GUIDANCE ON SUITABLE ORGANIC MATERIAL APPLICATIONS FOR LAND RESTORATION AND IMPROVEMENT

FINAL REPORT

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How to use this document

This guidance document covers the application of organic materials to selected habitats, either created from scratch or existing habitats, for restoration or improvement in Scotland. Organic matter, and to a lesser extent nutrients, are crucial to the sustainable creation of soil forming materials to restore and improve habitats. Guidance is provided on 'target' topsoil characteristics for multi-purpose and low fertility situations, and where possible typical rates of organic material applications for different land uses. The document contains a decision support checklist (below) for the use of organic materials in soil formation/habitat enhancement.

Decision support checklist

- What is the intended habitat (e.g. agriculture, forestry, species-rich grassland etc.)?
- What are the needs of the specific habitat (e.g. soil depth, organic matter content, nutrient supply/cycling, pH tolerance, drainage properties)?
- What is the status of the existing site/habitat (e.g. soil depth, organic matter content, nutrient status, pH, heavy metal content etc.)?
- What organic materials are available locally (e.g. compost, paper sludge, biosolids etc.)?
- Which locally available organic material(s) best meets the requirements of the intended habitat?
- Using information on properties of the site/existing habitat and available organic material(s); calculate the appropriate application rate to create/enhance the site for the intended habitat.
- Undertake a site-specific risk assessment.

1 Introduction

Organic material is a collective term used to describe materials rich in organic matter that are either a by-product of an existing process, such as biosolids (i.e. treated sewage sludge), or materials that have been produced as a result of some form of recycling process, such as compost (SNIFFER, 2010). Organic materials from a wide range of sources (e.g. anaerobic digestate, compost, paper crumble, biosolids etc.) are spread on land in Scotland. They contain useful quantities of major plant nutrients (e.g. nitrogen, phosphate, potash, magnesium and sulphur), which are all essential for plant growth, and are also a valuable source of organic matter, which can improve soil physical, chemical and biological properties: namely water holding capacity, workability, structural stability, nutrient supply, biological activity etc. The "Scottish Soil Framework" (Scottish Government, 2009) highlights the importance of soil organic matter to soil quality and fertility, and "The State of Scotland's Soil" report (Dobbie *et al*., 2011) identified loss of organic matter as one of seven key threats to soil functions.

It is essential that the application of organic materials to land is truly beneficial and is not harmful to the environment (i.e. soil, water and air quality) or human health. Well managed applications, which apply the appropriate amount of organic material to meet habitat needs, can have a number of benefits. However, where organic material applications are not well managed, they can potentially have adverse effects such as:

- Heavy metals accumulation.
- Over supply of nutrients and associated (leaching) losses.
- Increased release of ammonia and production of greenhouse gases.

The list of organic materials considered in this document (Box 1) is not exhaustive and the exclusion of a material does not mean it is not suitable for the improvement or restoration of existing habitats.

Box 1: Organic materials included in this document
Compost (see section 4.4)
Biosolids (see section 4.5)
Digestate (see section 4.6)
Paper sludge/crumble (see section 4.7)
Water treatment cake (see section 4.8)
Forestry residues (see section 4.9)
Distillery residues (see section 4.10)
Ash wastes (see section 4.11)

Where organic materials are applied to create habitats from scratch this is often on brownfield sites, for example, former opencast coal sites, residual industrial use sites, ex landfill sites etc. A major barrier to habitat creation on these sites is often the lack of suitable on-site soil forming materials in which plants can establish and grow (Bending *et al.,* 1999; Ecoscope, 2000; Williamson *et al.,* 2003). Organic materials, along with other mineral soil-forming materials, such as subsoil, coal shale, canal dredgings etc. can be valuable additions in creating soil forming materials to improve and restore habitats. In addition, the application of organic materials (e.g. compost and biosolids) can improve soil physical properties and provide a supply of plant available major nutrients. Land uses on improved/restored land can include tree planting (e.g. for commercial forestry/woodland or recreational use), 'energy' crops (i.e. those which are grown specifically to be harvested for energy generation), amenity grassland and agricultural production etc. Box 2 lists those habitat covered in this report.

Box 2: Habitats included in this document
Agriculture (permanent grassland, crop land) (see section 3.1)
Energy crops (miscanthus, willow, poplar) (see section 3.2)
Amenity areas (grassland, bushes, trees) (see section 3.3)
Species-rich grassland (see section 3.4)
Heathland (see section 3.5)
Peatland (see section 3.6)
Commercial and native forestry/woodland (see section 3.7)

Soils must be created with sufficient depth to allow plant roots to develop normally. Prior to application of the organic material the on-site mineral material should be appropriately cultivated/loosened. Organic materials should then be spread over the treatment area and subsequently incorporated into the mineral material (usually to a maximum depth of 0.4 m) as soon as possible following application. Appropriate aftercare must be provided to ensure good long-term performance, which will depend on the individual site and vegetation, and may include the application of weed control products until the plants become established.

Creating or improving existing habitats using organic materials or other soil forming materials takes time and it may not be possible to achieve the desired changes over the short-term (e.g. soil structure etc.). However, there are management strategies and techniques available which can increase the rate at which improvements take place.

2 Regulations

In Scotland, recycling organic materials to non-agricultural land is regulated by The Waste Management Licensing (Scotland) Regulations 2011, as amended, (WMLR) (SSI, 2011). Applications of materials classified as waste may be undertaken on non-agricultural land through an exemption, via either Paragraph 7 (forests, parks etc.), Paragraph 8 (storage and spreading of sludge on non-agricultural land) or Paragraph 9(1) (remediation or restoration). It must be demonstrated that the application will result in ecological improvement. The material used for restoration must also be fit-for-purpose. For compost and digestate, materials that comply with either BSI PAS 100 (BSI, 2011) or PAS 110 (BSI, 2014) are no longer classified as waste and are therefore outside the scope of the WMLR, provided they are spread in accordance with SEPA's position statement (SEPA, 2004; SEPA, 2013).

Organic material applications to non-agricultural land should be managed to minimise nutrient pollution through good practice, but are not restricted by the limits set for agricultural land, for example, in Nitrate Vulnerable Zones-NVZs (SSI, 2013). In addition, the maintenance or improvement of surface and groundwater quality under the Water Framework Directive may influence the organic material application strategy within a river basin district.

The handling and placing of the soil forming materials, and blending of the on-site mineral material and applied organic materials, should only be carried out in **dry conditions** and in accordance with good practice (MAFF, 2000; Defra, 2005). The aim of the restoration shall be to achieve a homogenous mixture of mineral and organic materials to a (maximum) depth of 40 cm and adequate root depth to 1-1.5 m, which will provide sufficient available water supply and drainage, and nutrient supply to support the target habitat.

3 Habitat requirements

Soil organic matter content, nutrient supply and pH are usually the most important determinants of the suitability of a site for habitat restoration/re-creation or improvement (Bending *et al.*, 1999; Ecoscope, 2000; Williamson *et al.*, 2003). Hence, it is important for the on-site mineral material to be analysed prior to the application of organic materials to provide guidance on appropriate organic material application rates to create a soil forming material. The organic matter content, pH and nutrient ranges of the desired habitat needs to be established. The British Standards Institute "Specification for Topsoil and Requirements for Use" (BSI, 2007) provides a useful benchmark for the improvement or creation of topsoils for multi-purpose and low fertility situations (Table 1). Notably, the nutrient status of the created soil should not exceed the values in Table 1 and must be appropriate for the habitat that is being created/improved.

Table 1. BSI Topsoil characteristics for multi-purpose and low fertility topsoils

Parameter	**Multi-purpose**			**Low fertility***		
Soil texture (% m/m)						
Clay content (%)	5-35			5-35		
Silt content (%)	0-65			0-65		
Sand content (%)	30-85			30-85		
*Soil organic matter content (% m/m)**						
Clay 5-20%	3-20			1-10		
Clay 20-35%	5-20			1-10		
*Maximum coarse fragment content (% m/m)***						
>2 mm	0-30			0-30		
>20 mm	0-10			0-10		
>50 mm	0			0		
pH	5.5-8.5					
Total plant nutrient content	N ≥ 0.15 % m/m			N < 0.1 % m/m		
Extractable plant nutrient content*** (using Olsen's P and ammonium nitrate (K & Mg) methods)	P 16-100 mg/l[1] K 121-900 mg/l[2] Mg 51-600 mg/l[3]			P <15 mg/l[4] K <120 mg/l[5] Mg <600 mg/l[6]		
Carbon:nitrogen ratio	<20:1			<20:1		
Exchangeable sodium %	<15			<15		
Phytotoxic contaminants by soil pH (mg/kg DS)						
Soil pH range	<6	6-7	>7	<6	6-7	>7
Zinc	<200	<200	<300	<200	<200	<300
Copper	<100[++]	<135	<200	<100	<135	<200
Nickel	<60[+++]	<75	<110	<60	<75	<110
Visible contaminants (% m/m)						
> 2 mm	<0.5			<0.5		
Of which plastics	<0.25			<0.25		
Of which sharps	zero in 1 kg air dried soil			zero in 1 kg air dried soil		

[1] ADAS P Index 2-5; SAC status M-VH; [2]ADAS K Index 2-5; SAC status M-VH; [3]ADAS Mg Index 2-6; SAC status M-VH
[4] ADAS P Index ≤1; SAC status ≤ L; [5]ADAS K Index ≤1; SAC status ≤-L; [6]ADAS Mg Index ≤6; SAC status ≤ VH
* For habitats such as heathlands and species rich grasslands nutrient and organic matter content should be towards the lower end of the quoted range.
** For land restoration sites the coarse fragment content in the restored soil will typically be greater than that quoted
*** MAFF (1986). In catchments sensitive to phosphorus losses, an upper limit of 70 mg/l (ADAS Index 4; SAC very high status) may be more appropriate (ADAS/Bangor University, 2014; Defra, 2010; EA, 2006)
++ <80 mg/kg copper where pH is in range 5.0<5.5 (SI, 1989)
+++ <50 mg/kg nickel where pH is in range 5.0<5.5 (SI, 1989)

Habitats will differ in their required topsoil and rooting depths. Throughout this report we refer to topsoil as the upper part of the soil being enriched with organic matter and nutrients, and rooting depth as the depth of material which can be explored by roots (i.e. topsoil and subsoil depths). In general a rooting depth of at least 1 m is recommended for agricultural crops (Bending *et al.* 1999; Ecoscope, 2000) and 1.5 m for woodland (Moffat, 1995; Dobson and Moffat, 1993; Ecoscope 2000). Similarly, it is important that the topsoil and subsoil are not compacted and can be explored by roots. A bulk density not exceeding 1.3-1.5 g/cm^3 in the topsoil/upper subsoil and not exceeding 1.5-1.7 g/cm^3 in the deeper subsoil is recommended (Moffat and Bending, 1992; Bending *et al*., 1999; Ecoscope, 2000). The lower values are recommended as targets for agriculture and the higher values for woodland.

3.1 Agricultural land

Agricultural land in both lowland and upland areas in Scotland is mainly the result of agricultural management practices that have evolved over many centuries. In recent times, Government policy has shifted from a focus on food production to one where environmental protection is also important. Agricultural land can be created on restored sites provided that suitable organic materials are used to create an appropriate soil forming material.

The appropriate organic matter content, pH and soil nutrient status, and to a lesser extent rooting depth, will depend on the type of agricultural land being created (e.g. grassland has a lower pH requirement than arable land), Table 2. Having pH and nutrient status for all major nutrients at the optimum levels following good agricultural practice (e.g. Defra 2009) in the topsoil across the entire field is important to ensure that major or minor nutrient supply is optimised to achieve optimum yields and consistent crop quality.

Table 2. Optimum soil pH in Scotland (SAC, 2010a; SRUC, 2013b)

Crop	Mineral soil	Organic/peaty soils
Continuous arable cropping	6.0-6.2	5.7-5.9
Grassland	6.0	5.3-5.5

The BSI "Specification for Topsoil and Requirements for use" (BSI, 2007) suggests that the minimum rooting depth shall be normally 450 mm for grass and for arable crops. Although roots can extend beyond 1000 mm, not all of that will be within the topsoil. As such the depth of topsoil required should **not normally exceed 400 mm** (SNIFFER, 2010); beyond that depth, suitable (loosened) subsoil should provide the remainder of the required rooting depth. To acquire sufficient nutrients and water from the soil via the roots, it is important to develop good soil structure so that root growth is not adversely affected by poor physical soil conditions, such as compaction (Defra, 2005; Ecoscope, 2000). When a habitat is being created, it is important that all activities are carried out so as to minimise soil compaction (Bending *et al*., 1999), as once compacted layers are created it can be difficult to remove them.

3.2 Energy crops

Energy crops are annuals or perennials grown for the specific purpose of energy and not food production (Rowe *et al*., 2009; Caslin *et al*., 2010). They are mainly cultivated on agricultural land, but can be grown on brownfield or marginal land, providing suitable preparation is undertaken. Nutrient additions to energy (biomass) crops are recommended to optimise crop yields and maintain soil fertility, in relation to crop yields and nutrient offtake (Caslin *et al*., 2010; Defra, 2010).

The species considered in this report are willow (*Salix* spp.), poplar (*Populus* spp.) and miscanthus.

Short rotation coppice - Willow (*Salix* spp.) and Poplar (*Populus* spp.).

Willow

Willows are grown as short rotation coppice (SRC) due to their rapid growth rate and are harvested on a 2-5 year cycle, following coppicing of the first year's growth. Willows can grow on a wide range of soil types, with a pH optimum of 6.5 and a suitable range of 5.5 to 7.0 (TSEC Biosys, 2006b). The soil should be cultivated (loosened) to a depth of at least 30 cm. For successful root development, the site may require sub-soiling (where compaction is present) to a depth of 40 cm, in addition to deep ploughing. Water consumption is high and an annual rainfall of 600-1000 mm is considered ideal for willow growth (Defra, 2004).

During establishment willows are vulnerable to weed competition and so a broad-spectrum herbicide should be used prior to planting. Willow has a low demand for nitrogen and no N fertiliser should be applied during the establishment year (Caslin *et al*., 2010; Defra, 2010). N recommendations for the first year after cutback are 90 kg/ha (Defra, 2010) and 120-150 kg N/ha (Caslin *et al*., 2010). Phosphate and potash applications are recommended to maintain soil P/K Indices of 1; SRUC status low (Defra, 2010; Johnson, 1999).

Crop residue quality and quantity, in addition to the original soil status, play an important role in altering soil organic matter content under SRC. Conversion of (agricultural) land to SRC has potentially beneficial effects on soil organic matter dynamics, with reported gains in soil organic matter of up to 20% (Vanguelova and Pitman, 2011). Crop residue inputs will increase low soil organic matter levels, improving soil quality and biodiversity. SRC is also likely to improve soil structure compared to annually cultivated crops, with improved water infiltration from increased soil organic matter and deeper rooting depth. However, during site preparation and harvesting soil compaction may occur as a result of frequent traffic movements.

Willow is known to have a high nitrogen uptake capacity in the years following establishment and coppicing thus minimising N losses; in a 9-year study of SRC willow nitrate leaching losses of 1.6 kg N/ha/year where recorded following fertilisation application rates ranging from 90 to 127 kg N/ha/year (Aronsson *et al*., 2000). Also, a study on unfertilized SRC willow and poplar showed that nitrate leaching losses were reduced by around 25 kg N/ha in year 1 compared with intensively managed agricultural land, with a further reduction in nitrate leaching of around 50% compared with arable land predicted for proceeding years (Makeschin, 1994).

Poplar

Poplar grown as SRC are densely planted high yielding crops harvested on a 2-5 year cycle, following coppicing of the first year's growth. Poplar will grow in most soils, but medium textured and well-structured soils are the best; waterlogged, dry or very stony soils are least suitable. Optimum pH is 6.5, with a suitable pH in the range 5.5 to 7.5 (TSEC Biosys, 2006a). The soil should be cultivated (loosened) to a depth of at least 30 cm. For successful root development the site may require sub-soiling (where compaction is present) to a depth of 40 cm, in addition to deep ploughing. Poplar has a high requirement for water and where rainfall is <600 mm irrigation may be required to optimise crop yields. During establishment poplars are vulnerable to weed competition and so a broad-spectrum herbicide should be used prior to planting. Nutrient management advice is similar to willow (Defra, 2010).

Biomass grasses – Miscanthus (*Miscanthus sinensis* spp.)

Miscanthus

Miscanthus can be grown on soils ranging from sands to those high in organic matter and has an optimum pH range between 5.5 and 7.5 (TSEC Biosys, 2006c). Competition from weeds during establishment can affect yield so a broad spectrum herbicide can be applied prior to planting. The crop has good nutrient use efficiency due to the translocation of nutrients to the rhizomes during senescence and retention of leaf litter in the field. Annual harvesting of the stems, from year 2 onwards (i.e. the year following crop establishment), results in little nutrient removal from the field. Annual N fertiliser applications in the range 60-80 kg N/ha are recommended (Defra, 2010) in the third crop year after planting. Phosphate and potash applications are recommended to maintain ADAS soil P and K Indices of 1 or 2; SAC low or moderate status.

Increases in soil organic matter in relation to the establishment of Miscanthus are linked to wider improvements in soil condition, including improved water retention, related to increased litter inputs (Makeschin, 1994). A study of four Miscanthus plantations in Germany, reported an increase in soil organic matter storage in the topsoil of 11.7 t/ha compared to the grassland control over 4 years (Kahle *et al*., 2001).

Christian and Riche (1998) found relatively high nitrate leaching losses in the first year of Miscanthus establishment, but by the third year over-winter leaching losses fell to 3, 11 and 30 kg N/ha following fertiliser application rates of 0, 60 and 120 kg N/ha losses, respectively. Indicating that, like SRC plantations, Miscanthus can lead to reduced nitrate leaching compared with arable crops post establishment.

3.3 Amenity land

Amenity plantings can be broadly defined as public areas containing plants (usually mown or un-mown grass, trees/woodland, shrubs, herbaceous plants, bedding plants and bulbs or a mixture of these). Amenity landscapes include planted areas within parks and gardens, community woodlands, sports pitches, roadsides and roundabouts, cemeteries, car parks and public visitor attractions. Some amenity plantings, such as those in city centre parks, may require fairly intensive maintenance (e.g. annual or biannual replacement of bedding plants, cutting of grass and pruning of trees and shrubs), whereas others require very little maintenance after the initial phase (e.g. community woodland or motorway verges and banks).

There are no published fertiliser recommendations for amenity plantings *per se*, and few published values for target nutrient status. However, amateur and professional publications and websites emphasise requirements to ensure appropriate soil conditions and sufficient nutrients for successful plant establishment and growth (Pears, 2001; Royal Horticultural Society, 2007; Garden House Nursery, 2001). Their recommendations are often somewhat imprecise in relation to nutrient requirements and for that reason it is also useful to refer to the British Topsoil Standard (BSI, 2007) for guidance on satisfactory soil organic matter and nutrient levels. Four main types of amenity plantings are defined below.

Native woodland/community woodland, non-native trees, shrubs and herbaceous plantings

This type of planting can be considered similar to some types of forestry in that the subjects are expected to remain in-situ for many years, with variable amount of maintenance ranging from practically no maintenance to annual cutting back of herbaceous plants and pruning of shrubs. Nutrient offtakes from this type of habitat will usually be relatively low; however in some cases regular ‘replacement’ phosphate or potash applications might be needed.

Annual bedding schemes

During the past 20 years, local authorities have greatly reduced the total area under their control which is managed in this way, but small areas of amenity land continue to be planted with annual bedding, particularly land close to civic buildings, war memorials and key public and private parks and gardens. Most amenity land managed for annual displays is planted twice annually (in spring and autumn) and the plants are either destroyed after use or kept under glass over winter for replanting in spring. Nutrients will be removed annually, since the plants are typically planted as young plants, which grow using soil nutrients into mature plants, which are removed before they fully die down/die off; generally low level ‘replacement’ nitrogen, phosphate and potash applications are recommended on an annual basis. Annual nutrient applications are greatly preferable to ‘large’ nutrient applications prior to the first planting, because at that stage the plants will not be large enough to take up all available nutrients and nutrient losses can occur.

Mown grass

Mown grass is maintained for a range of purposes, including for general public recreation/amenity and for sports such as golf, football and rugby. The annual nutrient offtake from mown grass will depend on whether the grass cuttings are removed or mulched and left on the surface; generally low level ‘replacement’ nitrogen, phosphate and potash applications are recommended on an annual basis. Again, annual nutrient applications are greatly preferable to ‘large’ nutrient applications prior to sowing, because grass seed germination may be inhibited by ‘high’ salt concentrations associated with addition of large quantities of nutrients. Grass plants will not be large enough to take up all available nutrients and nutrient losses can occur.

Unmown grass/wildflower meadow

Local authorities are increasingly reducing the areas of turf under their care which is regularly mown throughout the year in favour of leaving some areas completely un-mown, or more usually mown only once or twice per year. Many land managers try to create a wild flower meadow in their un-mown grass areas and/or plant bulbs into the grass; nutrient additions are generally not made to these communities.

Soil characteristics required for creation of amenity plantings

The ideal chemical and physical characteristics of soils required for amenity plantings differ depending on the nature of the plants and planting schemes under discussion. The nutrient requirements of amenity plantings are generally fairly low; with the highest requirements (particularly in the longer term) being for intensively mown grass and bedding schemes which are planted once or twice per year. In other words, where plant material in the form of shoots (cut from grass) or whole plants (as in dead/spent bedding plants) are removed (along with nutrients taken up during the season) then there is a need to replenish those nutrients if soil fertility is to be maintained. Where plants or plant parts are not regularly harvested from amenity plantings, then nutrients tend to be recycled back to the soil in the form of fallen leaves and branches, and annual nutrient requirements tend to be relatively low. Most authors warn against excessive fertiliser application (particularly N) because very fertile soils can result in several problems in amenity plantings, for example, weed growth can be encouraged at the expense of more desirable (and intended) plants, and grass cutting maintenance costs can be high.

Although there is almost no published information on target nutrient indices for amenity areas, it makes sense to draw approximate parallels to the lower end of soil fertility levels recommended in the British Topsoil Standard (BSI, 2007):

- Native woodland, non-native trees, shrubs and herbaceous plantings, and mown grass are considered as being broadly similar to multi-purpose topsoil (see Table 1).
- Unmown grass/wildflower meadow is considered as being broadly similar to low fertility topsoil (see Table 1).

The ideal rooting depth for amenity plantings varies greatly depending on the nature of the plantings. For example, amenity grass can function on very shallow soils providing there is sufficient water in the dry spells and adequate drainage in the wet spells. However, it is likely to be more resilient in soils of at least 0.5 m depth, with a freely draining subsoil beneath. A minimum depth of 1.5 m is recommended for woodland (Foot & Sinnett, 2006a) and shrubs and herbaceous plantings are likely to thrive best in similar depths. Where organic materials are applied, they are best incorporated into the topsoil, since organic materials left on the surface (particularly those which contain or are likely to release readily available N) are likely to stimulate weed growth.

3.4 Species-rich grassland

Species-rich grassland is a broad term used to describe grassland habitats of high nature conservation interest, which are those that have not been subject to (recent) agricultural improvement or intensive management. It is estimated that around 40% of Scottish species-rich grasslands have been lost during the past 23 years (SAC, 2010b). The term encompasses five UK priority habitat types as identified in the UK Biodiversity Action Plan (2012), all of which occur in Scotland to some extent, namely: lowland meadows (also termed neutral or mesotrophic grasslands), lowland calcareous grassland, lowland acid grassland, upland calcareous grassland and upland hay meadows (also termed neutral or mesotrophic meadows). These are outlined in more detail below.

Lowland meadows

These include most forms of unimproved neutral (or mesotrophic) grassland across enclosed lowland landscapes. This habitat has undergone a massive decline in the 20th century, almost entirely due to the intensification of agriculture and it is estimated that less than 15,000 ha of species-rich neutral grassland survives today in the UK. Lowland is defined as below the level of agricultural enclosure (the altitude at which this occurs varies across the UK, typically becoming lower as one travels north). It is thought that around 2,000 to 3,000 ha of the main form of this habitat exists in Scotland, with particular concentrations in the crofting areas of Lochaber, Skye and the Western Isles.

Lowland calcareous grassland

This is characterised by vegetation dominated by grasses and herbs on shallow, well-drained soils which are rich in bases (principally calcium carbonate) formed by the weathering of chalk and other types of limestone or base-rich rock. Although the base status of such soils is usually high, with a pH of above 6, it may also be lower and calcareous grassland communities can occur on soils with a pH as low as 5. Lowland is defined as below the level of agricultural enclosure (the altitude at which this occurs varies across the UK, typically becoming lower as one travels north). This habitat supports a very rich flora including many nationally rare and scarce species.

Lowland acid grassland

This includes both enclosed and unenclosed acid grassland throughout the lowlands (normally below *c.*300m). It often occurs as an integral part of lowland heath landscapes, in parklands and locally on coastal cliffs and shingle. It is normally managed as pasture. Acid grassland is very variable in terms of species richness and stands can range from relatively species-poor (less than 2 species per m^2) to species-rich (in excess of 25 species per m^2). As with other lowland semi-natural grassland types, acid grassland has undergone substantial decline in the 20th century. Scotland is estimated to have less than 5,000 ha of this habitat and much of it is likely to be on the upland fringe. Extensive areas of acid grassland are included within sites designated as common land.

Upland calcareous grassland

This occurs on lime-rich soils situated above the upper limit of agricultural enclosure, both in the sub-montane and montane zones. Most examples occur above 250-300 m altitude, but the habitat is also found within unenclosed moorland at lower elevations, and descends to sea level in north-west Scotland. Upland calcareous grassland typically occurs as a component of habitat mosaics, which are generally managed as rough grazing land for domestic livestock. They are generally restricted to shallow soils derived from a variety of lime-rich bedrocks. It is estimated that there are 10,000-13,000 ha of this habitat in Scotland.

Upland hay meadows (another type of neutral or mesotrophic grassland)

These mostly occur in upland valleys in the north of England, with outliers in Scotland (mainly in Perthshire and Aberdeenshire). Recent estimates indicate that there are less than 100 ha left in Scotland. Upland hay meadows are confined to areas where non-intensive hay-meadow management has been applied in a sub-montane climate. They are most characteristic of brown earth soils on level to moderately sloping sites between 200 m and 400 m altitude. Many are still managed as hay meadows, but they are also found on river banks, road verges and in woodland clearings. Most of the variation within this habitat is attributable to management treatments. The fields are typically grazed in winter, mainly by sheep. In late April to early May, the meadows are closed to livestock in order to facilitate hay production. Mowing takes place in late July to early August, although in unfavourable weather conditions, it may be delayed as late as September. Following mowing, grazing then takes place until the weather deteriorates. Traditionally, the meadows have been given a light dressing of farmyard manure in the spring, and this, together with occasional liming, helps maintain the richness and diversity of the most species-rich stands.

Soil characteristics required for creation or maintenance of species-rich grasslands

The nutrient requirements of species-rich grassland are typically low or very low. The appropriate soil pH, drainage status and to a lesser extent soil depth will depend on the type of species-rich grassland being maintained, enhanced or created. It is clear that several key soil properties: including soil pH, extractable soil P, available soil N and soil wetness are the main determinants of species richness in grasslands.

pH is a major determinant of both species richness (Critchley *et al.,* 2002b) and also the range of species present. Species diversity is generally greater on neutral or basic soils (pH > 7.0) compared with acidic soils, but that does not mean that acid soils are not desirable in many situations (particularly in Scotland, where acid soils predominate in many areas), since they can support communities and in some cases rare plants which are important in their own right, and as food and habitats for fauna. Typical pH range values for the neutral, calcareous and acidic soils are summarised in Table 3.

Many studies have shown that species-richness in grassland tends to be associated with soils which have low extractable P concentrations (Critchley *et al.,* 2002a, b; Gilbert *et al.,* 2009; Gough & Marrs, 1990; Walker *et al*., 2002). Critchley *et al.* (2002b) found only a very weak linear relationship between soil extractable P concentration and species richness, but high species richness (> 30 species/m^2) only occurred where soil extractable P values were between 4 and 15 mg/l (using Olsen's P method) (ADAS Index 0-1; SAC very low-low status). Gilbert *et al.* (2009) clearly showed that extractable P concentrations differed in soils supporting different plant communities. In general, species-rich communities were found on soils with lower extractable P concentrations, whereas species-poor communities were found on soils with higher extractable P concentrations. Also, it was found that water regime and land management were important (along with soil P concentration) in determining species richness in European wet grasslands (Hajek *et al*., 2008).

There is clear evidence that excessive nitrogen (N) applications can reduce species richness in grasslands. Several authors have demonstrated that air-borne N pollution (which has increased in recent decades) has led to gradual increases in the availability of N within natural ecosystems, which has contributed to reductions in the number of species in grasslands of high botanical value (Bobbink *et al*., 1998; Stevens *et al*., 2004; Wilson *et al*., 1985). N deposition can affect natural habitats in many ways, for example: by acidifying soils, by favouring the growth of fast-growing N responsive species at the expense of more desirable species, through direct toxicity due to N gases and aerosols, and also indirectly through increased susceptibility to secondary stresses such as pathogens, drought and frost. Although N is essential for all plants, it is clearly desirable to limit the availability of N within species-rich grasslands, as many species within such habitats are N limited and are only able to compete and thrive under such low N regimes (Kirkham *et al*., 2014).

Since available N is an important determinant of species richness in grassland, it is important to limit nitrogen additions, so as not to encourage the growth of the N responsive species at the expense of the high botanical value plants.

Soil extractable potassium (K) and magnesium (Mg) concentrations have been shown to have only weak relationships with species richness and are thought to be considerably less important in determining species richness than pH, soil extractable P, available N and hydrological factors (Critchley *et al*., 2002a).

Table 3. Typical ranges of soil parameters in important in species-rich grassland habitats.

Parameter	Neutral soils	Calcareous soils	Acid soils
pH	6.0-6.4[1]	6.8-7.9[1]	< 5.0[2]
Extractable P (using Olsen's P method)	<15 mg/l		
Crop available N (mg/kg)*	< 10[3]	<12.5[3]	<15[3]

Source: [1]Critchley *et al*., 2002a; [2]Walker *et al.,* 2002; [3]Bakker & Berendse, 1999

* Topsoil concentrations based on 20 cm depth (adapted from: neutral soils = <20 kg/ha, calcareous soils < 25 kg/ha and acid soils < 30 kg/ha)

Manipulation of soil pH, extractable P content and N availability can have a major impact on species diversity, but management of the developing/improving grassland is also very important. Issues such as weed control and grazing and cutting regime must not be underestimated (Natural England, 2010a, b and c; SAC, 2010b).

Species-rich grassland requires very few nutrients when being created on a new site (Ecoscope, 2000; Gough and Marrs, 1990) and require nutrients over the long-term at low or very low levels, as there is little or no nutrient offtake (and since grazing animals return nutrients in dung). Hence, very careful consideration needs to be given to the selection of suitable materials for these habitats; materials which contain low nutrient levels are likely to be the only ones worth considering. Examples include waste peat (e.g. overburden from quarrying or building works), wood fibre and coir (both of which are unlikely to be available in large quantities) or small quantities of compost.

The British Standard low fertility topsoil criteria, which are based on the findings of Critchley *et al.* (2002a; 2002b) are a useful reference to the soil properties that are likely to be suitable for the creation/restoration of species-rich grassland (Table 1).

Topsoil depth in natural species-rich grassland varies widely. The Ecoscope Manual (2000) mentions soil depth in relation to habitats created for "nature conservation" which will include species-rich grassland. It recommends a minimum (settled) subsoil depth of 0.5 m, but says that no topsoil is required for this type of habitat. It is likely that soil chemical properties, soil organic matter content and soil wetness are much more important than soil depth in relation to species richness.

3.5 Heathland

Heathland vegetation occurs widely on mineral soils and organo-mineral soils (surface organic matter layer <0.5m deep) throughout the uplands and moorlands of Scotland. It is characterised by the presence of dwarf shrubs with a cover of at least 25%. The dominance of heathland by dwarf shrubs is attributed largely to their tolerance of low pH nutrient-poor conditions.

Lowland heathland

Lowland heathland comprises a range of habitats characterised by the abundance of heather or gorse species on nutrient poor soils, usually below 300 m. Heathland in Scotland is rarely defined as lowland heathland; most Scottish heathland occurs above the upper limits of agricultural enclosure (JNCC, 2004). Lowland heathland is classified into two main types:

- Dry heaths typically occur on freely-draining acidic soils of generally low nutrient content. Ericaceous dwarf-shrubs dominate the vegetation. The most common is heather or ling *Calluna vulgaris*, often in combination with gorse or bilberry. Other dwarf-shrubs can be important locally.

- Wet heath usually occurs on acidic, nutrient-poor, shallow organo-mineral or sandy soils with impeded drainage. Mixtures of cross-leaved heath, grasses, sedges and Sphagnum bog mosses typically dominate the vegetation (JNCC, 2004).

Upland heathland

Upland heathland is defined as lying below the alpine or montane zone (at about 600–750 m) and usually above the upper edge of enclosed agricultural land (generally at around 250–400 m, but descending to near sea-level in northern Scotland). Upland heath in 'favourable condition' is typically dominated by a range of dwarf shrubs such as heather, bilberry, crowberry, bell heather and, in the south and west, western gorse (JNCC, 2008). Upland heathland incorporates both dry and wet heaths, dependent on local environmental conditions:

- Dry heath is typically dominated by dwarf shrubs such as heather, bell Heather, bilberry and crowberry. These dwarf shrubs will generally comprise over 75% cover where the heath is in good condition.
- Wet heaths are dominated by a mixture of heather, cross-leaved heath, deer grass and purple moor-grass, over an understorey of mosses often including several of the bog moss Sphagnum species.

Soil characteristics required for creation or maintenance of heathland

Heathland develops on nutrient poor, sandy or loamy soils, which are acidic (pH < 4.5) or weakly acidic (pH between 4.5 and 6) (De Graaf *et al*., 2009). Heathland vegetation is also typically associated with the low availability of nutrients, such as phosphorus (Gimingham, 1972). The appropriate soil pH, drainage status and to a lesser extent soil depth will depend on the type of heathland being maintained, enhanced or created.

In order to restore or create a heathland habitat the main challenge will often be to reduce the pH of the intended heathland site and to minimise nutrient additions. For example, the increased soil pH and fertility associated with agriculture have been identified as major obstacles to heathland re-establishment (Marrs, 1993; Pywell *et al*., 1994; Marrs *et al*., 1998; Walker *et al*., 2007). Small increases in pH alter the competitive balance between heathland and grassland species. Furthermore, as pH rises, functional niches become available for a greater spectrum of plant species which act as competitors (Owen and Marrs, 2000). In general, organic matter and nutrient additions will not be beneficial for the improvement or restoration of heathland habitats.

3.6 Peatlands

Peat consists of the partly decomposed remains of plants that once grew upon its surface. It develops in areas with high soil water tables, where the annual input of dead organic matter from the vegetation exceeds the rate of breakdown in the waterlogged, anaerobic conditions (Proctor, 2013). Peatland can be defined as any wetland with peaty or organic soils, whether or not the natural vegetation remains and peat is still being formed (Forestry Commission, 2000). Many systems of peatland classification exist, but for the purposes of this report, peatlands have been broadly classed as either mires (which can be sub-divided into bogs and fens), or other peatlands. These are described in further detail below.

Bogs (also called ombrotrophic bogs) are peat-forming mires which are supplied with water and nutrients only from rain, snow, mist and dust. They are naturally acidic, nutrient-poor systems. They include blanket bogs, lowland raised bogs and intermediate bogs.

Blanket bogs in Scotland are found at all altitudes from almost sea level to the tops of some of the highest mountains in the Cairngorms. Their distribution is defined by areas with a wet and cool climate (Lindsay *et al*., 1988). As the name suggests, blanket bogs can 'blanket' large areas of the Scottish landscape and within large expanses may consist of a mosaic of peatland habitats. On sloping areas the bog vegetation may receive some nutrient inputs from overland flow and in areas with flatter topography may be strictly ombrotrophic and nutrient poor. The edges of both raised and blanket mires can be fringed with other peatland vegetation types, such as fens flushed with mineral rich groundwater; see below for definitions of raised bogs and fens (Forestry Commission, 2000). Blanket bogs are a UK Biodiversity Action Plan (UKBAP) priority habitat and are highlighted in the Scottish Biodiversity Strategy (Scottish Executive, 2004; Scottish Government, 2013).

Raised bogs are typically restricted to lowland areas and have a characteristic, gently sloping and raised mound of waterlogged peat. The dome of peat typically develops from the gradual encroachment of wetland vegetation around the edge of a water body and the eventual infilling of the area with a mass of peat and wetland vegetation. As the peat dome builds upwards, the vegetation changes nutrient status as it loses hydrological contact with the groundwater and becomes solely precipitation fed in its centre (ombrotrophic). Changes in land use practices now mean that lowland raised bogs are often surrounded by farmland or woodland (Forestry Commission, 2000). Raised bogs are also found in the uplands associated with blanket bogs. Lowland raised bogs are a UKBAP priority habitat, highlighted in the Scottish Biodiversity Strategy (Scottish Government, 2013) and are considered a conservation priority in both intact and degraded states.

Fens receive rainwater and also water flowing from surrounding land as surface run-off or flow through soils and rocks (McBride *et al*., 2011). They are typically found at the edges of lochs/lakes, on river floodplains and by springs and seepages. They vary widely in size from marginal habitats to covering large areas of land. Fens vary widely in terms of their pH values and nutrient status, depending on their position and on the local geology. Fens are a UKBAP priority habitat with a habitat action plan.

It is estimated that there are around 27,900 ha of raised bog, 1,056,200 ha of blanket bog, 10,600 ha of intermediate bog and at least 1,200 ha of fen in Scotland, along with extensive areas of other peatland habitats (Proctor, 2013). The area of intact or actively peat forming peatlands has declined throughout history and the rate of loss has increased in recent decades. Good quality lowland raised bogs are now especially rare and many are now classed as being in a degraded state (JNCC, 2011). This degradation is attributed to a range of factors such as drainage for agriculture and forestry, overgrazing and climatic change.

Peatlands hold a vast stock of carbon and can add more by sequestering carbon from the atmosphere. But this natural carbon capture and storage ability can only happen if peatland habitats are healthy and functioning. The application of organic materials to these habitats is unlikely to be beneficial from an improvement/restoration viewpoint, other than forestry residues (which are rich in organic matter and low in nutrient availability). Forest residue use should be carefully managed (i.e. spread thinly) so as not to affect the existing ecosystem and established vegetation.

Bog and peatland plants are very different to those growing in other habitats, and the depth of rooting varies greatly depending on the physical nature of the habitat, in particular the hydrology. Where the decision is made to use organic materials (e.g. relatively inert materials such as waste peat from other parts of the site) during the peatland restoration process, it should be incorporated (or more likely laid down as a single layer) using methods which are appropriate to help create the desired hydrology for the site.

3.7 Commercial and native forestry/woodlands

Historically, forests/woodlands tend to have survived on, or have been planted on, ground of generally poorer quality than agricultural land, for example, steep slopes or areas with soils that are unsuitable or marginal for agriculture, e.g. seasonally waterlogged peats and gleys and infertile sandy soils. However, in more recent decades forests/woodlands have often been established on a wider range of soil types, including restored or brownfield soils (Forestry Commission, 2011).

There are 1.33 million hectares of forest/woodlands in Scotland (Scottish Executive, 2006) of which 29% is made up of native tree species. At present, forest/woodlands cover 17% of Scotland's land area compared with 5% at the start of the 20^{th} century; the increase is mostly due to planting of conifer species such as Sitka spruce, Norway spruce, Lodgepole pine and Japanese larch.

Soil characteristics required for creation or improvement of forest/woodlands

Forest/woodland soils are typically slightly acidic, although forest/woodland habitats can be developed on a variety of soil types, with a suitable pH range, depending on the tree species that will be planted. A minimum standard for a soil forming material for forest/woodland creation is summarised in Table 4. To ensure that the soil cover placed on the site is suitable for tree growth it must:

- Provide sufficient available soil moisture and nutrients to support and sustain healthy, mature trees.
- Provide anchorage for roots and to avoid windthrow.
- Provide a minimum soil rooting depth of 1.5 m.

Table 4. Minimum standards of soil-forming materials acceptable for forest/woodland establishment (adapted from Moffat and Bending, 1992; Dobson and Moffat, 1993; Bending *et al.*, 1999; Foot and Sinnett, 2006a).

Parameter	**Standard**	**Comments**
Texture	No limitations; however, the placement location of materials of different texture on site should be related to site factors such as topography	Preferred textures include materials with >25% clay
Bulk density (after placement)	<1.5 g/cm^3 to at least 50 cm depth. <1.7 g/cm^3 to below 1 m depth	
Stoniness: clay or loam	<40% by volume of material greater than 2 mm in diameter and <10% by volume of material greater than 100 mm in diameter	Measure mass of stone >2 mm and >100 mm in a known mass/volume of soil; divide each value by 1.65 to calculate the volume
Stoniness: sand	<25% by volume of material greater than 2 mm in diameter and <10% by volume of material greater than 100 mm in diameter	
pH	4 to 8	Based on 1:2.5 soil:$CaCl_2$ (0.01 M) suspension
Electrical conductivity	<0.25 s/m	Based on a 1:1 soil:water suspension
Iron pyrite content	<0.05%	British Standard 1016 Method
Topsoil nutrient content[*]	Extractable P > 16 mg/l Extractable K > 121 mg/l Extractable Mg > 51 mg/l	Using Olsen's P method Using ammonium nitrate method

[*] ADAS Index 2 and above; SAC moderate status and above

The general minimum guideline soil depth where the end-use is woodland is 1.5 m of rootable material (Bending *et al.*, 1999; Dobson & Moffat, 1993; Ecoscope, 2000). This value should reflect the final rootable depth (rootable implies that the soil must be free from compaction) following any settlement of the soil. This depth requirement should be reviewed in areas of low rainfall (where drought may restrict tree growth) and according to the nature of the soil cover (e.g. stoniness, soil texture) to ensure that drought does not unduly restrict tree growth.

Soil compaction is the key physical feature that can prevent sustainable forest/woodland development being achieved. Tree establishment and growth can be severely affected where soil compaction limits root growth thereby limiting access to air, water and nutrient resources (Bending *et al*., 1999; Ecoscope, 2000). Soil compaction can also affect mature trees, which will tend to be less stable than those with a more developed root system. However, attempts to loosen ground that is not compacted can damage the soil. Therefore, both the need for and depth of loosening should always be checked by digging pits to inspect the soil condition and confirm the need for the loosening operation.

Foot and Sinnett (2006b) suggest that the depth of cultivation or loosening required will vary according to the depth at which compaction has occurred. Thus, in a soil with a shallow plough pan, it is only necessary to loosen the ground to 50 mm below the base of the plough pan. Loosening to relieve deep compaction in restored soils should aim to reach the maximum possible loosening depth in the first loosening operation and ideally this should be greater than 1 m depth.

Moisture conditions are critical in all loosening operations, particularly in the layers above and just below the compacted zone. It is essential that the soil is dry and friable during the operation, to avoid damaging the upper layers and to achieve good loosening performance (Foot and Sinnett, 2006b). The most suitable time for loosening is therefore in late July to late August, but the actual timing will depend upon local conditions and the type of compaction which is to be treated. There is only one real opportunity to loosen the ground to best effect for forest/woodlands and this is prior to planting the trees. Ripping between tree lines after planting is not suitable and can cause damage to planted tree stock (Foot and Sinnett, 2006b).

Tree planting needs to be conducted while the trees are dormant, usually between mid-November and late March, irrespective of the timing of cultivations. The direct sowing of tree seeds is a less reliable means of establishment due to seedling sensitivity to soil conditions and weed competition. After any form of cultivation, the ground will be prone to resettlement and slumping if exposed to wet weather conditions or trafficking. Also, where deep loosening has been conducted, there may be some resettlement leading to an uneven soil surface, depending upon the loosening method selected.

The ground condition after cultivation will stabilise more rapidly and retain a good structure for much longer if ground cover is established as soon as possible after the loosening operation. It can be highly beneficial to sow a grass sward (in September) immediately after cultivation to keep soil fissures and cracks open, and maintain good drainage through the soil. Grass roots grow very rapidly, produce dense fibrous and deep-rooting networks, and are better than tree roots at breaking up and stabilising soil structure. They also create root channels which tree roots can later exploit. Tree planting can then take place into the grass sward (Foot and Sinnett, 2006b).

The tree species to plant should be chosen to best suit the specific site and soil conditions. Most types of tree have a range of site and soil conditions for their optimal growth, a wider range of conditions which they tolerate, and further conditions which they cannot tolerate, for further details see Moffat (2006) and Saville *et al*. (1997). There are, however, significant advantages; for native biodiversity if native British tree species can be planted in preference to non-native species. Native tree species typically support many more native insect and lichen species than non-native trees (Southwood, 1961).

Compared to arable land or managed grassland, woodland typically receives only very small (often zero) and infrequent inputs of manufactured mineral fertiliser. Woodland established on nutrient poor soils may require fertiliser application, whilst young trees become established, but use in established forests is uncommon. The main use of fertiliser in forestry is for the restoration of brownfield land. As trees grow slowly, forest habitats can be fertilised by organic materials (e.g. biosolids or compost) that supply nitrogen and phosphorus over time, as a result of the mineralisation of organically bound nutrients.

A general recommendation for infertile sites for mineral P and K (i.e. when the soil P and K status is less than ADAS Index 2, SAC moderate status) based on Forestry Commission recommendations for trees, is an application of about 100 kg of potash (K_20)/ha and about 60 kg of phosphate (P_20_5)/ha to the soil at planting/sowing (Sellers, 2006). On poor sites, the Forestry Commission has a mineral nitrogen fertiliser recommendation for trees of 150 kg N/ha to be applied at planting. This may need to be supplemented with further yearly mineral fertiliser applications of N in the spring of 50–60 kg/ha if no N is being supplied by an organic slow release fertiliser (Sellers, 2006). Foliar analysis can be used to check the adequacy of nutrient supply (Saville *et al.,* 1997).

Short-term (1-5 years) enhanced N losses can occur from forests/woodlands, as a result of soil disturbance accompanying establishment (Atkinson, 1989) or due to tree felling or windblow (Stevens and Hornung, 1988; Harding *et al*., 1992). Also, whole-tree harvesting, and the removal of forest residues such as brash and tree stumps, can contribute to a net loss of N. Poorly timed fertiliser applications can also increase nutrient losses, with aerial applications to new or young conifer crops on nutrient poor upland soils presenting the greatest risk. Modelled N losses from all forest habitats in Scotland were estimated to account for only 1.2% of total N losses in 2004, compared with 74% from agriculture (Anon, 2006).

4 Nutrient supply and release, and losses following the use of organic materials

The properties of a range of organic materials that can potentially be used in land restoration/reclamation (or for agricultural benefit) are summarised in this chapter. There is information (where available) on each material in terms of its properties (e.g. nutrient content and release, heavy metals). However, organic materials by their very nature are variable and the information given is for guidance only. It is important that all calculations/decisions are based on an analysis of the specific organic material(s) to be used; those quoted in this document are a guide to typical values. The list of organic materials considered is not exhaustive and the exclusion of a material does not mean it is not suitable.

Typically, organic materials are used as a one-off application to sites where there is little or no soil or vegetative cover. Depending upon the aim of the restoration/reclamation project, the SNIFFER Code of Practice (SNIFFER, 2010) recommends maximum application rates (dry tonnes) of up to 100 t/ha for habitat establishment/amenity land and up to 500 t/ha for soil formation (Table 5). Similarly, the WRc Manual of Good Practice for the Use of Sewage Sludge in Land Reclamation recommends application rates in the range 100-500 dry tonnes/ha (WRc, 1999). However, in some cases, for example, where the soil is very infertile/highly acidic, higher application rates may be justified. Conversely, for some end-uses (e.g. heathland habitats) much lower application rates may be appropriate (see Section 2 for more details on habitat requirements).

Table 5. Typical rates of organic material applications for different land uses (SNIFFER, 2010)

Aim of reclamation	Sub-categories	Typical maximum application rate (dry tonnes/hectare)	Notes
Habitat establishment /amenity land		50-100	Plant growth trials are recommended to ensure that nutrient levels are not excessive for the purpose
Soil formation	• Non-food crop production • Return to agricultural land • Landfill cap • Colliery spoil restoration	100-500[1]	The maximum application rate will vary depending on the condition of the land and contaminant concentration in both the organic amendment and the soil

[1] Depending on site-specific conditions the maximum application rate may need to exceed 500 t/ha. Application rates >500 t/ha would need to be justified to the environmental regulator and approved in advance.

Note: This table provides a range of typical **maximum** application rates, since different quantities are required for different organic materials to achieve similar results and pose different risks to the environment. For nutrient rich organic materials with a low C:N ratio the maximum application rate is likely to be at the lower end of the range, whereas, for higher C:N ratio materials with low nutrient contents and stable organic matter the maximum application rate is likely to be at the upper end of the range. The actual application rate should be the lowest rate calculated after considering all the factors (i.e. the requirements of the target habitat combined with the characteristics of the onsite mineral material and properties of the available organic materials). Similarly for sites with moderate soil fertility/nutrient status and a target habitat that does not require increased soil fertility the application rate is likely to be much lower than the maximum application rate for the type of organic material and at sites with little or no soil fertility/nutrients and a target habitat which requires increased soil fertility, application rates will likely be closer to the maximum application rate for the material.

It is important that organic material application rates are site-specific and are based on the properties of the organic material applied, the purpose of the application (e.g. soil forming, soil improvement or as a top dressing), the quality of in-situ mineral material and the intended use of the land following application (i.e. habitat); for more information see Section 4. Regardless of the application rate, heavy metal concentrations in the final topsoil should not exceed the values stipulated in Table 6, unless there are justifiable reasons (for example, it is a contaminated site which is already in excess of the limit values).

Table 6. Soil metal limits according to pH (mg/kg dry matter) (SI, 1989)

Heavy metal	Limit according to soil pH (mg/kg dry matter)			
	5.0<5.5	5.5<6.0	6.0<7.0	>7.0
Zinc	200	250	300	450
Copper	80	100	135	200
Nickel	50	60	75	110
Lead	300	300	300	300
Cadmium	3	3	3	3
Mercury	1	1	1	1

4.1 Nitrogen losses following land application

To estimate the amount of nitrogen that will be available to the target habitat following organic material application the MANNER-*NPK* model was used (Nicholson *et al.*, 2013), Figure 1. The model estimates the amount of N following organic material application that is likely to be lost via nitrate leaching to water (potentially causing eutrophication of sensitive ecosystems), as ammonia to air (a component of acid deposition) or as nitrous oxide to air (a greenhouse gas with global warming potential *c.*300-fold greater than carbon dioxide) as a function of the readily available N and dry matter content of the organic materials, application timing and technique, rainfall following application etc. Phosphorus and potassium availability in the longer-term following land application are considered to be the same as for manufactured fertiliser. In the short-term (i.e. the next crop grown) phosphorous availability is predicted to be around 50% and potassium availability 80-90% compared with manufactured fertiliser (Defra, 2010; SRUC, 2013a).

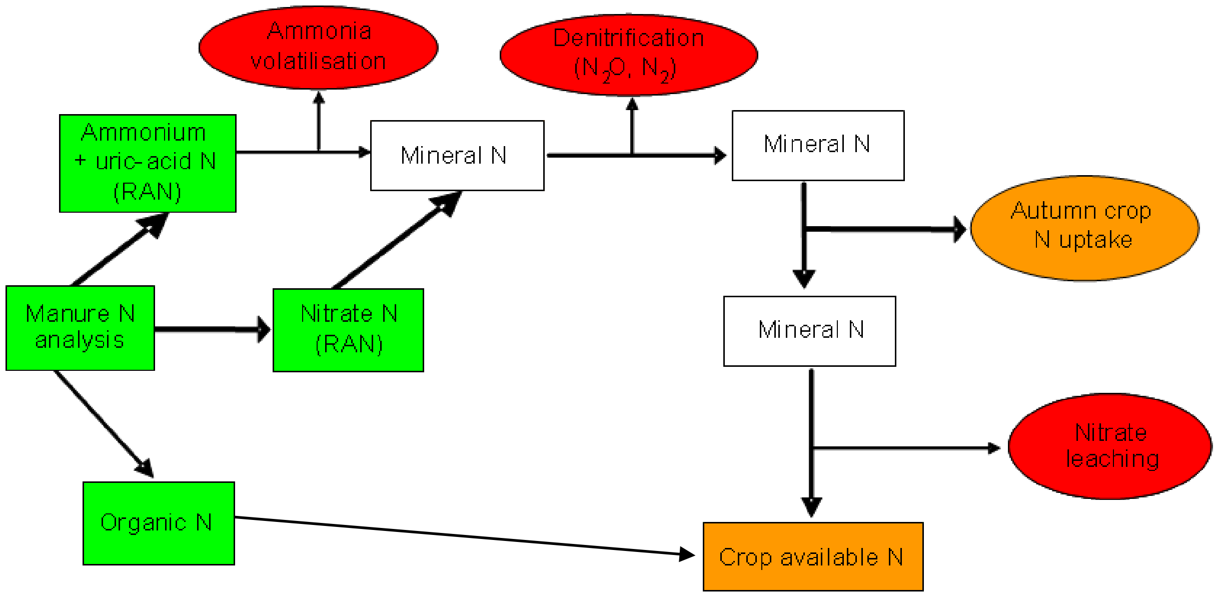

Figure 1. MANNER-*NPK* flow diagram

Although MANNER-*NPK* was designed for use in agricultural management, the predictions of N availability are equally valid for other land uses, such as forestry or energy cropping, and are independent of the quality of soil forming material that the organic material is applied to. The model is driven by research data on nitrogen losses and transformations, coupled with knowledge of the processes controlling the nitrogen cycle, which are used to predict losses following organic material applications to land.

MANNER-*NPK* predictions cover:

Ammonia volatilisation: The amount of N that is volatilised and lost to the atmosphere as ammonia gas, taking into account the organic material ammonium-N content and a number of other factors including, application technique, method and timing of soil incorporation, topsoil moisture, land use, dry matter content for liquid organic materials, wind speed and rainfall); all of which have been shown in field experiments to influence ammonia emissions.

Nitrate leaching: The amount of N that is leached below the crop root zone (>90cm), taking into account the readily available N content of the organic material remaining following ammonia volatilisation losses and after any autumn crop N uptake. MANNER-*NPK* estimates drainage volumes and nitrate leaching losses based on postcode specific climate data, and takes into account the volumetric moisture content of the soil, the amount of rainfall following application and the end of over-winter soil drainage (i.e. up to 31 March).

Nitrous oxide and di-nitrogen losses: The amount of nitrous oxide (N_2O)-N lost through a combination of nitrification and denitrification processes; using an emission factor of *c*.2% of the readily available N remaining after ammonia volatilisation losses. MANNER-*NPK* also estimates di-nitrogen (N_2)-N lost through denitrification processes, based on a standard ratio between N_2O-N and N_2-N losses of 1:3.

Mineralised N: MANNER-*NPK* estimates organic N mineralisation based on soil temperature (thermal time) and N mineralisation differences between fast (i.e. pig slurry and poultry manures) and slow (i.e. farmyard manure and cattle slurry) organic N release materials.

Crop available nitrogen: The amount of organic material total N which is available to the next crop grown in the year of application and in subsequent years. This includes N released from organic forms.

4.2 Phosphate, potash, magnesium and sulphur

Organic materials are valuable sources of other nutrients as well as nitrogen, although not all of the total nutrient content is plant available within the first year. Unless there is specific information, it is assumed that 50% of phosphate content and 80-90% of the potash content will be available to the next crop grown (SRUC, 2013a). Organic materials also supply useful quantities of sulphur and magnesium, but there is only limited (or in many cases no) data on availability. Sulphur and magnesium inputs from organic materials should largely be regarded as contributing to the soil reserves.

4.3 Losses (i.e. leaching) of phosphorus and heavy metals

Following creation of a soil forming material, rainfall percolation through the final soil profile can potentially cause nutrients to leach into surface and groundwaters (as is the case for all land). As described above, nitrate leaching losses (and other nitrogen loss pathways) have been estimated for each material individually, using the MANNER-*NPK* model.

Phosphorus within organic materials will either be taken up by established vegetation or will bind to the inorganic/organic compounds within the soil forming material/existing habitat. This means that unless the soil P status is high (e.g. ADAS Index 5 and above; SAC status very high) then the risk of elevated phosphorus leaching losses are low. The scientific literature shows that there is a clear link between soil Olsen extractable P and soluble P concentrations in surface waters (Bhogal *et al*., 2008). Moreover, Heckrath *et al.* (1995) and Smith *et al.* (1998) related P concentrations in drainage waters from arable soils to soil extractable P and identified 'change points' at 60-70 mg/l Olsen extractable P (top end of P Index 4). However Bhogal *et al.* (2008) state that "60mg/l extractable phosphorous may not be sufficiently protective of water quality." SRUC (2015) have developed an index system to reflect the phosphorus sorption capacity (PSC) of Scottish soils. Soils with a low PSC have a higher risk of P leaching than those with a high PSC and a threshold of 60 mg/l extractable P might already be too high for soils with a low PSC.

Similarly for heavy metals, their mobility is strongly influenced by the pH of the soil forming material/existing habitat (DoE, 1996). In slightly acid/neutral conditions (i.e. where the pH of soil is >pH6), metals such as copper and lead become less mobile in the soil (and bioavailable) due in part to the chemical forms of the ions within the soil; whereby they become bound to organic compounds within the soil forming material/existing habitat (Keller *et al.*, 2002). In sites with a low pH (i.e. where the pH of the soil is <5) great care is needed to ensure heavy metals do not become more bioavailable (potentially harming sensitive plants) or are leached from the soil profile.

4.4 Compost

EWC 190503: Off-specification compost consisting only of biodegradable waste
EWC 200201: Biodegradable waste

Compost is a natural product resulting from the controlled biological decomposition of biodegradable materials, such as garden and food waste. Green compost is solely derived of green waste from domestic gardens, municipal parks and recreational areas, whereas green/food compost contains a mixture of garden and food waste. Both green and green/food compost are derived from feedstock material that has been collected separately from other waste streams. In Scotland, where compost has met the standards set out in BSI PAS 100 (BSI, 2011) and its use complies with the SEPA position statement (SEPA, 2004) it is considered as fully recovered and therefore is no longer regarded as a waste material.

Both green and green/food compost are suitable for use at sites intended for a variety of end-uses, such as energy crop production, grassland and woodland establishment. The application of compost is an effective way of maintaining and building soil organic matter levels which will help to improve soil structural stability, drainage status and the retention of nutrients. The organic matter in compost is 'stable' and more resistant to degradation than in many other organic materials and therefore has a longer lasting effect.

The benefits and potential negative impacts of compost applications to land are listed in Box 3, below.

Box 3: Compost
Benefits and potential negative impacts of application to land

Benefits:

- Improves soil structure (particularly in clay rich mineral materials) leading to better drainage, aeration and root penetration.
- Improves the water holding capacity and aggregate stability of low organic matter mineral materials.
- Provides slow-release plant available nutrients, such as nitrogen and phosphorus.
- Has a (small) liming capacity that can stabilise soil pH leading to increased soil buffering capacity.
- Applications increase soil biological activity and the size of the microbial population.

Potential negative impacts:

- Compost applications can cause temporary nitrogen 'lock-up' where they have a high C: N ratio (>20-25:1).
- Can contain elevated heavy metals concentrations which in some situations can limit application rates.

Nutrient content of green and green compost

The nutrient content of compost varies depending on the individual source and treatment process; 'typical' values for green and green/food compost that are commonly applied to land are summarised in Table 7.

Table 7. Typical nutrient contents (kg/t fresh weight) of green and green/food compost (Defra, 2010; SRUC, 2013a)

Major nutrients	Green compost		Green/food compost	
	Total	Available (% in year 1)	Total	Available (% in year 1)
Nitrogen (N)	7.5	<0.2 (<1%)$^{+}$	11	0.6 (5%)$^{+}$
Phosphate (P_2O_5)	3.0	1.5 (50%)$^{++}$	3.8	1.9 (50%)$^{++}$
Potash (K_2O)	5.5	4.4 (80%)$^{++}$	8.0	6.4 (80%)$^{++}$
Sulphur (SO_3)	2.6	n.d.	3.4	n.d.
Magnesium (MgO)	3.4	n.d.	3.4	n.d.

n.d. no data

$^{+}$ Readily available

$^{++}$ Crop available

The typical values (above) can be used as a guide, however, the nutrient content of compost will vary between composting plants. It is recommended that an up to date analysis is obtained, this can be done by:

- Obtaining a copy of a recent laboratory analysis from the compost supplier.
- Having a sample of compost analysed at a reputable accredited laboratory e.g. a member of the Professional Agricultural Analysis Group (PAAG, 2013).

Application

Compost application rates will be site-specific and will depend on the properties of the material applied, the purpose of the application (e.g. soil forming, soil improvement or as a top dressing), the quality of in-situ mineral material and the intended use of the land following application

Where compost is being used as a soil forming material, mixing ratios usually range between 5 and 25% on a volume/volume basis, depending on site-specific factors and the planned end use (WRAP, 2011). Compost for soil improvement is usually spread over the treatment area and subsequently incorporated into the soil to a maximum depth of 0.4 m, as soon as possible following application. Based on a mixing ratio of 5-25% to a 0.4 m depth this would equate to an application rate of between 100-500 dry tonnes/hectare (200-1000 m^3/ha).

Soil organic matter, nutrient concentrations and heavy metal concentrations in the final topsoil should be in accordance with the habitat need.

Nitrogen losses following compost applications

Following compost application, small amounts of nitrogen can be lost via nitrate leaching to water, as ammonia and nitrous oxide to air. Nitrogen loss pathways following green compost application (four application timings) to two soil types in high (*c.*1300 mm) and low (*c.*800 mm) rainfall areas were estimated, using the MANNER-*NPK* model (Nicholson *et al.*, 2013), in Table 8 and

Table 9, and following green/food compost in Table 10 and Table 11.

Table 8. MANNER-*NPK* predictions of crop available N supply and N losses following green compost application in a high rainfall area (% total N)

Season	Autumn[1]		Winter[2]		Spring[3]		Summer[4]	
	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam
Crop available N current crop (%)[+]	6	6	7	7	8	8	4	4
Crop available N following crop (%)[++]	3	2	3	2	3	2	3	2
Crop available N in each of years 3-5 (%)	1.5	1	1.5	1	1.5	1	1.5	1
Mineralised N (%)	1	1	1	1	1	1	3	3
Nitrate-N loss (%)	2	4	1	1	0.4	0.3	None	None
Ammonia-N loss (%)	1	1	1	1	1	1	1	1
Denitrified-N loss (%)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.13

Note: assumed a green compost N content of 7.5 kg N/t fw (60% dry matter) and readily available N content of 0.2 kg/t fw. Compost was surface broadcast and incorporated by rotary cultivation 1-2 days post application. No rainfall within 6 hours of spreading; wind speed calm. Annual average rainfall 1300 mm.

1 Assumed an application data of 1 September and 900 mm of rainfall until the end of drainage
2 Assumed an application data of 1 November and 650 mm of rainfall until the end of drainage
3 Assumed an application data of 1 February and 200 mm of rainfall until the end of drainage
4 Assumed an application data of 1 July and no drainage following application
+ Grassland habitat
++ Crop year 2

Table 9. MANNER-*NPK* predictions of crop available N supply and N losses following green compost application in a low rainfall area (% total N)

Season	Autumn[1]		Winter[2]		Spring[3]		Summer[4]	
	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam
Crop available N current crop (%)[+]	7	6	8	7	8	8	4	4
Crop available N following crop (%)[++]	3	2	3	2	3	2	3	2
Crop available N in each of years 3-5 (%)	1.5	1	1.5	1	1.5	1	1.5	1
Mineralised N (%)	1	1	1	1	1	1	3	3
Nitrate-N loss %)	1	4	1	1	0.1	Non	None	None
Ammonia-N loss (%)	1	1	1	1	1	1	1	1
Denitrified-N loss (%)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Note: assumed a green compost N content of 7.5 kg N/t fw (60% dry matter) and readily available N content of 0.2 kg/t fw. Compost was surface broadcast and incorporated by rotary cultivation 1-2 days post application. No rainfall within 6 hours of spreading; wind speed calm. Annual average rainfall 800 mm.

1 Assumed an application data of 1 September and 500 mm of rainfall until the end of drainage
2 Assumed an application data of 1 November and 350 mm of rainfall until the end of drainage
3 Assumed an application data of 1 February and 100 mm of rainfall until the end of drainage
4 Assumed an application data of 1 July and no drainage following application
+ Grassland habitat
++ Crop year 2

Table 10. MANNER-*NPK* predictions of crop available N supply and N losses following green/food compost application in a high rainfall area (% total N)

Season	Autumn[1]		Winter[2]		Spring[3]		Summer[4]	
	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam
Crop available N current crop (%)	6	6	8	7	9	9	5	5
Crop available N following crop (%)	3	2	3	2	3	2	3	2
Crop available N in each of years 3-5 (%)	1.5	1	1.5	1	1.5	1	1.5	1
Mineralised N (%)	1	1	1	1	1	1	3	3
Nitrate-N loss (%)	3	4	1	3	3	1	None	None
Ammonia-N loss (%)	3	3	3	3	3	3	3	3
Denitrified-N loss (%)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Note: assumed a green/food compost N content of 11 kg N/t fw (60% dry matter) and readily available-N content of 0.6 kg/t fw. Compost was surface broadcast and incorporated by rotary cultivation 1-2 days post application. No rainfall within 6 hours of spreading; wind speed calm. Annual average rainfall 1300 mm.

[1] Assumed an application data of 1 September and 900 mm of rainfall until the end of drainage
[2] Assumed an application data of 1 November and 650 mm of rainfall until the end of drainage
[3] Assumed an application data of 1 February and 200 mm of rainfall until the end of drainage
[4] Assumed an application data of 1 July and no drainage following application
[+] Grassland habitat
[++] Crop year 2

Table 11. MANNER-*NPK* predictions of crop available N supply and N losses following green/food compost application in a low rainfall area (% total N)

Season	Autumn[1]		Winter[2]		Spring[3]		Summer[4]	
	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam
Crop available N current crop (%)	7	6	8	7	9	9	5	5
Crop available N following crop (%)	3	2	3	2	3	2	3	2
Crop available N in each of years 3-5 (%)	1.5	1	1.5	1	1.5	1	1.5	1
Mineralised N (%)	1	1	1	1	1	1	3	3
Nitrate-N loss (%)	2	4	1	2	None	None	None	None
Ammonia-N loss (%)	3	3	3	3	3	3	3	3
Denitrified-N loss (%)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Note: assumed a green/food compost N content of 11 kg N/t fw (60% dry matter) and readily available-N content of 0.6 kg/t fw. Compost was surface broadcast and incorporated by rotary cultivation 1-2 days post application. No rainfall within 6 hours of spreading; wind speed calm. Annual average rainfall 800 mm.

[1] Assumed an application data of 1 September and 500 mm of rainfall until the end of drainage
[2] Assumed an application data of 1 November and 350 mm of rainfall until the end of drainage
[3] Assumed an application data of 1 February and 100 mm of rainfall until the end of drainage
[4] Assumed an application data of 1 July and no drainage following application
[+] Grassland habitat
[++] Crop year 2

In summary, the supply of compost nitrogen is relatively insensitive to application timing, and only low amounts of N are supplied in the medium-term following application. Similarly, nitrate leaching and gaseous N losses predicted were to be small, reflecting the stable (organically-bound) forms of N in green and green/food compost.

4.5 Biosolids

EWC 190805: Sludges from treatment of urban waste water

Treated sewage sludge (i.e. 'biosolids') is produced through the treatment of urban waste water at waste water treatment works and can be in cake, granular/pellet or liquid forms. Solid materials (e.g. digested cake, lime stabilised cake) are the most common products. The 1989 "Sludge (Use in Agriculture) Regulations" (SI, 1989) define 'treated sludge' as: "sludge or septic tank sludge which has undergone biological, chemical or heat treatment, long-term storage or any other appropriate process so as to significantly reduce its fermentability and the health hazards resulting from its use".

The benefits and potential negative impacts of biosolids applications to land are listed in Box 4, below.

Box 4: Biosolids
Benefits and potential negative impacts of application to land

Benefits:

- Major nutrients (nitrogen and phosphorus) which will contribute towards plant needs.
- Nitrogen availability depends on the treatment process; aerobically treated biosolids (e.g. composted, thermally dried) release nitrogen over a prolonged period, whereas anaerobically treated biosolids tend to be higher in readily available N (ammonium-N) which is immediately available for plant uptake.
- Around 50% of the phosphate is estimated to crop available in the first year.
- Applications increase soil biological activity and the size of the soil microbial population.
- Stable organic matter that can improve soil physical properties e.g. water holding capacity, drainage status, structure etc.
- Where lime treated products are spread they can neutralise soil acidity.

Potential negative impacts:

- In common with other organic materials, biosolids application outside the window of active crop growth can result in nutrient losses to surface or ground waters; application timings should reflect crop nutrient demand and be managed to minimise pollution.
- Heavy metals, which may limit application rates, depending on the receiving mineral material.
- Applications should not be made where the soil pH is <5.0.
- Odour issues may cause problems, during storage and spreading.

Nutrient content of biosolids

The nutrient content of biosolids varies depending on the individual source and treatment process; 'typical' values for two biosolids products commonly applied to land are summarised in Table 12. Notably, most biosolids products are supplied by water companies with specific nutrient content data.

Table 12. 'Typical' nutrient contents (kg/t fresh weight) of biosolids: digested cake and lime stabilised cake (Chambers *et al*., 2014; Defra, 2010; SRUC 2013a)

Major nutrients	Digested cake		Lime stabilised cake	
	Total	Available (% in year 1)	Total	Available (% in year 1)
Nitrogen (N)	11	1.6 (15%)$^{+}$	8.5	0.9 (10%)$^{+}$
Phosphate (P_2O_5)	11	4.5 (50%)$^{++}$	17	8.5 (50%)$^{++}$
Potash (K_2O)	0.6	0.5 (90%)$^{++}$	0.8	0.7 (90%)$^{++}$
Sulphur (SO_3)	8.0	n.d.	11	n.d.
Magnesium (MgO)	1.6	n.d.	2.4	n.d.

n.d. no data
$^{+}$ Readily available
$^{++}$ Crop available
Note: total phosphate and sulphur and associated extractable phosphate figures have been revised based on more recent information (Chambers *et al*., 2014) and hence differ from those published in Defra (2010) and SRUC (2013a).

Nitrogen losses following biosolids applications

Following biosolids application, nitrogen might be lost via nitrate leaching to water or as ammonia and nitrous oxide to air. Nitrogen loss pathways following a biosolids cake application (four application timings) to two soil types in high (*c.*1300 mm) and low (*c.*800 mm) rainfall areas, estimated using the MANNER-*NPK* model (Nicholson *et al*., 2013,) are summarised in Table 13 and Table 14.

Note: N availability and losses from lime stabilised biosolids will be similar to biosolids cake.

Table 13. MANNER-*NPK* predictions of crop available N supply and N losses following biosolids cake application in a high rainfall area (% total N)

Season	Autumn[1]		Winter[2]		Spring[3]		Summer[4]	
	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam
Crop available N current crop (%)[+]	14	13	20	16	24	24	16	16
Crop available N following crop (%)[++]	6	3	7	4	7	4	8	4
Crop available N in each of years 3-5 (%)	3	1.5	3.5	2	3.5	2	4	2
Mineralised N (%)	2	2	2	2	2	2	7	7
Nitrate-N loss (%)	11	17	6	11	3	3	<1	<1
Ammonia-N loss (%)	5	5	5	5	5	5	5	5
Denitrified-N loss (%)	1	1	1	1	1	1	1	1

Note: assumed a biosolids N content of 11 kg N/ t fresh weight (25% dry matter), ammonium-N content of 1.7 kg/t fresh weight. Biosolids were surface broadcast and incorporated by rotary cultivation 1-2 days post application. No rainfall within 6 hours of spreading; wind speed calm. Annual average rainfall 1300 mm.

[1] Assumed an application data of 1 September and 900 mm of rainfall until the end of drainage
[2] Assumed an application data of 1 November and 650 mm of rainfall until the end of drainage
[3] Assumed an application data of 1 February and 200 mm of rainfall until the end of drainage
[4] Assumed an application data of 1 July and 0 mm of drainage following application
[+] Grassland habitat
[++] Crop year 2

Table 14. MANNER-*NPK* predictions of crop available N supply and N losses following biosolids cake application in a low rainfall area (% total N)

Season	Autumn[1]		Winter[2]		Spring[3]		Summer[4]	
	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam
Crop available N current crop (%)[+]	18	13	22	19	25	27	16	16
Crop available N following crop (%)[++]	6	3	7	4	7	4	8	4
Crop available N in each of years 3-5 (%)	3	1.5	3.5	2	3.5	2	4	2
Mineralised N (%)	2	2	2	2	2	2	7	7
Nitrate-N loss (%)	7	17	4	8	2	<1	<1	<1
Ammonia-N loss (%)	5	5	5	5	5	5	5	5
Denitrified-N loss (%)	1	1	1	1	1	1	1	1

Note: assumed a biosolids N content of 11 kg N/ t fresh weight (25% dry matter), ammonium-N content of 1.7 kg/t fresh weight. Biosolids were surface broadcast and incorporated by rotary cultivation 1-2 days post application. No rainfall within 6 hours of spreading; wind speed calm. Annual average rainfall 800 mm.

[1] Assumed an application data of 1 September and 900 mm of rainfall until the end of drainage
[2] Assumed an application data of 1 November and 650 mm of rainfall until the end of drainage
[3] Assumed an application data of 1 February and 200 mm of rainfall until the end of drainage
[4] Assumed an application data of 1 July and 0 mm of drainage following application
[+] Grassland habitat
[++] Crop year 2

In summary, to make best use of the N supplied in biosolids, applications are best made in the late winter-spring period, with moderate amounts of N supplied in the medium term following application. Moderate amounts of N were estimated to be lost via nitrate leaching and gaseous N losses, reflecting the (largely) organically-bound forms of N in biosolids.

Storage

Prior to storing sewage sludge, SEPA must be notified through the registration of a Paragraph 8.1 waste management exemption. This notification must include where the material will be stored, and if it is to be spread to non-agricultural land.

4.6 Digestate

EWC 190603: Liquor from anaerobic treatment of municipal waste
EWC 190604: Digestate from anaerobic treatment of municipal waste
EWC 190605: Liquor from anaerobic treatment of animal and vegetable waste
EWC 190606: Digestate from anaerobic treatment of animal and vegetable waste

Anaerobic digestion (AD) involves the breakdown of biodegradable material in the absence of oxygen by micro-organisms, called methanogens. AD is widely used to treat sewage sludge in Scotland and can also be used to treat other organic materials, including domestic and commercial/industrial food 'wastes', livestock manures and crops (e.g. maize, grass). Feedstocks can be either source segregated (19.06.05; 19.06.06) or non-source segregated (19.06.03; 19.06.04). During the AD process methane is released that can be used to provide heat and power, and digestate is produced, which can be applied to land as a fertiliser and soil conditioner, adding nutrients and organic matter to soils. In Scotland, where digestate has met the standards set out in BSI PAS 110 (BSI, 2014) and complies with the SEPA position statement (SEPA, 2013) it is considered as fully recovered and therefore is no longer regarded as a waste material.

There are three main types of digestate (whole, liquid and fibre), with whole digestate being the most commonly available. The fibre fraction typically has a dry matter content of between 20 and 40%, and the whole/liquid fraction between 1 and 6%, although these proportions will vary depending upon the separation process or processes employed.

At present agriculture is the dominant end-market for whole digestate, fibre and liquor; with only small amounts used in land restoration/reclamation (WRAP, 2012). However, digestate has the potential to be used as a fertiliser (whole, fibre and liquor) and a soil improver (fibre fraction only) for the restoration or improvement of existing habitats.

The benefits and potential negative impacts of digestate applications to land are listed in Box 5, below.

Box 5: Digestate
Benefits and potential negative impacts of application to land

Benefits:

- A good source of crop available N, particularly for use during the spring/summer growing season.
- Useful amounts of phosphate, potash and sulphur.
- Fibre digestate (in particular) can help to build soil organic matter levels, which can improve soil physical properties.

Potential negative impacts:

- When plants are not actively growing, can result in elevated nitrate leaching losses.
- Liquid digestate typically has a high biochemical oxygen demand and care is needed when applying digestate (as with other liquid organic materials) to land to minimise water pollution risks.
- May result in ammonia volatilisation (particularly when not soil incorporated) and nitrous oxide emissions.
- May cause odour problems, especially with high trajectory liquid spreading methods, and where soil incorporation is delayed/incomplete.

Nutrient content of food and manure-based digestates

Digestate varies in its nutrient content, depending on the feedstock material, nature of the AD process and post-digestion processing. The 'typical' nitrogen, phosphate and potash contents of food-based and manure (cattle slurry)-based digestate are listed in Table 15.

Table 15. Typical nutrient contents (kg/m^3 fresh weight) of whole food-based and manure (cattle slurry)-based digestate (SRUC, 2013a)

Major nutrients	Food-based digestate		Manure-based digestate	
	Total	Available (% in year 1)	Total	Available (% in year 1)
Nitrogen (N)	5.0	4.0 (80%)$^{+}$	2.6	1.4 (55%)$^{+}$
Phosphate (P_2O_5)	0.5	0.25 (50%)$^{++}$	1.2	0.6 (50%)$^{++}$
Potash (K_2O)	2.0	1.6 (80%)$^{++}$	3.2	2.9 (90%)$^{++}$
Sulphur (SO_3)	0.4	n.d.	0.7	n.d.
Magnesium (MgO)	0.1	n.d.	0.6	n.d.

n.d. no data
$^{+}$ Readily available
$^{++}$ Crop available

As the nutrient content of digestate will vary between AD plants, it is recommended that an up to date analysis is obtained, this can be done by:

- Obtaining a copy of a recent laboratory analysis from the biofertiliser supplier.
- Having a sample analysed at a reputable accredited laboratory e.g. a member of the Professional Agricultural Analysis Group (PAAG, 2013).

To make optimum use of the N content of digestate it should be applied at times of active crop growth - generally during the early spring to summer period. Ammonia emissions (and odour nuisance) can be reduced by *rapidly incorporating* digestate into soils, ideally within 24 hours, or where liquid digestate is being applied by using bandspreading or shallow injection equipment (where possible).

There is no specific information available on digestate application rates for sectors other than agriculture. The use of liquid (whole or separated liquor) digestate in land restoration/reclamation, because of its low dry mater and low organic matter content, will primarily be as a source of nutrients (especially nitrogen).

Nitrogen losses following digestate applications

Following digestate application, nitrogen can be lost via nitrate leaching to water or as ammonia and nitrous oxide emissions to air. Nitrogen loss pathways following liquid (whole) food or manure-based digestate application (four application timings) to two soil types, in high (1300 mm) and low (800 mm) rainfall areas, estimated using the MANNER-*NPK* model (Nicholson *et al*., 2013), are summarised in Table 16 and Table 17 for food-based digestate, and in Table 18 and Table 19 for manure-based digestate.

Table 16. MANNER-*NPK* predictions of crop available N supply and N losses following food-based digestate application in a high rainfall area (% of total N)

Season	Autumn[1]		Winter[2]		Spring[3]		Summer[4]	
	clay loam	**sandy loam**	**clay loam**	**sandy loam**	**clay loam**	**sandy loam**	**clay loam**	**sandy loam**
Crop available N current crop (%)[+]	26	5	29	4	44	45	60	60
Crop available N following crop (%)[++]	1	1	2	1	2	1	2	1
Crop available N in each of years 3-5 (%)	0.5	0.5	1	0.5	1	0.5	1	0.5
Mineralised N (%)	0.4	0.4	0.4	0.4	0.4	0.4	2	2
Nitrate-N loss (%)	36	56	33	58	18	18	<1	<1
Ammonia-N loss (%)	17	17	17	17	17	17	17	17
Denitrified-N loss (%)	5	5	5	5	5	5	5	5

Note: assumed a food-based digestate N content of 5 kg N/t fw (4% dm) and ammonium-N content of 4 kg/t fw. Digestate was surface broadcast and incorporated by rotary cultivation 1-2 days post application. No rainfall within 6 hours of spreading; wind speed calm. Annual average rainfall 1300 mm.

[1] Assumed an application data of 1 September and 900 mm of rainfall until the end of drainage
[2] Assumed an application data of 1 November and 650 mm of rainfall until the end of drainage
[3] Assumed an application data of 1 February and 200 mm of rainfall until the end of drainage
[4] Assumed an application data of 1 July and 0 mm of drainage following application
[+] Grassland habitat
[++] Crop year 2

Table 17. MANNER-*NPK* predictions of crop available N supply and N losses following food-based digestate application in a low rainfall area (% of total N)

Season	Autumn[1]		Winter[2]		Spring[3]		Summer[4]	
	clay loam	**sandy loam**	**clay loam**	**sandy loam**	**clay loam**	**sandy loam**	**clay loam**	**sandy loam**
Crop available N current crop (%)[+]	40	7	39	21	53	62	60	60
Crop available N following crop (%)[++]	1	1	2	0	2	1	2	1
Crop available N in each of years 3-5 (%)	0.5	0.5	1	0	1	0.5	1	0.5
Mineralised N (%)	0.4	0.4	0.4	0.4	0.4	0.4	2	2
Nitrate-N loss (%)	21	54	23	41	9	<1	<1	<1
Ammonia-N loss (%)	17	17	17	17	17	17	17	17
Denitrified-N loss (%)	5	5	5	5	5	5	5	5

Note: assumed a food-based digestate N content of 5 kg N/t fw (4% dm) and ammonium-N content of 4 kg/t fw. Digestate was surface broadcast and incorporated by rotary cultivation 1-2 days post application. No rainfall within 6 hours of spreading; wind speed calm. Annual average rainfall 800 mm.

[1] Assumed an application data of 1 September and 500 mm of rainfall until the end of drainage
[2] Assumed an application data of 1 November and 350 mm of rainfall until the end of drainage
[3] Assumed an application data of 1 February and 100 mm of rainfall until the end of drainage
[4] Assumed an application data of 1 July and 0 mm of drainage following application
[+] Grassland habitat
[++] Crop year 2

Table 18. MANNER-*NPK* predictions of crop available N supply and N losses following manure-based digestate application in a high rainfall area (% of total N)

Season	Autumn[1]		Winter[2]		Spring[3]		Summer[4]	
	clay loam	**sandy loam**	**clay loam**	**sandy loam**	**clay loam**	**sandy loam**	**clay loam**	**sandy loam**
Crop available N current crop (%)[+]	22	9	21	3	31	32	30	30
Crop available N following crop (%)[++]	2	1	2	1	2	1	2	1
Crop available N in each of years 3-5 (%)	1	0.5	1	0.5	1	0.5	1	0.5
Mineralised N (%)	0.4	0.4	0.4	0.4	0.4	0.4	1	1
Nitrate-N loss (%)	22	34	23	40	12	11	<1	<1
Ammonia-N loss (%)	9	10	10	10	10	10	23	23
Denitrified-N loss (%)	3	3	3	3	3	3	2	2

Note: assumed a manure-based digestate N content of 2.6 kg N/t fw (4% dm) and ammonium-N content of 1.4 kg/t fw Digestate was surface broadcast and incorporated by rotary cultivation 1-2 days post application. No rainfall within 6 hours of spreading; wind speed calm. Annual average rainfall 1300 mm.

[1] Assumed an application data of 1 September and 900 mm of rainfall until the end of drainage
[2] Assumed an application data of 1 November and 650 mm of rainfall until the end of drainage
[3] Assumed an application data of 1 February and 200 mm of rainfall until the end of drainage
[4] Assumed an application data of 1 July and 0 mm of drainage following application
[+] Grassland habitat
[++] Crop year 2

Table 19. MANNER-*NPK* predictions of crop available N supply and N losses following manure-based digestate application in a low rainfall area (% of total N)

Season	Autumn[1]		Winter[2]		Spring[3]		Summer[4]	
	clay loam	**sandy loam**	**clay loam**	**sandy loam**	**clay loam**	**sandy loam**	**clay loam**	**sandy loam**
Crop available N current crop (%)[+]	31	11	28	15	37	43	30	30
Crop available N following crop (%)[++]	2	1	2	1	1	1	2	1
Crop available N in each of years 3-5 (%)	1	0.5	1	0.5	0.5	0.5	1	0.5
Mineralised N (%)	0.4	0.4	0.4	0.4	0.4	0.4	1	1
Nitrate-N loss (%)	13	33	16	28	6	<1	<1	<1
Ammonia-N loss (%)	10	10	10	10	10	10	23	23
Denitrified-N loss (%)	3	3	3	3	3	3	2	2

Note: assumed a manure-based digestate N content of 2.6 kg N/t fw (4% dm) and ammonium-N content of 1.4 kg/t fw. Digestate was surface broadcast and incorporated by rotary cultivation 1-2 days post application. No rainfall within 6 hours of spreading; wind speed calm. Annual average rainfall 800 mm.

[1] Assumed an application data of 1 September and 500 mm of rainfall until the end of drainage
[2] Assumed an application data of 1 November and 350 mm of rainfall until the end of drainage
[3] Assumed an application data of 1 February and 100 mm of rainfall until the end of drainage
[4] Assumed an application data of 1 July and 0 mm of drainage following application
[+] Grassland habitat
[++] Crop year 2

In summary, to make best use of digestate N, applications should be made in spring, with only small amounts of N supplied in the medium-term following application. Moderate-high amounts of N were estimated to be lost via nitrate leaching and gaseous N losses reflecting the (high) readily available N content of digestate, and in particular food-based digestate.

4.7 Paper crumble (sludge)

EWC 030305: De-inking sludges from paper recycling

Paper crumble is the residue from the preparation of recycled paper prior to its re-use in the paper production process, or from the processing of virgin fibre from a variety of fibre sources, such as wood or cotton. It contains short cellulose fibres which are not suitable for use in paper production, printing inks and mineral components such as kaolin, talc and calcium carbonate.

The production of paper waste from paper mills is a result of two principal routes of effluent treatment *i.e.* primary or secondary (either chemical/physical or biological) treatment processes. Primary treatment involves initial screening of the mill effluent to increase the fibre content of the paper waste material *e.g.* by settlement. Secondary chemical/physical or biological treatment is used to reduce the biological/chemical oxygen demand of the effluent and to increase the dry solids content of the paper waste. The secondary treatment process determines the composition of the sludge and its effect when applied to land. Biologically-treated paper crumble (sludge) typically has higher nutrient and heavy metal contents than chemically/physically-treated paper crumble (Gibbs *et al*., 2005); these differences are a result of using biologically active materials, such as sewage sludge, to drive the biological treatment process.

The benefits and potential negative impacts of paper crumble (sludge) applications to land are listed in Box 6, below.

Box 6: Paper crumble (sludge)
Benefits and potential negative impacts of application to land

Benefits:

- Liming value: total neutralising value (on a calcium oxide basis) is typically between 1% and 21% (mean of 8%) on a dry solids basis.
- Supplies major plant nutrients; nitrogen, phosphorus, potassium and sulphur.
- Supplies organic matter (30-70% on a dry solids basis) which can improve soil physical properties e.g. drainage status, water holding capacity, soil structure, etc.
- Applications increase biological activity and the size of the microbial population.

Potential negative impacts:

- The ‘high’ carbon:nitrogen ratio of paper crumble can cause nitrogen ‘lock-up’. Nitrogen could be added to the crumble to prevent this or the crumble application could be supplemented with manufactured fertiliser N or a nitrogen ‘rich’ organic material.
- Can contain elevated heavy metal concentrations.
- Odour issues may cause problems, during storage and spreading.

Nutrient content of chemically/physically and biologically treated paper crumble (sludge)

Paper crumble (sludge) varies in its nutrient content, depending on the treatment process. The ‘typical’ nitrogen, phosphate, potash, sulphur and magnesium contents of chemically/physically and biologically treated paper crumble are listed in Table 20.

Table 20. Typical nutrient contents (kg/t fresh weight) of chemically/physically and biologically treated paper crumble (Defra, 2010; SRUC, 2013a)

Major nutrients	Chemically/physically treated	Biologically treated
Nitrogen (N)	2.0	7.5
Phosphate (P_2O_5)	0.4	3.8
Potash (K_2O)	0.2	0.4
Sulphur (SO_3)	0.6	2.4
Magnesium (MgO)	1.4	1.0

Following the application of chemically/physically treated paper crumble nitrogen 'lock-up' commonly occurs, due to the high carbon:nitrogen (C:N) ratio of the crumble which immobilises soil N. As a general rule, around 0.8 kg of manufactured N is required per tonne (fresh weight) of paper sludge applied to compensate for the nitrogen 'lock-up' in the soil. As biologically treated paper crumble has a lower C:N ratio, nitrogen 'lock-up' is not usually experienced following land spreading (Defra, 2010).

If paper crumble (particularly chemically/physically treated materials) is used on its own, there is a risk of N immobilisation due to the high C:N ratio. As a result, a source of nitrogen is often applied at the same time (e.g. biosolids, manufactured fertiliser N etc.). Paper crumble can also be pre-treated prior to land application by the addition of fertiliser N, or by composting with other organic materials, which reduces its C:N ratio, as well as the volume and moisture content of the composted end-material. There are no data on the crop availability of P and K present in paper crumble.

It is recommended that laboratory analysis is carried out to measure the specific liming value (expressed as total neutralising value) of paper crumble to assess its likely impact on soil pH.

The appropriate paper crumble application rate will depend on the properties of the paper crumble, the purpose of the crumble application (e.g. soil forming, soil improvement or as a top dressing) and the quality of the in-situ mineral material. Table 1 provides a useful reference point for paper crumble application rates.

Nitrogen losses following paper crumble application

Following paper crumble application, nitrate losses to water and ammonia/nitrous oxide emissions to air are likely to be very small, as a result of N 'lock-up'. Due to the typically high C:N ratio of paper crumble it is not appropriate to use the MANNER-*NPK* model to estimate typical N release or losses following land application. Following N 'lock-up' in the short-term following application, long-term N supply is likely to be increased.

4.8 Water treatment cake (sludge)

EWC 190902: Sludges from water clarification

Water treatment cake (sludge) is the residue resulting from the treatment of raw water to produce potable water in water treatment works. The cake is composed of the impurities removed and precipitated from the water, together with the residues of any treatment chemicals used. Typical processes include centrifuging, coagulation (using iron hydroxide or aluminium sulphate), filtration, dewatering and thickening.

Cakes typically contain small amounts of major nutrients: nitrogen, phosphorus, potassium, sulphur and magnesium (Defra, 2010). Heavy metal concentrations largely reflect the background content of soils in the catchment and are not elevated by the treatment process (Davis and Rudd, 1998).

The benefits and potential negative impacts of water treatment cake applications to land are listed in Box 7, below.

Box 7: Water treatment cake
Benefits and potential negative impacts of application to land

Benefits:

- Supplies major plant nutrients; nitrogen, phosphorus, potassium, sulphur and magnesium.
- Cake derived from peat run-off from upland catchments can contain a significant amount of organic matter.
- Sand as fine grit particles can have soil conditioning properties, improving the drainage status of heavy soils and adding 'body' to very light sandy textured soils.
- Can have a liming value (particularly for softening sludges) that neutralises soil acidity.

Potential negative impacts:

- Where the aluminium content is high, operators should take care to prevent any of the cake entering a watercourse, because (inorganic) aluminium can be toxic to aquatic life.
- Aluminium (in inorganic form) can stunt root growth and cause induced phosphate deficiency in crops. As a precautionary measure, aluminium treated cakes should only be applied to soils of pH 6 and above (EA, 2013).

Nutrient content of water treatment cake

The type and characteristics of the water treatment cake depend on the water treatment process and the quality of the raw water. Typical nitrogen, phosphate, potash, sulphur and magnesium contents are summarised in Table 21.

Table 21. Typical nutrient contents (kg/t fresh weight) of water treatment cake (Defra, 2010; SRUC, 2013a)

Nutrient	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)	Sulphur (SO_3)	Magnesium (MgO)
Water treatment sludge	2.4 (0.1% RAN)	3.4	0.4	5.5	0.8

There is no specific information on recommended application rates which will depend on the properties of the cake, the purpose of the application (e.g. soil forming, soil improvement etc.), the quality of in-situ mineral material and the intended use of the land following application.

Nitrogen losses following water treatment cake application

Following water treatment cake application, nitrate leaching losses to water and ammonia/nitrous oxide emissions to air are likely to be small, as the nitrogen content in the cake is largely in an organically-bound (slowly mineralised) form; associated with soil sediment material in the cake. Due to the low and stable N content of water treatment cake it is not appropriate to use the MANNER-*NPK* model to estimate typical N release properties or losses following land application.

4.9 Forestry residues

EWC 020107: Wastes from forestry

Forestry residues can be generated when trees are felled, for example, for the siting of wind turbines or following forest thinning. Trees which are not commercially viable for use as timber; typically <7cm diameter (Forest Commission, 2012), might be chipped in-situ, and spread over the surrounding areas as a mulch. However, the effects of woodchip amendments on soil nutrient availability and other environmental impacts on water and soil quality largely remain unstudied. Scottish Natural Heritage, Forestry Commission Scotland and SEPA have developed joint guidance to clearly outline where the spreading of forest residues is appropriate, taking into account site specific circumstances (SEPA/SNH/FCS 2014).

The benefits and potential negative impacts of forestry waste applications to land are listed in Box 8, below.

Box 8: Forestry residues
Benefits and potential negative impacts of application to land

Benefits:

- Chipped wood/bark can have value as a conditioner, improving soil water infiltration and water supply properties.

Potential negative impacts:

- High application rates can smother existing plants and prevent regeneration from the seed bank.
- The high C:N ratio can temporarily 'lock-up' plant available N.
- Particles in land run-off can have a negative impact on plant and animal life and aquatic health. It is recommended that buffers should be maintained around water bodies.

Note: The effect of the chipped/mulched material on tree seedling regeneration and weed growth is likely to depend on the density of material spread over the ground surface. Similarly, the rate of decomposition will depend on the particle size of the chipped/mulched material. Where particle size is small, decomposition is likely to be more rapid than from coarse materials.

Typical total nutrient contents of specific tree species and a generalised figure for trees are summarised in. Table 22.

Table 22. Typical total nutrient contents (kg/t fresh weight) of forestry residues (adapted from Anderson, 2006)

Nutrient	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)	Calcium (Ca)
Scots pine	2.15	0.56	1.34	1.42
Spruce	2.68	0.87	1.83	4.83
Douglas fir	1.72	0.82	1.43	1.79
Silver birch	2.78	0.40	1.23	3.33
Oak	2.46	0.37	1.97	7.92
Generic trees	*2.5*	*0.5*	*1.5*	*4.0*

Nitrogen losses following forestry residue application.

Following forestry residue application, nitrate leaching losses to water and ammonia/nitrous oxide emissions to air are likely to be small, as a result of N 'lock-up'. For example, Homyak *et al*. (2008) reported that a wood-chip application can potentially immobilize between 19 and 38 kg N/ha in the first year after harvesting, depending on the rate of wood-chip application and thereby reduce the amount of N available for leaching in the short-term following application. In contrast, Miller and Seastedt (2009) reported that woodchips did not alter inorganic nitrogen availability at ambient levels of soil fertility during the first two years of the study, but were associated with increased soil N availability in the third growing season.

4.10 Distillery residues

EWC 02.07.02: Wastes from Spirits Distillation
EWC 02 07 05: Sludges from on-site effluent treatment

The production of alcoholic beverages produces large volumes of distillery efficient liquid waste. Several wastes are produced during the process of spirits distillation, including pot ale, distillery effluent and bioplant sludge. Pot ale (also known as burnt ale or spent wash) is a high-protein residue from wash stills (02 07 02); distillery effluent (also 02 07 02) is a by-product obtained from spirit stills, and distillery bioplant sludge is produced from a range of processes (02 07 05) at some plants. All three are relatively low dry matter, pumpable liquids, which can contain useful concentrations of major nutrients.

The benefits and potential negative impacts of distillery residue applications to land are listed in Box 9, below.

Box 9: Distillery residues
Benefits and potential negative impacts of application to land

Benefits:

- Supplies useful quantities of plant available nutrients; nitrogen, phosphate, potash, sulphur and magnesium.
- Nitrogen availability in distillery residues depends on the type of product, but all tend to release nitrogen over a prolonged period; from the mineralisation of organically-bound N.
- Pot ale can contain relatively high concentrations of Cu, which can be useful on Cu deficient soils.
- Low nutrient content distillery effluents can be beneficial as part of a managed irrigation plan.

Potential negative impacts:

- In common with other organic materials, the application of distillery residues outside the window of active crop uptake may result in nutrient loss to surface or ground water.
- Application of distillery residues can sometimes cause vegetation scorch; to minimise the risk of this, application rates are often kept below <50m^3/ha. Ideally they should be applied using bandspreading/shallow injection equipment to minimise leaf contact.
- Pot ale and bioplant sludges may have high concentrations of Cu (and sometimes also Zn) which can limit application rates.
- Distillery effluents typically have low pH values which can cause soil acidification.
- Distillery residues typically have a high biochemical oxygen demand and care is needed when applying these materials (as with other liquid organic materials) to land to minimise water pollution risks.

Nutrient content of 'typical' distillery residues

The nutrient content of distillery residues varies depending on the individual source and treatment processes; typical values for the main three types that are commonly applied to land are summarised in Table 23. Notably, distillery residues are supplied by individual companies who provide information on their nutrient content and other properties.

Table 23. Typical major and trace element contents (and dry matter contents in %) of distillery residues including pot ale, effluent and bioplant sludge (kg/m^3 fresh weight). Copper and zinc content is also shown in mg/l of the fresh material. ([1]SRUC, 2013a; [2]Sinclair, unpublished data)

Major nutrients	Pot ale (5%)		Effluent (1.5%)		Bioplant sludge (4%)	
(dry matter content)	**Total**	**Available**	**Total**	**Available**	**Total**	**Available**
Nitrogen (N)[1]	2.5	0.1 (4%)$^+$	0.6	< 0.1 (<17%)$^+$	2.2	0.2 (9%)$^+$
Phosphate (P_2O_5)[1]	1.8	0.9 (50%)$^{++}$	0.5	0.3 (50%)$^{++}$	2.1	1.1 (50%)$^{++}$
Potash (K_2O)[1]	1.1	1.0 (90%)$^{++}$	0.2	0.2 (90%)$^{++}$	0.5	0.5 (90%)$^{++}$
Sulphur (SO_3)[1]	0.2	n.d.	0.1	n.d.	0.4	n.d.
Magnesium (MgO)[1]	0.3	n.d.	0.1	n.d.	0.3	n.d.
Copper (mg/l)[2]	7.1	n.d.	n.d.	n.d.	350	n.d.
Zinc (mg/l)[2]	0.8	n.d.	n.d.	n.d.	6.9	n.d.

n.d. no data
$^+$ Readily available
$^{++}$ Crop available

Application rates

Distillery residues are generally used in agriculture as fertilisers, mainly to supply P and K. They are typically applied at rates of between 20 and 50 m^3/ha. They are not widely used in land restoration as they supply only small amounts of organic matter. If they were used it would be important to ensure that final soil heavy metal concentrations (particularly copper) do not exceed those stipulated in Tables 1 and 6.

Nitrogen losses following distillery residue applications

Following the application of distillery residues, nitrogen can be lost via nitrate leaching to water or as ammonia/nitrous oxide emissions to air. Nitrogen loss pathways following pot ale application (four application timings) to two soil types, in high (1300 mm) and low (800 mm) rainfall areas, estimated using the MANNER-*NPK* model (Nicholson *et al*., 2013) are summarised in Table 24 and Table 25.

Table 24. MANNER-*NPK* predictions of crop available N supply and N losses following pot ale application in a high rainfall area (% total N)

Season	Autumn[1]		Winter[2]		Spring[3]		Summer[4]	
	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam
Crop available N current crop (%)[+]	15	15	20	19	21	21	11	11
Crop available N following crop (%)[++]	7	4	8	4	8	4	9	5
Crop available N in each of years 3-5 (%)	3.5	2	4	2	4	2	4.5	2.5
Mineralised N (%)	3	3	3	3	3	3	8	8
Nitrate-N loss (%)	7	11	3	4	1	1	<1	<1
Ammonia-N loss (%)	1	1	1	1	1	1	1	1
Denitrified-N loss (%)	<1	<1	<1	<1	<1	<1	<1	<1

Note assumed a pot ale N content of 2.5 kg N/t fw (5% dm) and ammonium-N content of 0.1 kg/t. Pot ale was surface broadcast and incorporated by rotary cultivation 1-2 days post application. No rainfall within 6 hours of spreading; wind speed calm. Annual average rainfall 1300 mm.

1 Assumed an application data of 1 September and 900 mm of rainfall until the end of drainage

2 Assumed an application data of 1 November and 650 mm of rainfall until the end of drainage

3 Assumed an application data of 1 February and 200 mm of rainfall until the end of drainage

4 Assumed an application data of 1 July and no drainage following application

\+ Grassland habitat

++ Crop year 2

Table 25. MANNER-*NPK* predictions of crop available N supply and N losses following pot ale application in a low rainfall area (% total N)

Season	Autumn[1]		Winter[2]		Spring[3]		Summer[4]	
	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam	clay loam	sandy loam
Crop available N current crop (%)[+]	16	15	21	20	21	23	11	11
Crop available N following crop (%)[++]	7	4	8	4	8	4	9	5
Crop available N in each of years 3-5 (%)	3.5	2	4	2	4	2	4.5	2.5
Mineralised N (%)	3	3	3	3	3	3	8	8
Nitrate-N loss (%)	4	11	1	3	<1	<1	<1	<1
Ammonia-N loss (%)	1	1	1	1	1	1	1	1
Denitrified-N loss (%)	<1	<1	<1	<1	<1	<1	<1	<1

Note: assumed a pot ale N content of 2.5 kg N/t fw (5% dm) and ammonium-N content of 0.1 kg/t fw. Pot ale was surface broadcast and incorporated by rotary cultivation 1-2 days post application. No rainfall within 6 hours of spreading; wind speed calm. Annual average rainfall 800 mm.

1 Assumed an application data of 1 September and 500 mm of rainfall until the end of drainage

2 Assumed an application data of 1 November and 350 mm of rainfall until the end of drainage

3 Assumed an application data of 1 February and 100 mm of rainfall until the end of drainage

4 Assumed an application data of 1 July and no drainage following application

\+ Grassland habitat

++ Crop year 2

In summary, to make best use of pot ale N, applications should be made in the late winter-spring period, with only moderate amounts of N supplied in the medium-term following application. Moderate amounts of N were estimated to be lost via nitrate leaching (particularly following autumn application to the sandy loam soil).

4.11 Ash wastes

EWC code 10.01.02: Coal fly ash
EWC code 10 01 03: Fly ash from peat and untreated wood

Ash from the combustion of some fuels including coal, peat and untreated wood contain valuable plant nutrients, and generally low concentrations of heavy metals and organic contaminants. There are many types of ash, which are by-products from a wide range of processes and recovery systems. As their beneficial and potentially harmful properties differ widely it is important to analyse ash wastes (or by-products or products) to understand their chemical and physical properties before deciding on how best to use them on land.

Fly ash (as opposed to bottom ash, bag ash or boiler dust) consists of fine particles of ash which rise with the flue gases following combustion of coal, peat, wood or other combustible material. Fly ash is nowadays generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases are released into the atmosphere. The very fine pollutants (on average 230 µm in size) can make the ash difficult to handle in a dry state (Etiéngi *et al*., 1991). Fly ash is not strictly speaking "organic" (in the context of this report) as it typically has little or no remaining organic matter. Fly ashes tend to contain higher concentrations of undesirable elements and compounds than bottom ashes, and as a result can have a limited value for use in land restoration/reclamation.

The benefits and potential negative impacts of ash wastes applications to land are listed in Box 10, below.

Box 10: Fly ash (from coal, peat and untreated wood)
Benefits and potential negative impacts of application to land

Benefits:

- Supplies major plant nutrients; phosphorus, potassium, sulphur and magnesium.
- Cation exchange capacity, which when added to soil can increase nutrient retention.
- Can have a liming value that neutralises soil acidity.
- Can increase moisture retention in soils.

Potential negative impacts:

- The fine particles can make it difficult to handle in a dry state and can be easily blown by strong winds. Damping ash with water can reduce spreading accuracy as the ash tends to form lumps and may coat spreading machinery.
- Inhalation by humans and other animals can cause respiratory problems.
- Can be acidic or alkaline, and can influence soil pH; it is important to match the ash type to the properties and requirements of the receiving soil/vegetation type.
- High electrical conductivity which limits application rates in some situations.
- Can contain undesirably high concentrations of potentially toxic elements, including arsenic (As), aluminium (Al) and boron (B).
- Can contain undesirably high concentrations of organic compounds, such as dioxins and furans.
- Can be hydrophobic, leading to water being repelled rather than adsorbed.

Nutrient content of 'typical' fly ash wastes (from coal, peat and untreated wood)

Typical total nutrient contents for fly ash from the combustion of coal or from a mixture of peat and untreated wood are summarised in Table 26.

Table 26. Typical total nutrient contents (kg/t fresh weight) of coal fly ash and peat/wood fly ash (Basu *et al.*, 2009[a]; Korpijarvi *et al.*, 2012[b])

Major nutrients	Coal fly ash[a]	Peat/wood fly ash[b]
Nitrogen (N)	0	0
Phosphate (P_2O_5)	0.09 – 18.3	22.9
Potash (K_2O)	1.8 – 42	24
Sulphur (SO_3)	2.5 – 37.5	-
Magnesium (MgO)	0.7 – 129	-

Application rates

Much of the fly ash produced worldwide (including the UK) is used in civil engineering (e.g. construction of roads and stable platforms for roads and buildings), rather than to restore/reclaim land. Notably, the application of fly ash to agricultural land is not permitted in the UK under current waste regulations. It is likely that the potential disadvantages of using most types of fly ash in land reclamation/restoration outweigh the advantages. For example, Pitman (2006) recommended that fly ashes should not be used as fertilisers due to their typically high concentrations of heavy metals.

If fly ash was to be applied to brownfield land under the WMLR, applicants would need to demonstrate that the fly ash material was useful in soil restoration/reclamation and would not cause harm to the receiving soil and surrounding water environment.

Nutrient loss following fly ash application

Fly ash does not typically contain nitrogen, so there is no risk of N losses to the environment. However, it contains plant nutrients and variable concentrations of heavy metals/organic compounds. There is little information on the potential for leaching from fly ash treated soils, but likely risks will depend on the application rate and the concentrations of compounds within the ash (Korpijarvi *et al.*, 2012), and are likely to be minimised by maintaining a soil pH >6.0.

5 Decision support checklist for use of organic materials in soil formation/habitat enhancement

- What is the intended habitat (e.g. agriculture, forestry, species-rich grassland etc.)?
- What are the needs of the specific habitat (e.g. soil depth, organic matter content, nutrient supply/cycling, pH tolerance, drainage properties)?
- What is the status of the existing site/habitat (e.g. soil depth, organic matter content, nutrient status, pH, heavy metal content etc.)?
- What organic materials are available locally (e.g. compost, paper sludge, biosolids etc.)?
- Which locally available organic material(s) best meets the requirements of the intended habitat?
- Using information on properties of the site/existing habitat and available organic material(s); calculate the appropriate application rate to create/enhance the site for the intended habitat.
- Undertake a *site-specific risk assessment*; a list of some of the receptors of concern and potential mitigation measures are detailed on the following page:

Receptor	Potential impact	Pathway	Possible mitigation method
Surface water (e.g. ditch/stream)	Nutrient enrichment	Surface run-off, leaching, drains or direct application	➢ Buffer next to watercourse ➢ Low readily available nutrient content of organic material. ➢ No spreading if ground is frozen, waterlogged or heavy rain is forecast. ➢ Be aware of high runoff risks on sloping ground, particularly where slopes are greater than 12^{o} (20%). ➢ Incorporate organic material quickly. ➢ Alleviate compaction to promote infiltration. ➢ Establish vegetation as soon as practically possible to reduce run-off risks.
Ground water (e.g. aquifers)	Nutrient enrichment	Leaching	➢ Low readily available nutrient content of organic material. ➢ No spreading if ground is waterlogged or heavy rain is forecast. ➢ Establish vegetation as soon as practically possible to reduce leaching. ➢ Be aware of drains, especially for liquid materials.
Nearby wildlife (e.g. protected species, Sites of Special Scientific Interest)	Noise	Disturbance from site activities	➢ Buffer next to wildlife habitat (e.g. hedge, bund).
Nearby residents (e.g. residential or industrial premises)	Odour/ammonium	Airborne compounds	➢ Buffer next to housing (e.g. hedge). ➢ Operate only when wind direction is away from premises.
Soil quality	Heavy metals	Soil heath	➢ Comply with "Sludge (Use in Agriculture) Regulation" final soil heavy metal concentrations.
Soil quality	Compaction	Spreading/site activities	➢ No spreading (or site activities) if ground is too 'wet' (e.g. waterlogged) to carry the weight of machinery.

6 Glossary

Aerobic: Condition when oxygen is present.

Ammonia (NH_3): A gaseous compound composed of nitrogen and hydrogen, with a pungent odour.

Anaerobic: Condition where there is an absence of oxygen.

Anaerobic digestate: Organic material resulting from anaerobic digestion of biodegradable organic materials. The main types of digestate are whole digestate and separated (fibre and liquid) digestate.

Animal By-Products Regulations: A set of European regulations designed to ensure food safety under the 'farm to table' approach set out in the EU White Paper on Food Safety adopted in January 2000. They contain strict animal and public health rules for the collection, transport, storage, handling, processing and use or disposal of all animal by-products (ABPs).

Ash: Ash is produced from the combustion of solid fuels, including coal, peat and untreated wood.

Bacteria: A group of micro-organisms with a primitive cellular structure, in which the genetic material is not retained within an internal membrane (nucleus).

Biodegradable: Can be broken down through biological processes.

Biosolids: Treated sewage sludge

BSI PAS100:2011: Publicly available specification which covers the entire production process for composts and ensures that composts are quality assured, traceable, safe and reliable.

BSI PAS110:2014: Publicly available specification which covers the entire production process for anaerobic digestate and ensures that digestates are quality assured, traceable, safe and reliable.

Bulk density: The mass per unit volume of materials.

Carbon dioxide (CO_2): A colourless, odourless, tasteless gas that is produced as a result of respiration by plants and animals, including most microorganisms.

Compost: A stable, sanitised, organic material, which has been made commercially through mixing, self-generated heating and aeration.

Composting: The natural breakdown of biodegradable materials through mixing, self-generated heating and aeration to form a stable, organic material.

Crop available: The amount of nutrients (e.g. phosphate and potash) available to a crop in the (next) growing season.

Crop available nitrogen: The readily available nitrogen that remains for crop uptake after accounting for any losses of nitrogen. This also includes nitrogen released from organic forms.

Denitrification: Microbial conversion of nitrate and nitrite in anaerobic soil to nitrogen gas or nitrous oxide.

Digestate: Organic material resulting from anaerobic digestion of biodegradable organic materials. The main types of digestate are whole digestate and separated (fibre and liquid) digestate.

Distillery residues: Liquid waste produced as a by-product of the production of alcoholic beverages.

Ecosystem: A biological community of interacting organisms and their physical environment.

Energy crop: Annual or perennials plants grown for the specific purpose of energy generation and not food production.

Eutrophication: Enrichment of ecosystems by nitrogen or phosphorus. In water it causes algae and higher forms of plant life to grow too fast. This disturbs the balance of organisms present in the water and the quality of the water concerned. On land, eutrophication it can stimulate the growth of certain plants which then become dominant so that natural diversity is lost.

Extractable nutrient (particularly phosphorous and potassium): The quantity of nutrient regarded as available to plants present in the soil as measured by laboratory analysis. The result will vary depending on the extractant used (e.g. Olsen's P vs. Modified Morgan's P).

Feedstock: The biodegradable materials present at the start of a composting or anaerobic digestion process.

Fly ash: Fly ash consists of fine particles of ash which rise with the flue gases following combustion of coal, peat, wood or other combustible material.

Forestry residues: Forestry wastes generated when trees are mulched or chipped in-situ and spread to land.

Greenhouse gas: A gas that contributes to the greenhouse effect by absorbing infra-red radiation. Carbon dioxide, methane and nitrous oxide are the main greenhouse gases.

Green waste: Grass cuttings, leaves and pruning's, from parks or gardens.

Habitat: The natural home or environment of an animal, plant, or any other organism.

Leaching: Process by which water-soluble substances such as nitrate or sulphate are removed from the soil by drainage water passing through it.

Liming value: Property of a material (measured as a neutralising value) that increases soil pH.

Major nutrient: Essential element required in large quantities from soils by plants, e.g. nitrogen, phosphorus and potassium.

Micro nutrient: Essential element required in small quantities from soils by plants (e.g. boron, copper, manganese, zinc etc.). Cobalt and selenium are taken up in small amounts by crops and are needed in human and livestock diets.

MANNER-*NPK*: A decision support system that will predict the nitrogen, phosphorus and potash value of applied organic materials, taking into account soil type, application timing/technique and ammonia, nitrate and denitrification losses.

Manufactured topsoil: Material produced by combining mineral matter and organic matter (and, where appropriate, fertiliser and lime), and which provides the same function as topsoil.

Micro-organism: An organism too small to see with the naked eye that is capable of living on its own.

Mineral soil: A soil mainly comprised of mineral material, with less than 10% organic matter.

Mineralisation: Microbial breakdown of organic matter in the soil, releasing nutrients in plant-available inorganic forms.

Nitrate (NO_3): Nitrate is soluble in the soil solution and can be leached as drainage water moves through the soil.

Nitrate vulnerable zone: An agricultural area which has been designated as being at risk from nitrate pollution by the regulations which implement the EU Nitrates directive in Britain.

Nitrous oxide (N_2O): A potent greenhouse gas that is emitted naturally from soils, especially where high nitrate concentrations and anaerobic conditions exist.

Organic material: Material derived from any living organism (e.g. livestock, human, plants) that supplies organic matter together with plant nutrients, usually in lower concentrations compared with manufactured fertilisers.

Organo-mineral soil: A peaty soil with a surface organic layer (>10% organic matter) less than 0.5m deep.

Paper crumble/sludge: The residue from the preparation of recycled paper prior to its re-use in the paper production process, or from the processing of virgin fibre from a variety of fibre sources, such as wood or cotton.

PAS100:2011: See BSI PAS100:2011.

PAS110:2014: See BSI PAS100:2014.

Pathogen: Any organism capable of producing disease through infection.

pH: A measure of the concentration of hydrogen ions in solution. pH below 7 = acidic, pH above 7 = alkaline.

Pot ale: Pot ale (also known as burnt ale or spent wash) is a high-protein residue from distillery wash stills.

Potentially toxic elements: Chemical elements that have the potential to cause harm to humans, animals, plants and/or microorganisms.

Readily available nitrogen: Nitrogen (i.e. ammonium and nitrate-N) that is potentially available for rapid crop uptake.

Sewage sludge: A semi-liquid waste obtained from the treatment of municipal sewage.

Soil conditioner (or soil improver): Organic material added to the soil to primarily maintain or improve its physical properties, and which can also improve its chemical and/or biological properties.

Soil forming material: Materials used to create a manufactured soil by combining organic matter, mineral material and lime and/or fertiliser as appropriate to provide a medium that can develop properties similar to naturally-occurring topsoil.

Soil organic matter: Often referred to as humus. Composed of organic compounds ranging from un-decomposed plant and animal tissues to fairly stable brown and black material, with no trace of the anatomical structure of the material from which it was derived.

Subsoil: Soil layer extending between the topsoil and the little weathered material below, or material that functions as subsoil in a constructed soil in a landscaping project on to which topsoil can be spread. Typically, subsoil has a lower concentration of organic matter and available plant nutrients than topsoil.

Topsoil: The upper layer of an in-situ soil profile, usually darker in colour and more fertile than the layer below (subsoil), and which is a product of natural chemical, physical, biological and environmental processes. The thickness of a natural topsoil varies with land use and management from only 100 mm to 300 mm in some sites to more than 350 mm in deeply cultivated agricultural sites.

Volatilisation: Loss of nitrogen (as ammonia) from the soil to the atmosphere.

Water treatment cake (sludge): Water treatment cake (sludge) is the residue resulting from the treatment of raw water to produce potable water in water treatment works.

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Appendix I

SAC Status compared to ADAS Index for soil P, K and Mg (mg/l) (SAC, 2010a).

SAC Status (ADAS Index)	Extractable P (mg/l)		Extractable K (mg/l)		Extractable Mg (mg/l)	
	SAC[1]	RB209[2]	SAC[1]	RB209[3]	SAC[1]	RB209[3]
VL (Index 0)	0-1.7	0-9	0-39	0-60	0-19	0-25
L (Index 1)	1.8-4.4	10-15	40-75	61-120	20-60	26-50
M- (Index 2)	4.5-9.4	16-20	76-140	121-180	61-200	51-100
M+ (Index 2)	9.5-13.4	21-25	141-200	181-240	61-200	51-100
H (Index 3)	13.5-30	26-45	201-400	241-400	201-1000	101-175
VH (≥ Index 4)	>30	>45	>400	>400	>1000	>175

[1] SAC Modified Morgan's method

[2] Olsen's P method

[3] Ammonium nitrate extract method