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Specification for performance parameters and test methods for green roof substrates

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Foreword

Publishing information

This British Standard is published by BSI Standards Limited, under licence from The British Standards Institution, and came into effect on 31 August 2019. It was prepared by Technical Committee AW/20, *Topsoil, Other Growing Media & Turf*. A list of organizations represented on this committee can be obtained on request to its secretary.

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Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its methods are expressed as a set of instructions, a description, or in sentences in which the principal auxiliary verb is “shall”.

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

The word “should” is used to express recommendations of this standard. The word “may” is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the clause. The word “can” is used to express possibility, e.g. a consequence of an action or an event.

Notes and commentaries are provided throughout the text of this standard. Notes give references and additional information that are important but do not form part of the recommendations. Commentaries give background information.

Where words have alternative spellings, the preferred spelling of the Shorter Oxford English Dictionary is used (e.g. “organization” rather than “organisation”).

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

0 Introduction

A green roof is typically understood to be an intentionally vegetated roof or platform disconnected from the underlying ground. Green roofs range from simple shallow/lightweight systems comprising only vegetation supported by substrates, to accessible roof gardens characterized by deeper substrates and diverse planting. A distinction between “extensive” systems with less than 150 mm substrate and “intensive” systems with more than 150 mm substrate is often made. However, many alternative system configurations are observed in practice. Substrate is a key component of any green roof and directly contributes to its success. The suitability of a green roof substrate can be assessed by measuring key performance parameters.

NOTE 1 For more information on how extensive and intensive substrates are typically characterized, see [Annex A](#).

Green roofs are living systems, reliant on a complex set of factors, including climatic conditions and nutrient and water availability. There are, therefore, many considerations when designing and installing a green roof to achieve the desired green roof habitat, ecosystem service provisions and aesthetic quality. Weight restrictions, installed substrate, planting regimes, as well as the aspect and environment in which a building is located, can limit what is achievable on a green roof.

NOTE 2 For more information on green roofs, not confined to substrates, see the GRO Green Roof Code [\[1\]](#).

Green roofs have the potential to deliver multiple benefits. These include positive impacts on urban amenity, health and well-being, biodiversity (habitat creation), building energy savings, roof membrane protection, improvements in air quality, urban heat island mitigation and urban flood risk reduction.

Many green roof systems incorporate an underlying drainage layer or drainage board below the substrate to ensure that the system is effectively drained. In some instances this layer can also provide sub-surface irrigation to the substrate. Methods to assess the suitability of substrates for this type of system are not dealt with in this standard.

NOTE 3 Drainage boards are typically plastic, egg cup, and are also called reservoir boards.

Green roofs contribute to urban green infrastructure, which increases the interactions between people and natural habitats. The effects of this are wide-ranging, from encouraging people to undertake physical activity to improving mental well-being through reducing anxiety and improving concentration [\[2\]](#). In addition, a number of physical stressors, such as air pollution, which are being increasingly shown to have negative impacts on mental health, are also mitigated by green infrastructure, including green roofs [\[3\]](#).

Green roofs have the potential to act as high quality habitats in their own right, or contribute to the wider ecological landscape, particularly for mobile species such as birds and pollinating invertebrates such as bees [\[4\]](#). Key limiting factors are:

- 1) their relative inaccessibility for colonizing species, especially on very high or very urban roofs [\[5\]](#); and
- 2) limitations posed by their design, such as soil moisture content [\[6\]](#) and the diversity of the plant community present [\[7\]](#).

Greater diversity on green roofs can be achieved by planting appropriate plant mixes at the time of construction (e.g. wildflower meadows) or by designing green roofs to maximize natural colonization; this method usually takes longer to achieve results than direct planting. Success in establishing viable plant communities, however, relies on producing environmental conditions conducive to plant growth, of which initial substrate selection is key.

From a stormwater management perspective, green roofs (even shallow, extensive, systems) offer considerable potential to intercept and retain small rainfall events. However, they have finite capacity, and additional downstream measures are required to ensure protection from extreme events within a fully scoped Sustainable Drainage System (SuDS). Substrate characteristics can significantly affect the ability of a green roof to retain stormwater.

NOTE 4 Further information is provided in the CIRIA SuDS Manual (Woods-Ballard et al., 2015) [8].

1 Scope

This British Standard specifies requirements for the testing of substrates (the growing medium) for constructed green roofs intended to provide long term support for specified plant communities. This includes extensive and intensive green roof substrates.

This British Standard provides methodologies for testing green roof substrates covering the complete application range, and recommended specifications for physical and chemical characteristics considered to be optimal for extensive substrates.

This British Standard only addresses methods and parameters to ensure that the substrate used does not become a limiting factor for successful green roof installation. It does not address the wider range of other design considerations, such as the supporting structure, construction, planting options or post-build maintenance.

It is recognized that there are green roof systems that do not incorporate a substrate layer and these are not covered in this British Standard.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes provisions of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN 932-1:1997, *Tests for general properties of aggregates — Part 1: Methods for sampling*

3 Terms and definitions

For the purposes of this British Standard, the terms and definitions given in [BS 3882:2015](#) and the following apply.

3.1 green roof

intentionally vegetated roof or platform disconnected from the underlying ground

NOTE 1 Green roofs can occur naturally but this British Standard covers constructed green roofs.

NOTE 2 Green roofs are also known as living roofs.

3.1.1 extensive green roof

roof that generally provides a visual or biodiverse interest and is considered to be less suitable as an amenity or leisure space

[SOURCE: GRO Code, **2.2.1**]

*NOTE 1 Planting often includes (1) perennial succulent species, most often *Sedum* spp., which flower from April to September, (2) annual wildflower mixes, with some perennials, which are likely to flower in spring and autumn, and become dormant or die during winter and late summer before re-seeding and (3) a mixture of the two. All*

three of these systems are designed to require low levels of maintenance. Wildflower mixes have been developed to promote biodiversity, supporting a wide variety of species, particularly insects. *Sedum* spp. provide less support for biodiversity but have been installed due to their ability to survive harsh environmental conditions, which provides a more consistent aesthetic effect, both seasonally and over longer time periods.

NOTE 2 A fourth type of green roof was prevalent in the early 2000s, at the time labelled a "brown" roof. These were roofs that were intentionally left unplanted in order for local colonization to occur. The success of these roofs in terms of biodiversity was varied, depending on substrate properties and nearby habitats.

3.1.2 intensive green roof

roof principally designed to create recreational and amenity space

[SOURCE: GRO Code, 2.2.4]

3.2 substrate

growing medium typically consisting of a lightweight aggregate component (conforming to [BS EN 13055](#)) blended with soil organic material, such as topsoil (for various purposes), which has been tested to the [BS 3882](#) topsoil specification standards, or a green waste material tested to PAS 100

3.2.1 lightweight substrate

substrate composed of granular material of mineral origin, loose bulk density not exceeding 1 200 kg/m³ (1.20 mg/m³)

[SOURCE: BS 13055:2016, 3.1]

NOTE Lightweight aggregate can be natural, manufactured from natural sources, manufactured from by-products or recycled source materials and by-product aggregates.

3.3 particle size distribution

range in sizes of the particles within a substrate, as determined by the percentage mass of each specified fraction

[SOURCE: BS 3882:2015, 3.3, modified]

NOTE Fractions below 2 mm can be classified into sand, silt and clay.

3.4 bulk density

weight per volume of substrate

NOTE Its loading capacity per unit area.

3.4.1 bulk density at field capacity

bulk density of substrate after excess moisture has drained away via gravimetric pressure after saturation

NOTE 1 This is the technical weight at which substrates start to drain via gravimetric pressure. Therefore, substrates are not to exceed this weight on a field install, unless drainage is impeded, or precipitation input exceeds drainage output.

NOTE 2 Field capacity is the volumetric moisture a substrate can physically retain within its pore structure under normal gravimetric conditions (as a percentage of total volume).

3.5 substrate pH value

measure of the acidity or alkalinity of substrate

[SOURCE: BS 3882:2015, 3.6]

NOTE pH 7 is neutral; values less than 7 are acidic, values greater than 7 are alkaline.

3.6 electrical conductivity

measurement relating to the concentration of soluble ionic constituents, particularly ammonium, calcium, chloride, magnesium, nitrate, phosphate, potassium, sodium and sulphate

NOTE A high substrate electrical conductivity might indicate a detrimentally high level of salinity.

3.7 substrate organic matter

decomposed remains of plants, animals, organic manures or other forms of decomposed organic matter

[SOURCE: BS 3882:2015, 3.5, modified]

NOTE 1 Measured as a percentage mass.

NOTE 2 It does not include fossil and other unreactive organic matter such as coal.

NOTE 3 See [Annex A](#) for further details.

3.8 carbon:nitrogen ratio

indication of the potential for a substrate to release nitrogen for plant growth

NOTE The potential to release (or immobilize) nitrogen also depends on the bioavailability of the carbon and the nitrogen.

3.9 potentially phytotoxic element

element which, when present in excess, has the potential to inhibit plant growth or kill plants

[SOURCE: BS 3882:2015, 3.7]

NOTE For the purpose of this British Standard these elements are cadmium, copper, lead, nickel and zinc.

3.10 biodiversity

variety of flora and fauna occupying a given area

NOTE This could include diversity of individuals, species, communities or genetic material. High diversity is usually considered to be positive.

3.11 habitat

natural environment, or home, that supports a given individual or species

NOTE An individual might complete its full life cycle in just one habitat, or move between different habitats. Thus, the quality of habitat needed for an individual/species varies depending on the functional needs of that individual/species, and connectivity between habitats can be important for some individuals/species, but not all. A habitat can comprise a purely physical landscape (e.g. a bare rock surface on which a bacterium lives), but more commonly is an interplay between physical and biological agents (e.g. a plant on which a spider has built its web).

3.12 mill

sieving substrate samples with mechanical means in order to separate substrate into > 2 mm fraction and < 2 mm fraction

NOTE 1 Mechanical means are used to break up any aggregation of substrate particles but not to cause physical damage to aggregate.

NOTE 2 Milling is gentle so as not to crush materials down, just to separate out particle size fractions.

3.13 visible contaminant

undesirable potentially injurious foreign object discernible by the naked eye

[SOURCE: BS 3882:2015, 3.8]

3.14 drainage board

underlying drainage layer, either granular or synthetic sheet

NOTE Can form part of a "blue roof": a roof design that is explicitly intended to store water, typically rainfall. Blue roofs that are used for temporary rooftop storage may be classified as "active" or "passive" depending on the types of control devices used to regulate drainage of water from the roof.

4 Sampling substrates (for both intensive and extensive blends)

4.1 General

All materials shall be assessed for origin. If wastes are blended into the substrates from unknown sources (such as site scrapings, building rubble, etc.) they shall not be used.

Peat shall not be used as an organic component of substrate.

For most testing methods, materials < 40 mm (in particle size) shall be used. If high percentages of particles are above < 40 mm then larger test portions shall be needed for the testing procedures.

NOTE 1 This is volume required per test/replicate, as most tests require three samples – the amount of material needed to run the tests needs to be calculated based on these volumes, the number of samples to be processed and the testing procedures to be followed and their individual requirements (see [Clause 5](#)).

All samples for testing shall be selected from stockpiles no more than four weeks after blending has occurred, and ideally selected as soon as substrates have been freshly blended to limit the settlement of fines to the bottoms of the stockpiles, which would mean that sampling is less representative.

NOTE 2 A full set of heavy metals and hydrocarbon tests might be required for materials of waste/recycled origin.

4.2 Sampling from stockpiles

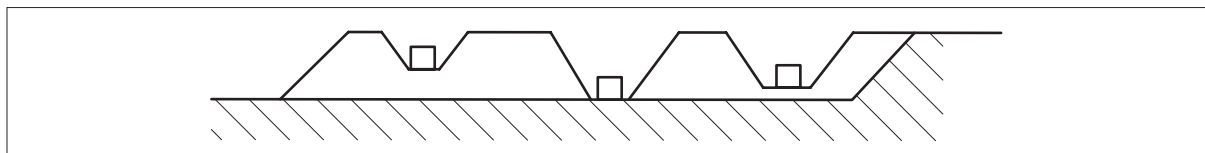
COMMENTARY ON 4.2

Text modified from BS EN 932-1:1997, 8.8.

Samples of approximately equal size shall be taken from different points at different heights or depths, distributed over the complete stockpile (see [Figure 1](#)). The stockpile shall ideally be freshly blended so as to prevent settlement of fines to the bottom of the piles as much as possible and samples shall be selected at different depths of the pile to ensure representative substrate material is sent for laboratory testing. If small bags have been supplied, ideally three randomly selected bags shall be sent for testing so the laboratory can sub-sample the materials effectively.

NOTE See [Annex A, A.1](#) for further information on quality assurance sampling protocols.

Figure 1 — Sampling from flat stockpiles



Laboratory subsampling shall follow the mixing and quartering method in accordance with BS EN 932-1:1997, 9.4 to ensure representative samples are used for analysis and that fines are not excluded from testing due to settlement.

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Table 1 — Target ranges of extensive green roof substrate physical and chemical properties

Substrate characteristic	Target values
Particle size distribution	
Particles ≤ 0.053 mm (% weight) ^{A)}	≤ 13.5
Particles > 8 mm (% weight) ^{A)}	< 60
Foreign bodies (% weight); i.e. not listed in substrate ingredients	< 0.1
Physical properties	
Field capacity (% v/v)	≥ 25.0 – ≥ 67.5
Total porosity (%)	> 22.5
Porosity at field capacity (%)	≥ 10
Saturated hydraulic conductivity (mm min ⁻¹)	0.6 – 100
Chemical properties	
Organic matter (% weight) ^{B)}	2.0 – 17.5
pH	5.4 – 9.0
EC (mS cm ⁻¹)	1.9 – 3.5
Plant available nutrients	
Phosphate (mg l ⁻¹)	> 30
Potassium (mg l ⁻¹)	> 100
Total nitrogen (%)	< 4.0
C:N ratio	1:10 – 1:32
Potentially phytotoxic elements	
Cadmium (mg l ⁻¹) ^{C)}	≤ 20
Copper (mg l ⁻¹) ^{C)}	≤ 50
Lead (mg l ⁻¹) ^{C)}	≤ 300
Nickel (mg l ⁻¹) ^{C)}	≤ 20
Zinc (mg l ⁻¹) ^{C)}	≤ 80

^{A)} Substrates should contain a spread of particle sizes between 0.053 mm – 8 mm. If a substrate is dominated by an excessive amount of particles of one size, this might have a detrimental impact upon physical characteristics of the substrate.

^{B)} This value might be below 2% for bespoke mixes, i.e. substrate for intentionally low nutrient input systems or above 17.5% for mixes intentionally high in organic content (see [Annex A, A.2](#) for further details). Specifiers should be aware that substrates with organic levels greater than 17.5% might cause excessive plant growth which might require additional management to ensure long term health of the green roof and minimal vegetation fire risk. Further guidance on management of green roof fire risk can be found in the following documents: Fire Performance of Green Roofs and Walls [[12](#)] and The Green Roof Organisation GRO fire risk guidance document [[1](#)].

^{C)} The presence of these elements is to be expected in the majority of samples. However, if present at values greater than those listed; the elements might cause a phytotoxic effect on green roof plants and lead to excessive levels of these elements in roof runoff water. The five elements tested in this British Standard are not an exhaustive list but act as key/indicator elements of good quality substrate.

NOTE Target intensive physical and chemical properties are not provided in this standard. For further information refer to the GRO Code [[1](#)].

5 Method of test for determination of the particle size distribution and organic matter content, as loss on ignition (LOI), of green roof substrates

5.1 Principle

The particle size analysis is determined by separating the different green roof substrate fractions into specified particle diameter ranges by methods of sieving and sedimentation.

5.2 Apparatus and reagents

NOTE Balance to two decimal places.

5.2.1 *Oven*, capable of maintaining a temperature of 105 (± 5)°C.

5.2.2 *Muffle furnace or oven*, capable of maintaining a temperature of 400 (± 10)°C.

5.2.3 *Water bath*.

5.2.4 *Hot plate*.

5.2.5 *Bottle shaker*.

5.2.6 *Crucible*.

5.2.7 *Pipette sampler*.

5.2.8 *Mesh sieves*, 16, 8, 4, 2, 1, 0.5, 0.25, 0.125 and 0.053 mm.

5.2.9 *25% volume hydrogen peroxide* (250 ml H₂O₂ diluted to 1 000 ml with deionized water).

5.2.10 *10% sodium hexametaphosphate* (100 g (NaPO₃)₆, dissolved to 1 000 ml with deionized water).

5.2.11 *Octan-2-ol*.

5.3 Procedure

5.3.1 Preparation of sample and measurement of stone, gravel, moisture and organic matter content

Spread material sample of 1L (if upper size of aggregate < 4 mm) out on a tray for drying (see [Table 1](#) for other aggregate size quantities). Place in a drying room, which should be maintained at an ambient temperature typically between 20 °C and 30 °C but not exceeding 40 °C. When the sample is dry, obtain a representative sub-sample of 200 – 300 g. Mill the sample to separate > 2 mm and < 2 mm fractions so that the finer material passes through a 2 mm sieve.

Retain any particles larger than 2 mm.

Place a sample of approximately 30 – 50 g unmilled green roof substrate in a weighed oven-dried crucible to determine the moisture and organic matter contents. Weigh the crucible with contents then dry for a minimum of 12 h in an oven set at 105 (± 5)°C. Re-weigh then place in a high temperature oven at 400 (± 10)°C for 7 – 8 h and weigh. Calculate the organic matter content as the loss on ignition (LOI), and report as a percentage of oven-dried substrate sample placed in oven.

NOTE A crucible lid might be needed to prevent substrate loss in oven.

5.3.2 Particle size distribution (> 2 mm particles)

Put the gravel and stone fractions (> 2 mm) in a tray to soak in water. Wash with tap water to remove organic particles and then oven dry. Separate the stones (> 16 mm, 8 – 16 mm), coarse gravel (8 – 4 mm) and fine gravel (4 – 2 mm) by sieving and weighing each fraction separately.

5.3.3 Particle size distribution (< 2 mm particles)

Weigh out a sample of 20 (± 0.01) g milled (< 2 mm) green roof substrate and place in a glass beaker capable of holding at least 600 ml. Note weight of substrate.

To the sample of milled green roof substrate in the beaker add 100 ml 25 volume hydrogen peroxide.

NOTE 1 Two to three drops of octan-2-ol may also be added if excessive frothing occurs.

Observe periodically for 30 min and after initial reaction, further addition of hydrogen peroxide is required to maintain a volume of 200 ml. Leave to stand overnight (a water bath set at 50 (± 5)°C can be used to speed up the reaction).

Place the beaker on a hot-plate and swirl frequently, adding octan-2-ol and hydrogen peroxide (overnight the beaker can again be placed in the water bath set at 50 (± 5)°C). When the frothing subsides boil down to 100 ml until the sample no longer shows any sign of further reaction.

NOTE 2 Reaction is used to reduce amount of organic content in sample. Reaction should be continued until significant reduction in visible organic content is observed.

Cool then transfer to a shaking bottle with 20 ml of 10% sodium hexametaphosphate. Place in bottle shaker for 2 h. At the same time place 650 ml of water into a 1 000 ml measuring cylinder to allow it to adjust to room temperature.

NOTE 3 The water sample needs to be at room temperature to ensure consistency of particle settlement throughout sampling period. For each new batch of sodium hexametaphosphate, pipette a 20 ml sodium hexametaphosphate sample into 980 ml of water, stir and take three 20 ml samples into pre-weighed beakers and oven dry to determine average weight equivalent in 1 000 ml, for use in silt and clay calculations.

After 2 h shaking on a bottle shaker, transfer the contents of the bottle into the measuring cylinder, carefully wash any residue into the cylinder and make up to 1 L with water (also at room temperature).

Measure the temperature of the suspension and read the correct time for sampling for silt plus clay from [Table 2](#).

Stir thoroughly for 30 s (approximately 60 strokes). Ten seconds before time, slowly immerse the pipette to a depth of 20 cm (with the tap closed). Five seconds before time, open the top and take the sample, finishing five seconds after time. Release the pipette sample into a previously weighed oven-dried beaker. Refill the pipette with tap water and release into same beaker to wash out any residual material.

Leave overnight to allow further sedimentation and repeat for clay content using [Table 4](#) to determine the correct sampling depth in relation to temperature. Place samples in oven at 105 °C until samples are dry and no further changes in weight occur. Weigh dry samples.

Wash the samples through a 0.053 mm sieve into a tray. Place samples in oven at 105 °C until samples are dry and no further changes in weight occur. Weigh dry samples.

Sieve sand fraction using 100 mm diameter sieves of sizes 1 mm, 0.5 mm, 0.25 mm and 0.125 mm. These should be placed on a sieve shaker for 10 min.

Weigh material on each sieve and on the pan and note down.

Table 2 — Sampling times for silt plus clay content determination with the pipette method (20 cm sampling depth)

	Temperature (°C)									
	17 °C	18 °C	19 °C	20 °C	21 °C	22 °C	23 °C	24 °C	25 °C	
Time (min-s)	1-39	1-37	1-34	1-32	1-30	1-27	1-24	1-22	1-20	

NOTE 4 Table adapted by STRI Group from Soil Survey Laboratory Methods, Soil Survey, 1974 [11].

Table 3 — Sampling times for clay content determination with the pipette method

Hours settling	Clay (depth in cm)								
	Temperature (°C)								
	17°	18°	19°	20°	21°	22°	23°	24°	25°
8	9.3	9.6	9.8	10.0	10.2	10.4	10.7	10.9	11.1
9	10.4	10.7	11.0	11.2	11.5	11.8	12.1	12.4	12.7
10	11.6	11.9	12.2	12.5	12.8	13.1	13.4	13.7	14.0
11	12.8	13.1	13.4	13.7	14.0	14.3	14.6	15.0	15.3
12	14.0	14.3	14.7	15.0	15.3	15.7	16.0	16.4	16.7
13	15.0	15.4	15.8	16.2	16.6	17.2	17.6	18.0	18.5
14	16.3	16.7	17.1	17.5	17.9	18.3	18.7	19.2	19.6
15	17.5	17.9	18.4	18.8	19.2	19.7	20.1	20.6	21.0
16	18.6	19.0	19.5	20.0	20.5	21.0	21.4	21.9	22.4
17	19.7	20.2	20.7	21.2	21.7	22.2	22.7	23.2	23.7
18	20.9	21.5	22.0	22.5	23.1	23.7	24.2	24.8	25.4
19	22.0	22.6	23.1	23.7	24.3	24.9	25.4	26.0	26.6
20	23.2	23.8	24.4	25.0	25.6	26.2	26.8	27.4	28.0
21	24.5	25.1	25.7	26.3	26.9	27.5	28.1	28.8	29.4
22	25.6	26.3	26.9	27.5	28.1	28.7	29.4	30.0	30.6
23	26.7	27.4	28.1	28.8	29.5	30.2	30.8	31.5	32.2
24	27.9	28.6	29.3	30.0	30.7	31.4	32.1	32.8	33.5

NOTE 5 Table adapted by STRI Group from Soil Survey Laboratory Methods, Soil Survey, 1974 [11].

6 Method of test to determine the physical properties of green roof substrates: oven dry bulk density, bulk density at field capacity, hydraulic conductivity, field capacity, particle density and porosity

6.1 Principle

The dry substrate in a specified container is submerged in water so that all available pore spaces in the sample are filled with water (fully saturated). When completely water-saturated, it is possible to determine the rate at which water drains from the samples (saturated hydraulic conductivity). Following this, the substrate is removed and allowed to drain under gravimetric pressure to determine field capacity. Substrate material from the cylinders is oven-dried to determine the mass of the dried material. From this, oven-dried bulk density, field capacity bulk density, field capacity, porosity and particle density can be calculated. Results shall be expressed as the mean from three samples for each green roof substrate mix.

6.2 Apparatus

6.2.1 *Oven*, capable of maintaining a temperature of 105 (±5)°C.

6.2.2 *Metal containers (cylinders)*, 100 (±1) mm inside diameter and 125 (±10) mm in height.

NOTE 1 A double layer of voile or cheesecloth held on by rubber bands is used to keep the material fines in place.

NOTE 2 Larger containers might be required if aggregates contain particle sizes larger than 4 mm.

6.2.3 *Mesh*, cut into disks of diameter 100 mm.

6.2.4 *Saturated hydraulic conductivity drainage rack*.

6.2.5 *Balance*, capable to two decimal places.

6.2.6 *Compaction device*, with weight of 1.3 (±0.1) kg.

6.2.7 Glass beaker, 250 or 500 ml.

6.2.8 Measuring cylinder, 500 ml.

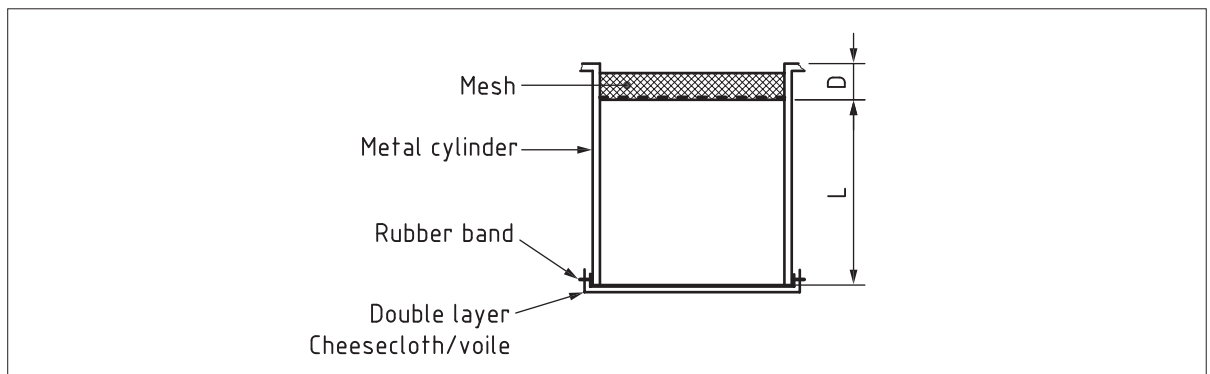
6.3 Procedure

6.3.1 Sample preparation

Green roof substrate is filled in the metal cylinder (as shown in [Figure 2](#)). The material is compacted by self-tamping – dropped from a 5 cm height under its own weight, onto a concrete block five times on two occasions during the fill process.

NOTE This is to represent true bulk densities of material when transported in bulk bags and once the material is placed onto the green roof (allows for natural settlement).

Figure 2 — Apparatus set up for cylinders



6.3.2 Method

Determine the mass of the empty, dry and clean cylinder and the dry voile/cheesecloth (M_1).

After being filled halfway, each cylinder is self-tamped from a height of 5 cm onto a concrete block five times. Substrate is then added to within 10 mm of the cylinder rim and each cylinder is self-tamped from a height of 5 cm onto a concrete block five times. A light tamp of 1.3 (± 0.1) kg from a height of 10 cm is taken to level off the surface. Ensure final level of substrate is within 20 – 30 mm of the top of the cylinder.

Slowly saturate the substrate material from beneath for a minimum of 24 h. Ensure water ponds on surface of green roof substrate. Place mesh and weight on surface of substrate to prevent movement of light-weight aggregates.

Remove cylinders from water and allow cylinders to freely drain under gravimetric pressure for 2 h.

Remove the mesh and the weight.

Determine the mass of the cylinder plus saturated voile/cheesecloth plus saturated substrate (M_2).

Determine the height (cm) and width (cm) and therefore the volume (cm^3) of substrate after saturation (L_1) (see [Figure 3](#)).

Calculate the cross-sectional area (CSA) (cm^2) of the cylinder using the following formula:

$$\pi * (r^2)$$

where:

r = radius of cylinder (width/ 2).

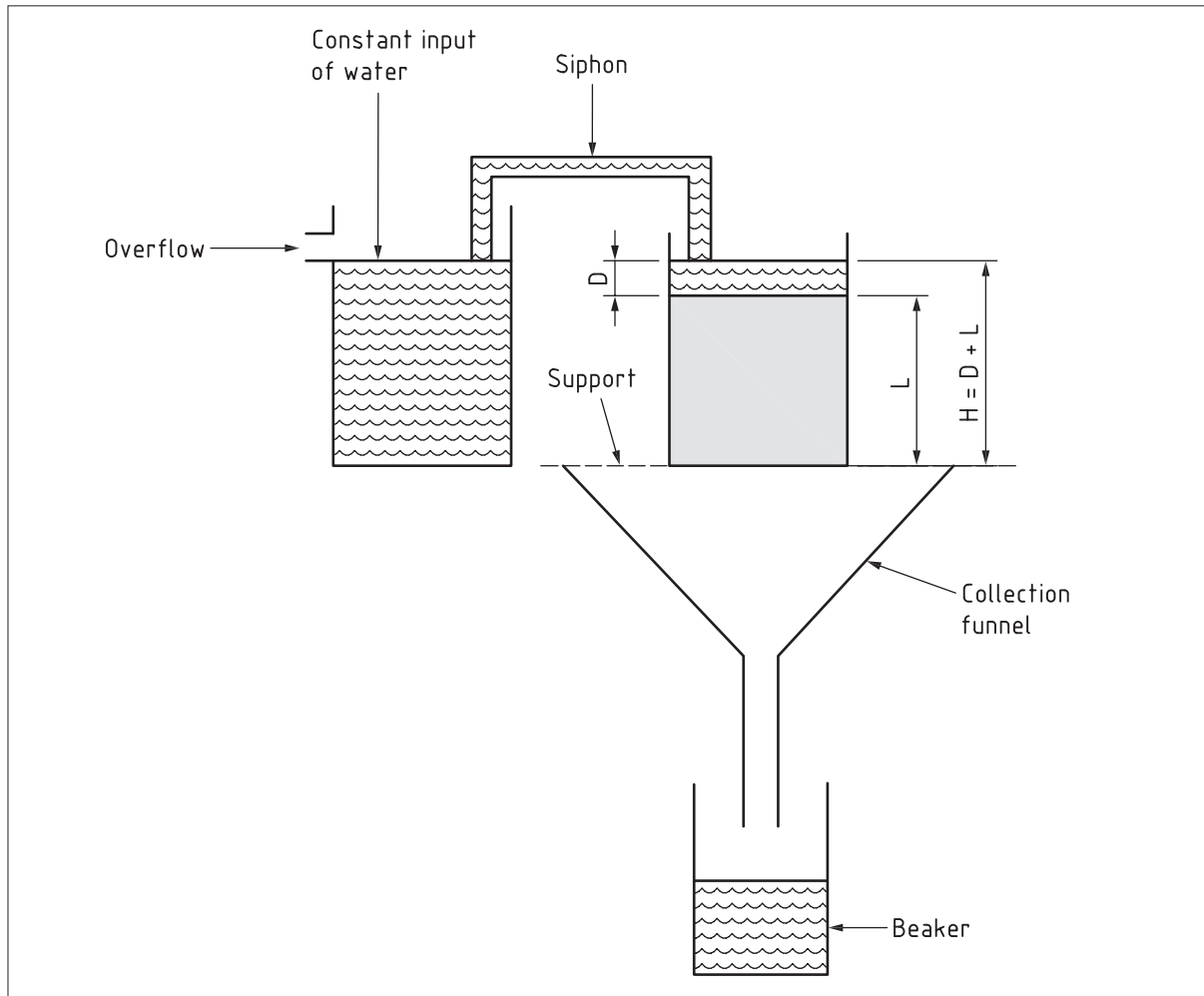
Stand the cylinder containing the substrate above a collection funnel and pond water on the surface (D) by means of the siphon arrangement to give a constant head of 25 (±5) mm (see Figure 3). After 15 min place a beaker under the funnel and record the volume of water (V, in ml) collected over time (t, in minutes). The length of the sample (L) and the ponding of the water on the surface (D) shall also be measured during the test to give the total head of water (H).

Next, spread the substrate out, no more than 3 cm deep into trays, and oven dry the substrate at 105 (±5)°C for 24 h. Weigh (g) the oven-dried substrate (M₃).

The saturated weight (g) of the voile/cheesecloth (SC) should also be independently determined.

Particle density is determined using a new sample of air-dried substrate. Add de-aired water up to 250 ml in a 500 ml measuring cylinder. Record the mass (M₅). Empty measuring cylinder, take balance with measuring cylinder in situ and weigh out 50 – 100 g of air-dried substrate ensuring that the level of substrate does not pass 250 ml and record the mass (M₄). Half fill cylinder to 250 ml, with de-aired water, stir and top up to exactly 250 ml. Weigh the total mass (M₆).

Figure 3 — Arrangement for saturated hydraulic conductivity measurements



NOTE Figure adapted from STRI Group test method [11].

6.4 Calculation of result

6.4.1 Bulk density of oven-dried substrate is calculated as:

$$D_b = M_3 / L_1$$

where:

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- D_b is bulk density oven-dried substrate (g/cm^3);
 M_3 is mass of oven-dried substrate after saturation (g);
 L_1 is volume of substrate before saturation (cm^3).

6.4.2 Particle density of the substrate is calculated as:

$$D_p = M_4 / M_4 + (M_5 - M_6)$$

where:

- D_p is particle density of surface-dried (saturated) substrate (g/cm^3);
 M_4 is mass of substrate sample in measuring cylinder;
 M_5 is mass of measuring cylinder with 250 ml water;
 M_6 is mass of measuring cylinder with substrate sample (M_4) and water filled to 250 ml.

6.4.3 Total porosity is calculated as:

$$TP = (1 - D_b/D_p) \times 100 \text{ (as \%)}$$

where:

- TP is total porosity (%);
 D_b is bulk density oven-dried substrate (g/cm^3);
 D_p is particle density (g/cm^3).

6.4.4 Hydraulic conductivity is calculated as:

$$KSAT = (V \times L_1) \times ([1 / (CSA/10)] / H) \times TCF$$

where:

- $KSAT$ is saturated hydraulic conductivity (mm/min);
 V is volume of water (ml), collected in t (min);
 L_1 is length of saturated sample (cm) (before conversion to volume);
 CSA is cross-sectional area of cylinder (cm^2);
 H is total head (cm);
 TCF is temperature correction factor for water at 5 °C (see [Table 4](#)).

NOTE Values of hydraulic conductivity should be standardized to a temperature of 5 °C by considering the viscosity of water at the measurement temperature relative to that at 5 °C, i.e. $KSAT \text{ at } 5 \text{ °C} = \text{measured } KSAT (\times \text{viscosity of water at measurement temperature/viscosity of water at } 5 \text{ °C})$.

Table 4 — *Temperature correction factor for viscosity of water at 5 °C*

Water temperature (°C)	Specific viscosity	Temperature Correction Factor (TCF) at 5 °C
1	0.9661	1.140
2	0.9334	1.101
3	0.9035	1.066
4	0.8746	1.032
5	0.8475	1.000
6	0.8218	0.970
7	0.7971	0.941
8	0.7734	0.913
9	0.7512	0.886
10	0.7297	0.861
11	0.7094	0.837
12	0.6899	0.814
13	0.6712	0.792
14	0.6534	0.771
15	0.6363	0.751
16	0.6200	0.732
17	0.6042	0.713
18	0.5892	0.695
19	0.5747	0.678
20	0.5608	0.662
21	0.5474	0.646
22	0.5345	0.631
23	0.5222	0.616
24	0.5101	0.602
25	0.4987	0.588
26	0.4875	0.575
27	0.4768	0.563
28	0.4665	0.550
29	0.4564	0.539
30	0.4468	0.527

6.4.5 Field capacity is calculated as:

$$FC = [(M_2 - M_3) / L_1] \times 100$$

where:

- FC is field capacity (g/cm³);
- M₂ is mass of cylinder plus saturated voile/cheesecloth (SC) plus saturated substrate (g);
- M₃ is mass of oven-dried substrate after saturation (g);
- L₁ is volume of substrate in cylinder after saturation (cm³).

6.4.6 Bulk density at field capacity is calculated as:

$$DbFC = M_2 / L_1$$

where:

- DbFC is bulk density at field capacity (g/cm^3);
 M_2 is mass of cylinder plus saturated voile/cheesecloth (SC) plus saturated substrate (g);
 L_1 is volume of substrate in cylinder after saturation (cm^3).

6.4.7 Porosity at field capacity is calculated as:

$$\text{PAF} = \text{TP} - \text{FC} \text{ (as \%)}$$

where:

- PAF is porosity at field capacity (%);
 TP is total porosity (%);
 FC is field capacity (g/cm^3).

7 Method of test for the analysis of green roof substrate pH

7.1 Principle

The green roof substrate pH is measured in a substrate/distilled water mixture by electrometry.

7.2 Apparatus

7.2.1 A bench pH meter, measuring pH with an accuracy of ± 0.01 pH units.

7.2.2 Buffer solutions, for pH 4.0 and pH 7.0.

7.2.3 Sample jars, 100 or 250 ml.

7.2.4 Soil scoop, 20 ml.

7.2.5 Whatman No. 1 filters¹.

7.3 Procedure

A set volume of unsieved air-dried green roof substrate is transferred to a sample jar. A set volume of distilled water is added to the sample at a ratio of 1:5 and shaken for 30 min at an ambient temperature of 20 °C.

NOTE 1 Volumes depend on substrate coarseness. If substrate has 85% of particles less than 2 mm then volume of substrate used is 20 ml. If substrate does not have 85% of particles less than 2 mm, a 50 ml volume of substrate is used.

The solution is filtered using Whatman No. 1 filters.

The batch of samples is measured in turn, either automatically or manually, with the pH meter.

The calibration of the pH electrode and meter using buffer solutions of pH 4.0 and 7.0 should be carried out before pH measurements are taken.

After use, the electrode shall be left in 3.0 M KCl and stoppered to prevent drying out.

NOTE 2 The results of pH measurement are expressed to one decimal place.

NOTE 3 A minimum of three samples for each substrate should be used.

¹ Whatman™ is a trademark of GE Healthcare Life Sciences. This information is given for the convenience of users of this document and does not constitute an endorsement by BSI of the product named. Equivalent products may be used if they can be shown to lead to the same results.

8 Method of test for the determination of electrical conductivity in a calcium sulphate solution extract of green roof substrate

8.1 Principle

Unsieved air-dried green roof substrate is extracted with saturated calcium sulphate solution and filtered. Electrical conductivity in the extract is measured.

8.2 Apparatus and reagents

8.2.1 *Bottles for extraction*, 100 ml or 250 ml borosilicate glass with screw tops.

8.2.2 *Soil scoop*, 20 ml.

8.2.3 *Bottle shaking machine*.

8.2.4 *Electrical conductivity meter*.

8.2.5 *Saturated calcium sulphate*.

8.2.6 *Whatman No. 2 filters*.

8.3 Procedure

A set volume of air-dried green roof substrate is placed in the bottle and a set volume at a ratio of 1:25 to the volume of substrate saturated calcium sulphate added.

NOTE 1 Volumes depend on substrate coarseness. If substrate has 85% of particles less than 2 mm then volume of substrate used is 20 ml. If substrate does not have 85% of particles less than 2 mm, a 50 ml volume of substrate is used.

Bottle is capped and shaken for 15 min.

Filter through 12.5 Whatman No. 2 filter paper. Retain filtrate for electrical conductivity analysis.

Measure electrical conductivity using meter, report result in $\mu\text{S cm}^{-1}$.

NOTE 2 See also MAFF Technical Bulletin 27, *The Analysis of Agricultural Materials Section 3, Soils; "The Determination of Soil Conductivity" [9]*.

9 Method of test for the determination of green roof substrate nitrogen content and C:N ratio

9.1 Principle

Air-dried substrate, milled (not crushed) to 2 mm particle size, is digested with concentrated sulphuric acid to convert nitrogen to ammonium (N). This is then steam distilled into boric acid solution and concentration determined titrimetrically. Carbon values are determined from previous organic matter values (LOI determined in [5.3.1](#)).

9.2 Apparatus and reagents

9.2.1 *Soil scoop*, 20 ml.

9.2.2 *Digestion tubes*, 100 ml.

9.2.3 *Digestion heating block*, capable of 420 °C.

9.2.4 *Kjeltab CK* (3.5 g K_2SO_4 + 0.4 CuSO_4).

9.2.5 *Steam distillation unit* (Kjeldahl type).

9.2.6 *Sulphuric acid (concentrate)*, 0.01 M.

9.2.7 *Boric acid, 10%.*

9.2.8 *Sodium hydroxide (50%).*

9.2.9 *Methyl red/methylene blue indicator solution.*

9.2.10 *CHN analyzer.*

9.3 Procedure

0.5 – 1 g (record actual weight used) milled green roof substrate samples are added to digestion tubes; add 1 Kjeltab CK + 6 ml H₂SO₄.

Digest at 420 °C for 1.5 – 2 h until clear.

Cool and add approximately 5 ml water.

Place digestion tube into steam distillation unit with outflow tube in a flask containing 10 ml of boric acid.

Dispense measure of sodium hydroxide and steam distil for approximately 1 – 2 min or until there is about 50 ml in flask.

Determine total (N) content via titration, add 2 – 3 drops of methyl red/methylene blue to distillate and titrate with 0.01 M H₂SO₄, until colour changes from green to purple.

$\%N = (\text{millimetres of titrated acid} \times 0.02802) / \text{weight of soil} \times (\text{true molarity} / 0.01).$

Carbon values are determined by multiplying loss on ignition (LOI) organic matter value by 0.58 and C:N ratio calculated accordingly.

NOTE Agricultural Materials; Section 3 Soils; "The Determination of Nitrogen in Soil using Micro Digestion Procedure" [10].

9.4 C:N ratio

Carbon and nitrogen analysis can also be calculated using a CHN analyzer.

Substrate samples should be sieved to fractions below 2 mm and might need to be crushed to a finer powder depending on the operating methodologies of the instrument to be used.

CHN analyzer protocols from the instrument manufacturers should be followed and calibrated as directed.

If this method is used, carbon, hydrogen and nitrogen values shall be quoted in test results.

10 Method of test for the analysis of green roof substrate potassium extractable by 0.5 M acetic acid solution

10.1 Principle

Green roof substrate is extracted with 0.5 M acetic acid solution and the extract analyzed for potassium concentration by flame photometry.

10.2 Apparatus and reagents

10.2.1 *Flame photometer, equipped with potassium filter.*

10.2.2 *Acetic acid solution, 0.5 m.*

10.2.3 *Glacial acetic acid, 30 ml diluted to a final volume of 1 L with deionized water.*

10.3 Procedure

10.3.1 Extraction of soil

A set volume of air-dried green roof substrate is transferred to a screw top jar of approximately 120 ml or 300 ml volume.

NOTE Volumes depend on substrate coarseness. If substrate has 85% of particles less than 2 mm then volume of substrate used is 10 ml. If substrate does not have 85% of particles less than 2 mm, a 30 ml volume of substrate is used.

Using a dispenser, a set volume of 0.5 M acetic acid solution is added at a ratio of 1:10 to the substrate sample and the sealed jar shaken for 1 h on a reciprocating shaker at an ambient temperature of 20 °C.

The contents are then filtered through a 15 cm Whatman No. 1 filter paper into a sealable container. Potassium analysis is carried out on the filtrate. If this is not carried out immediately then the jar shall be sealed.

10.3.2 Analysis of potassium filtrate

A sample of filtrate is aspirated into the flame photometer and flame emission reading taken. This is converted to potassium concentration using a calibration graph.

10.3.3 Calibration graph

The flame photometer is pre-calibrated with potassium concentration standard ranging from 0.5 mg L⁻¹ K to 20.0 mg L⁻¹ K prepared in 0.5 M acetic acid solution.

10.3.4 Expression of results

The potassium concentration in the filtrate is converted to the concentration of extractable potassium in the soil sample (expressed as mg L⁻¹ of K₂O) by multiplying the solution potassium concentration by 12.05.

11 Method of test for the analysis of green roof substrate phosphate-P extractable by 0.5 M acetic acid solution

11.1 Principle

Green roof substrate is extracted with 0.5 M acetic acid solution and the extract analyzed colorimetrically for the concentration of phosphate-P.

11.2 Apparatus and reagents

11.2.1 *UV/visible wavelength spectrophotometer*, capable of measuring absorbency values down to 0.005 absorbency units.

11.2.2 *Acetic acid solution*, 0.5 M.

11.2.3 *Glacial acetic acid*, 30 ml diluted to a final volume of 1 L with deionized water.

11.2.4 *Ammonium molybdate solution*.

11.2.4.1 *Ammonium molybdate tetrahydrate*, 12.0 g dissolved and made to 300 ml with deionized water.

11.2.4.2 *Antimony potassium tartrate*, 0.2743 g dissolved in deionized water and made up to 100 ml volume.

11.2.4.3 *Concentrated sulphuric acid*, 140 ml diluted to 100 ml with deionized water.

NOTE The solutions are mixed and stored in an amber bottle.

11.2.5 *Absorbic acid solution*.

- 11.2.6** *Ascorbic acid*, 0.18 g or 0.36 g dissolved in deionized water and made to 9 ml or 18 ml respectively, depending on batch size.

NOTE This is prepared before use.

- 11.2.7** *Mixed reagent*.

- 11.2.8** *Ammonium molybdate solution*, 21 ml or 42 ml mixed with 9 ml or 18 ml ascorbic acid solution respectively, depending on batch size.

11.3 Procedure

11.3.1 Extraction of soil

A set volume of air-dried green roof substrate is transferred to a screw top jar of 100 ml volume.

NOTE Volumes depend on substrate coarseness. If substrate has 85% of particles less than 2 mm then volume of substrate used is 10 ml. If substrate does not have 85% of particles less than 2 mm, a 30 ml volume of substrate is used.

Using a measuring cylinder, a volume of 0.5 M acetic acid solution is added at a ratio of 1:10 and the sealed jar shaken for 1 h on a reciprocating shaker at an ambient temperature of 20 °C.

The contents are then filtered through a 15.0 cm Whatman No. 1 filter paper into 100 ml or 300 ml screw top glass jars. Phosphate analysis is carried out on the filtrate. If this is not carried out immediately then the jars shall be sealed.

11.3.2 Analysis of phosphate in filtrate

A 1.5 ml volume of filtrate is pipetted into a 30 ml test tube. 27 ml of deionized water is added. Then 1.5 ml of mixed reagent is added and the flask shaken immediately.

After 20 min the light absorbency of the solution is measured at 882 nm on a uv/vis spectrophotometer. The measured absorbency is automatically converted to solution phosphate-P concentration in the volumetric flask using the calibration graph. This is then converted to the concentration of extractable phosphate in the soil (expressed as mg L⁻¹ of P₂O₅) by multiplying the solution phosphate-P concentration by 458.0.

11.3.3 Calibration graph

Phosphate concentration standards ranging from 0.05 mg litre⁻¹ P to 0.4 mg litre⁻¹ P are measured alongside the batch of samples on the uv/vis spectrophotometer to provide calibration graph.

11.3.4 Expression of results

Results are expressed in terms of mg litre⁻¹ of P₂O₅ in air-dried substrate.

12 Method of test for the analysis of green roof potential phytotoxins: copper, zinc, nickel, lead and cadmium, extractable by 0.05 M EDTA using atomic absorption spectrophotometry

12.1 Principle

Air-dried green roof substrate is extracted with 0.05 M EDTA diammonium salt solution adjusted to pH 7.0. The filtrate is analyzed for metal content by atomic absorption spectrophotometry.

12.2 Apparatus and reagents

- 12.2.1** *Bottles for extraction*, 100 ml or 250 ml borosilicate glass with screw tops.

- 12.2.2** *Soil scoop*, 20 ml.

12.2.3 *Bottle shaking machine.*

12.2.4 *Atomic absorption spectrometer.*

12.2.5 *EDTA, diammonium salt 0.05 M; pH adjusted to 7.0 with ammonia solution.*

12.3 Procedure

12.3.1 Extraction

A volume of air-dried substrate is added to a bottle and a set volume at a ratio of 1:5 to the volume of substrate of 0.05 M EDTA, diammonium salt, added.

NOTE Volumes depend on substrate coarseness. If substrate has 85% of particles less than 2 mm then volume of substrate used is 20 ml. If substrate does not have 85% of particles less than 2 mm, a 50 ml volume of substrate is used.

The bottle is sealed and shaken on a shaking machine for 1 h. The contents are filtered through a 12.5 cm Whatman No. 40 filter paper.

The filtrate is retained for the analysis of copper, zinc, nickel and lead by atomic absorption spectrophotometry.

12.3.2 Analysis by atomic absorption spectrophotometry

Solution standards are prepared to the following concentrations:

Copper: 0, 0.4, 0.8, 2.0 and 4.0 mg litre⁻¹;

Zinc: 0, 0.08, 0.16, 0.4, 0.8 and 1.6 mg litre⁻¹;

Lead: 0, 1.0, 2.0, 5.0 and 10.0 mg litre⁻¹;

Nickel: 0, 0.4, 0.8, 2.0 and 4.0 mg litre⁻¹; and

Cadmium: 0, 0.1, 0.2, 0.4 and 1.0 mg litre⁻¹.

13 Method of test for the identification of foreign objects within a green roof substrate sample

13.1 Principle

Green roof substrate is inspected for foreign objects (objects which are not listed in the substrate mixture or are deemed to pose a risk). These might include, but are not limited to, glass, ceramics, carpet, rubber, metal (particularly sharps such as screws and nails), plastic, particle sizes > 40 mm.

13.2 Procedure

A sample of air-dried green roof substrate of approximately 1 L is weighed and then spread out to a depth of approximately 1 cm on a large tray.

Any objects deemed to be of concern or of a foreign nature are removed from the substrate and their mass determined. Photographs of relevant objects might also be taken.

The percentage mass of foreign objects within the substrate is determined.

Annex A (informative)

Substrate sampling and categories

A.1 Sampling of substrates

The sampling method used for quality assurance (QA) purposes should be disclosed to the customer and described on the data sheet. If taken from stockpiles (as described in 4.2), one composite sample (minimum 2 kg) represents no more than 5 000 m³ of substrate.

A.2 Substrate categories

A.2.1 General

Manufacturers produce substrates for use on different types of green roof (as described in 3.1), which are covered by this British Standard. Generally, the most important variable for vegetation support is the substrate organic matter content (see 3.7), which tends to be low on most extensive green roofs and higher on intensive green roofs. This can be defined in terms of organic content by percentage mass of the substrate; where extensive green roofs typically contain between 4% – 8% by mass and intensive green roofs between 10% – 20% by mass. However, there are exceptions to these ranges which can be sub-categorized into low organic substrates (LOS), medium organic substrates (MOS) and high organic substrates (HOS).

NOTE 1 It is advised that any substrate be investigated carefully with respect to its suitability for the intended use. The supplier is advised to consult the customer regarding the intended use of the substrate and advise on suitability for the green roof envisaged.

NOTE 2 Low, medium and high organic substrate is not to be confused with low, medium or high fertility soils. Low fertility soils are typically characterized with 2% – 20% organic matter content (% mass) (see BS 3882), which is higher than HOS or intensive green roof substrates, which tend to be < 17.5% (% mass).

A.2.2 Low organic substrates (LOS)

Low organic matter substrates are used for extensive roofs that are broadly recognized for sparse vegetation, which can develop naturally, delivering the greatest diversity of plants and invertebrates. These substrates generally contain organic matter < 5% (% mass).

NOTE LOS in this British Standard are referring to “engineered substrate” rather than brown or rubble roofs.

A.2.3 Medium organic substrates (MOS)

Most extensive green roofs, such as *Sedum* roofs, wild flower or biodiversity roofs and turf roofs, are constructed using a medium organic substrate or extensive substrate. MOS typically have an organic matter content of between 4% – 8% (% mass). These substrates may also be used for more intensive type applications, but with the knowledge that organic matter content is relatively low.

A.2.4 High organic substrates (HOS)

High organic substrates are often used for intensive green roofs where greater amounts of nutrients are required to support larger plants, such as trees and shrubs or thick vegetation coverage as needed for lawn areas. At present, a typical intensive substrate or HOS would have an organic matter content of between 10% – 17.5% (% mass) but it could be much higher if specific plant species were required.

A.3 Substrate bulk densities

A.3.1 General

Green roof substrates are generally described as being lightweight (LW) (see [3.2.1](#)), however there are exceptions to this classification which can be sub-categorized into ultra lightweight (ULW) and heavyweight (HW).

A.3.2 Ultra lightweight (ULW)

These are the lightest weight substrates, typically having loose bulk densities of between 700 – 1 100 kg/m³. They may be specified when there is a roof loading restriction or the optimization on delivery costs where more volume can be carried for a given load weight. Such substrates are often based on lightweight expanded clay aggregate as the principle component, but other lightweight aggregates can also be used.

A.3.3 Heavyweight (HW)

These substrates are designed to provide a higher loose bulk density than other substrates, typically above 1 200 kg/m³. HW substrates may be specified where insulating materials need to be held down (this is often achieved on flat roofs using ballast materials) and could be produced using siliceous aggregate.

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Further reading

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