disadvantaged Areas (SDA’s) including Moorland Line land, farmers are encouraged to manage land in a way that promotes good soil structure and infiltration of rainwater to avoid run-off. The guidance encourages farmers to consider the following actions:

- Reduce stocking rates
- Reduce or avoid grazing when the soil is wet
- Alleviate compaction, for example by subsoiling or spiking (provided there are no buried earthworks or archaeological remains)

**Farming systems**

The Environmental Stewardship Schemes focus on arable and grassland farming systems.

**Soil types**

The Schemes cover all soil types, but some options focus on sandy and light silty soils on sloping land (i.e. land prone to erosion)


**Best management practices**

The ‘Think Soils’ manual is a practical guide to soil assessment, which also includes an overview of general land management principles including the following best management practices for soil management:

- Establish grass buffer strips
- Establish cover crops or green manures in the autumn
- Cultivate according to wind direction
- Maintain and enhance soil organic matter levels
- Establish new hedges
- Use nurse crops to limit wind blow
- Cultivate wheeling's between beds and along headlands to aid infiltration
- Cultivate headlands and gateways to remove compaction following planting

**Farming systems**

‘Think Soils’ considers the factors that influence erosion and run-off for the following farming systems: cereals, livestock and root crops, and vegetables.

**Soil types**

All soil types are considered within the ‘Think Soils’ manual, with a section on identifying soil structural problems in the field and case studies split by cross compliance soil type, i.e. ‘sandy and light silty’, ‘medium’, ‘heavy’, ‘chalk and limestone’, and ‘peaty’ soils.

Best management practices

Best Farming Practices sets out practical steps that farmers can take to benefit the environment and their business. The following lists the key actions in Best Farming Practices that farmers can take to protect and enhance the quality of soil.

- Establish grass buffer strips
- Establish cover crops or green manures in the autumn
- Early harvesting and establishment of crops in the autumn
- Use a cultivation plan; the type and timing of cultivations should be planned to minimise the periods when the soil is left in its most vulnerable condition
- Adopt reduced cultivation systems, minimum or non-inversion techniques and direct drilling
- Include periodic ploughing or subsoiling in minimum tillage systems
- Cultivate and drill across the slope
- Leave autumn seedbeds rough
- Maintain and enhance soil organic matter levels
- Reduce the length of the grazing day/grazing season
- Reduce field stocking rates when soils are wet
- Fence off rivers and streams from livestock
- Use appropriate machinery to avoid soil damage
- Use nurse crops to limit wind blow
- Cultivate wheeling’s between beds and along headlands to aid infiltration
- Cultivate headlands and gateways to remove compaction following planting

Farming systems

The publication covers good practice applicable to all farming systems including, arable, horticulture, livestock and upland systems.

Soil types

Best Management Practices includes reference to soil type where this has an influence on the recommended management strategy.


Best management practices

The Soil Code (the Code of Good Agricultural Practice for the Protection of Soil) is a practical guide to help Welsh farmers and growers avoid long-term damage to the soils which they farm. The Code also provides general guidance on practices which will maintain and increase the ability of soil to support plant growth:

- Targeted removal of land from arable rotation and revert to permanent amenity grass/heathland
- Introduce rotational grass; include grass leys in arable rotation on susceptible land
- Establish grass buffer strips
- Early harvesting and establishment of crops in the autumn
- Adopt reduced cultivation systems, minimum or non-inversion techniques and direct drilling
- Include periodic ploughing or subsoiling in minimum tillage systems
Defra SP1605 B – ANNEX 1

- Cultivate compacted tillage soils
- Relieve compaction, break up surface capping
- Cultivate and drill across the slope
- Leave autumn seedbeds rough
- Manage over-winter tramlines
- Maintain and enhance soil organic matter levels
- Fence off rivers and streams from livestock
- Establish new hedges
- Use appropriate machinery to avoid soil damage
- Use nurse crops to limit wind blow
- Establish cover crops or green manures in the autumn
- Adjust irrigation application rates to suit field and soil conditions so that the risk of surface run-off is minimised
- Use a soil management plan
- Apply mulch to surface of the seedbed
- Mix the topsoil and subsoil

Farming systems

The Code covers good soil management practice applicable to all farming systems.

Soil types

The management practices are suitable for all soil types unless otherwise stated within the Code. Where management practices are more suitable for a particular soil type, e.g. ‘sandy and light silty soils’, this is stated with the Code.

Inventory of best practice soil management methods

The following is an inventory of best practice soil management methods for environmental protection (e.g. to reduce phosphorus losses associated with sediment etc.) collated from the above documents and from Defra projects ES0203 (Cost-effectiveness of integrated diffuse pollution mitigation measures), WQ0106 (Development of a database of suitable mitigation options to reduce nutrient oversupply for use in guidance to farmers, and in the development of regulation) and SP08016 (Best practice for managing Soil Organic Matter in agriculture).

1. Use a cultivation plan
2. Adopt reduced cultivation systems, minimum or non-inversion techniques and direct drilling
3. Cultivate compacted tillage soils
4. Cultivate and drill across the slope
5. Cultivate according to wind direction
6. Leave autumn seedbeds rough
7. Manage over-winter tramlines
8. Maintain and enhance soil organic matter levels
9. Loosen compacted soil layers in grassland fields
10. Introduce rotational grass; include grass leys in arable rotation on susceptible land.
11. Establish grass buffer strips
12. Establish cover crops or green manures in the autumn
13. ‘Use nurse crops to limit wind blow’ or ‘apply mulch to surface of seedbed’
14. Early harvesting and establishment of crops in the autumn
15. Cultivate land for crops in spring rather than autumn
16. Delay cultivation in the autumn
17. Adjust irrigation application rates to suit field and soil conditions
18. Maintain field drainage systems
19. Reduce the length of the grazing day/grazing season
20. Reduce field stocking rates when soils are wet
21. Move feeders at regular intervals
22. Construct troughs with permeable base
23. Reduce overall stocking rates on livestock farms
24. Fence off rivers and streams from livestock
25. Construct bridges for livestock crossing rivers/streams
26. Re-site gateways away from high-risk areas
27. Farm track management
28. Establish new hedges
29. Remove land from arable rotation and revert to permanent grass
30. Arable reversion to low fertiliser input extensive grazing
31. Establish permanent woodlands
32. Grow biomass crops (i.e. willow, poplar, miscanthus)