The properties of Air-crete: A possible new substrate for green roofs in Sheffield.

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Abstract

To date the potential of green roofs in promoting biodiversity has resulted in the use of green roof technology worldwide. The substrate used in green roofs plays a significant role in increasing, not only the biodiversity value, but also the ecological benefits, as recycled ‘waste materials’ can be used. However, very little information exists regarding the characteristics and qualities of these recycled substrates. This study determines the potential of crushed aerated concrete as a basis for a green roof substrate. A combination of calcareous wildflower seeds and meadow grass mixture were sown on top of the four test compositions of concrete and compost, ranging from 100% concrete to 50% concrete and 50% compost. The study shows that the substrate with the highest percentage of compost also showed the highest water holding capacity and supported greater plant growth. These results are discussed in the context of potential future use of recycled substrates in green roof systems.

Introduction

Green Roofs have been present for centuries, ranging from the hanging gardens of Babylon which were one of Seven Wonders of the World, to the turf roofed dwellings of Ireland and Scandinavia (Livingroofs, 2007). However, modern green roofs have largely developed in the last 50 years and the growing interest in them means that their design and maintenance have to be investigated more thoroughly in order to establish a sustainable system. It is widely accepted that green roof systems can provide many benefits in urban areas, but particularly in terms of environmental benefits. A significant contribution to biodiversity value created by green roofs comes from the substrate material used (soil or growing medium) which can include brick rubble, quarry waste material, waste from the steel industry (furnace bottom slag), limestone and crushed concrete.

1.1 Green roof substrate characteristics

As green roof technology continues to improve, suitable selection of substrate and its depth is crucial. Although different factors such as the ability to tolerate low winter temperatures and water-stressed environmental conditions are important, selection of a proper substrate plays a crucial role for the best results (Rowe *et al*, 2006).

Generally an ideal substrate has to achieve various factors such as being lightweight, permanent, having high water absorbance and water holding capacity, while at the same time be readily drained and be able to sustain plant health without leaching nutrients that may harm the environment. According to German researches an ideal green roof media that is able to retain good capacity of moisture and aerate the roots of plants consists of 30-40% substrate and 60-70% pore space (Dunnett and Kingsbury, 2004). An important factor, when considering the substrate used, is the amount of organic matter as the organic matter is valuable in terms of water retention and nutrient availability. However, due to shrinkage (the substrate shrinking in hot weather due to drying out of high amounts of water-holding organic matter) and leaching, the percentage of organic matter, combined with substrate, must be kept at the minimum needed for suitable plant growth. Another characteristic of green roof substrates is that of the pH, as different substrates will exhibit differing pH, an appropriate substrate being relatively stable in the long term and must be within a range that allows plants to take up nutrients from the medium. (Beattie and Berghage, 2004). The pH will also affect the type of vegetation that will become established once the roof is planted, with calcareous species flourishing in alkaline substrates and acidic species in acidic substrates.

There are a wide range of materials that have been used as a basis for green roof substrates including clay, slate, expanded shale, rock wool, urethane foams, vermiculite, perlite, waste aggregates like crushed brick, crushed concrete and subsoil (Dunnett and Kingsbury, 2004; Hitchmough, 1994). All of these materials have a potential as green roof substrates with advantages and disadvantages, and each of them suitable for different types of vegetation. In fact there is no exact instruction for green roof substrate and it could be a combination of all of these materials but more importantly the substrate chosen depends on the environment and the nature of the site (Hitchmough, 1994). As a result what is absolutely clear is that the green roof substrates and their requirements are quite different and can not be the same as those used for ground-level gardens.

1.2 Aggregates as a basis for green roofs

The aggregate in a green roof system is the main component of the substrate which is non-organic and, because the amount of organic matter that is mixed with the aggregate is very low, must perform an appropriate function to support the plants and provide the pore space for water and air (Charles, 2005). Mineral or aggregate-based substrates may also have value in themselves by providing habitat, particularly for invertebrate species (Dunnett and Kingsbury, 2004). Many different types of aggregates are used in green roof industry, with the principal artificially lightweight aggregates produced in manufacturing plants, made from raw materials including shale, clay and slate (Holme, 1994). Each of these materials has specific properties and are the most beneficial aggregates as they meet the requirements of most green roof substrate, due to their availability and physical properties (Friedrich, 2005). Clay, for example, has a good moisture holding capacity; however a green roof substrate should contain very little clay or silt size material since it tends to get separate into hard and low-permeable layers and clogs drainage layers (Miller, 2003). Artificial minerals are also very useful and lightweight and can be used as substrate in green roofs but need to be mixed with other materials since they do not have the ability to store water and nutrients. Lightweight expanded clay granules are an ideal example of artificial minerals achieving all the essential requirements necessary for a green roof substrate (Dunnett and Kingsbury, 2004). They have been used alone as a growing medium in Germany for extensive green roofs including turf and wildflower vegetation (Osmundson, 1999). Another option for green roof substrate is sand. Because this material is used in construction works, it is relatively inexpensive but due to its high structural porosity and rapid leaching, it is unable to retain enough water and nutrients necessary for plant growth. Therefore sand would need to be mixed with material that can provide aeration for roots and retain water and nutrients (Osmundson, 1999). Other types of lightweight aggregates are those occurring from natural process like mined from volcanic deposits that include pumice and scoria (lava rock) (Holme, 1994).

The green roof industry prefers environmentally beneficial materials with low energy inputs and low cost. Although the artificial materials which have been mentioned above are suitable as a basis for green roof substrate they require energy inputs for their production. The most environmentally friendly materials are those that arise from waste or recycled products or from building construction works like crushed concrete and crushed bricks; in fact the development of local sources of material for green roof substrate could be a cost effective and the most environmentally beneficial way for green roof construction. Since they are readily available the energy used in their transport to the site is minimized and costs are reduced, also for the best result on plant growth these materials may be mixed with low percentage of organic matter in order to provide the required nutrients and moisture (Dunnett and Kingsbury, 2004). However, to date little research has been conducted on the characteristics and use of aggregates as green roof substrate. Crushed concrete is one of the waste aggregates that could be used as a green roof substrate.

There are several reasons for selecting crushed concrete as a potential green roof substrate. Crushed concrete is an aggregate material from building construction works with the original shape being available in the form of blocks and principally used in wall construction; combining strength, moisture resistance and high thermal efficiency (Celcon, 2007). The crushed form of this material, known as Air-crete (see Figure 1), from construction works reflects all the advantages of the original material including properties such as excellent thermal insulation, excellent sound insulation, light weight and frost resistant. Because this material is a recycled waste material it is very cheap and, due to its high porosity, may be able to hold sufficient water to support plant growth. Therefore the use of Air-crete may reduce costs for the industry as it reduces the need to dispose of the waste in landfill sites and therefore avoids landfill taxes, thus creating both financial and environmental benefits. Although air-crete products have been available in the UK for over 50 years, it is still seen by many as a 'new' product. Indeed, as with many new products, air-crete as a building material has much more to offer than is being utilized today.

Figure 1: Crushed aerated concrete with its high porosity property is very lightweight and can retain water in itself.

This research aims to investigate the potential of Air-crete as a basis for green roof substrate including its characteristics in terms of water attenuation and its effect on plant growth. It will also investigate how the amount of organic matter added to the concrete effects both the plant growth and water attenuation of the substrate.

1.3 Research Questions

1) Does crushed concrete (henceforth known as Air-crete) support vegetation growth on green roofs?
2) Does the proportion of organic matter mixed with the Air-crete significantly effect plant growth?
3) What is the water-holding capacity of Air-crete?

2. Methods

The first part of the experiment was performed as a 4-week greenhouse study at Tapton Experimental Gardens (University of Sheffield) and started on the 31st of August, 2007. Additionally, a laboratory test was conducted in 10 consecutive days (except weekends) in order to determine the water holding capacity and the ratio of evaporation of the same material and the role of organic matter in these two characteristics

2.1 Substrate

The substrate used was crushed aerated concrete with the particle size of 10-20mm made from Celcon standard blocks by Celcon Company.

2.2 Seed mixes

The types of seed mixtures used were a combination of calcareous wild flower seed mix and meadow grass mixture for chalk and limestone soils from Emorsgate Company. Calcareous wild flowers were chosen due to the alkaline nature of the substrate. The combination ratio of wildflower seed mix and grasses was 50% of each. The names of the species and their composition percentage have been presented in Table 1 and 2.

Species	Common name	Composition (%)
Achillea millefolium	Yarrow	2.5
Anthyllis vulneraria	Kidney Vetch	7.5
Centaurea nigra	Common Knapweed	5.0
Centaurea scabiosa	Greater Knapweed	5.0
Clinopodium vulgare	Wild Basil	2.5
Daucus carota	Wild Carrot	5.0
Filipendula vulgaris	Dropwort	2.5
Galium verum	Lady’s Bedstraw	5.0
Knautia arvensis	Field Scabious	7.5
Leontodon hispidus	Rough Hawkbit	5.0
Leucanthemum vulgare	Oxeye Daisy	5.0
Lotus corniculatus	Birdsfoot Trefoil	5.0
Origanum vulgare	Wild Marjoram	2.5
Pimpinella saxifraga	Burnet-saxifrage	2.5
Plantago media	Hoary Plantain	5.0
Primula veris	Cowslip	5.0
Prunella vulgaris	Selfheal	5.0
Ranunculus acris	Meadow Buttercup	5.0
Reseda lutea	Wild Mignonette	5.0
Sanguisorba minor	Salad Burnet	10.0
Scabiosa columbaria	Small Scabious	2.5

Table 1: Species name of the wildflower mix and composition (%) according to the supplier company

Species	Common name	Composition (%)
Briza media	Quaking Grass	2.5
Cynosurus cristatus	Crested Dogstail	37.5
Festuca ovina	Sheep’s Fescue	31.3
Festuca rubra	Slender Creeping Red Fescue	18.8
Koeleria macrantha	Crested Hair-grass	1.2
Phleum bertolonii	Smaller Cat’s tail	5.0
Trisetum flavescens	Yellow Oat-grass	3.8

Table 2: Species name of the grasses and composition (%) according to the supplier company

2.3 Organic matter

The green waste compost used for the purpose of this experiment was peat based compost produced from a blend of high quality sphagnum peat mixed with alternative sustainable ingredients obtained from B&Q Company. The compost also contained a wetting agent designed to help absorption when watering.

2.4 Establishment methods

To investigate the properties of crushed aerated concrete, small scale pots (S = 100 cm^2, see Fig 2) were used and filled with crushed concrete mixed with different proportions of organic matter (see Table 3) with 5 replicates for each combination.

Pot	Composition % of crushed concrete	Composition % of compost
A	100	0
B	90	10
C	70	30
D	50	50

Table 3. Composition (%) of crushed concrete with compost

Different proportions of compost and crushed concrete (see Fig 2), were mixed together, put in to the pots and watered properly before sowing the seeds. In order to prevent seeds becoming clogged in the pores of the air-crete the substrates were covered with a very thin layer of sand.

Figure 2: Four different compositions of crushed concrete mixed with organic matter at Tapton experimental garden, from left to right D – A

Seed mixtures were added to the top of each pot with the proportion of 0.2gr seed per pot. The sown seeds were covered by small amount of sand and watered slightly. Pots were kept in a greenhouse for germination and, in order to speed the germination rate, they were covered with newspaper until first germination. The pots were watered every other day.

2.5 Vegetation survey

After sowing, visual observation and monitoring occurred every day until germination. The seeds in each replicate germinated after 3 days (Figure 3). The seeds were allowed to grow for four weeks, after which all the plants were harvested, dried, weighed and counted to get an indication of the amount of growth in each pot (Figure 4).

Figure 3: The seedlings after 3 days. The composition of the pots in each row, right to left is: A – D

Figure 4: Seedlings after 4 weeks. The composition of the pots in each row, right to left is: A – D

2.6 Laboratory study

In order to determine the water holding capacity of the material, a laboratory study was conducted in the Animal and Plant Science Department (University of Sheffield. The same composition of materials as used for sowing the seeds, was selected for the study and the same beakers were used to weigh the known volumes of the material. Five replicates for each composition were used, thus enabling a mean weight to be calculated. The materials were put in the oven for 48 hours to be completely dried. Following this they were weighed and the dried-weight of the materials recorded. After weighting the dried materials, each was then soaked in water for 48 hours to examine the weight at saturation, and thus the water holding capacity.

To examine the evaporation rate, after 48 hours the excess water was emptied and saturated materials were spread into trays and kept on the window sill to be dried. (Due to restrictions in the A.P.S Department, we were unable to take the trays out of the laboratory therefore the trays had to be kept at the window sill. However the temperature inside the laboratory was very close to that outside).

The materials were weighed every day and the data was recorded systematically for a total of four consecutive days with an exception of weekends (Due to the restriction of A.P.S Department for access to the building at weekends) from 10th of September to 21st of September.

2.7 Analysis

Anderson-Darling Normality tests were undertaken on all data and consequently, ANOVAs and a Kruskal Wallis test were conducted.

3. Key Results

By the end of the experiment the 100% Air-crete (A) generally resulted in the least amount of growth and lowest visual appearance. All the plants grown in 50% Air-crete and 50% compost (D) reached near 100% coverage and had the highest visual appearance when compared with the other substrate compositions.

There was a significant difference in both the number of non-grass seedlings and grasses in the different mixes of substrates (F = 17.16, n = 5, p = 0.000; H = 11.40, n = 5, $D.F$ =3, p = 0.01, respectively), with substrates with more organic matter having consistently better growth (see Figure 5). However the amount of grasses in all types of substrate is very low. The pots were subjected to the same conditions in the greenhouse and the amount of non-grass and grass seeds were the same. Therefore, the difference in growth between the grasses and non-grasses may indicate that whilst the Air-crete is a suitable substrate for non-grass species, it is not suitable for a meadow grass mixture. This may be due to the fact that the non-grass species were specifically chosen as calcareous species, whilst the grasses are not as specific, thus may have found the substrate too alkaline.

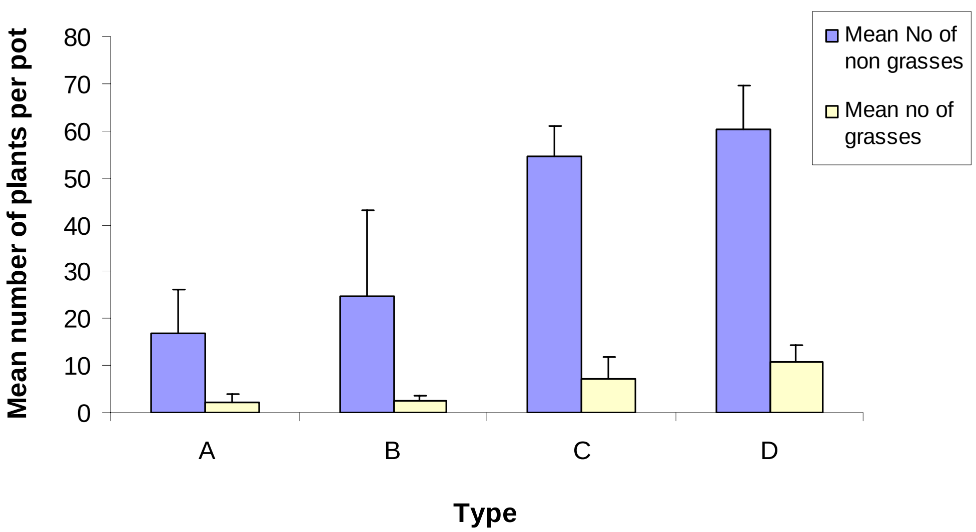

Figure 5: The mean number of grasses and non-grasses in each substrate composition type.

The better growth of vegetation in those pots with more organic matter indicates that whilst Air-crete does indeed support plant growth, a higher percentage of organic matter is needed to provide the best growing conditions. Whilst Air-crete is a cheap, lightweight and obviously effective substrate, the need for a high percentage of organic matter may present a problem in the use of green roofs, due to potential leaching and shrinkage issues. The amount of shrinkage and leaching would need to be examined further to investigate if this presented a significant problem.

The evaporation rate in each type of substrate is shown in Figure 6. The lack of equipment did not allow for conducting the water holding capacity test and evaporation rate test for all the types of substrates at the same dates. Type A had the highest evaporation rate and was, therefore, able to retain the smallest amount of water, whilst type D had the lowest evaporation rate and retained the highest amount of water (see Fig 6 and Table 4).

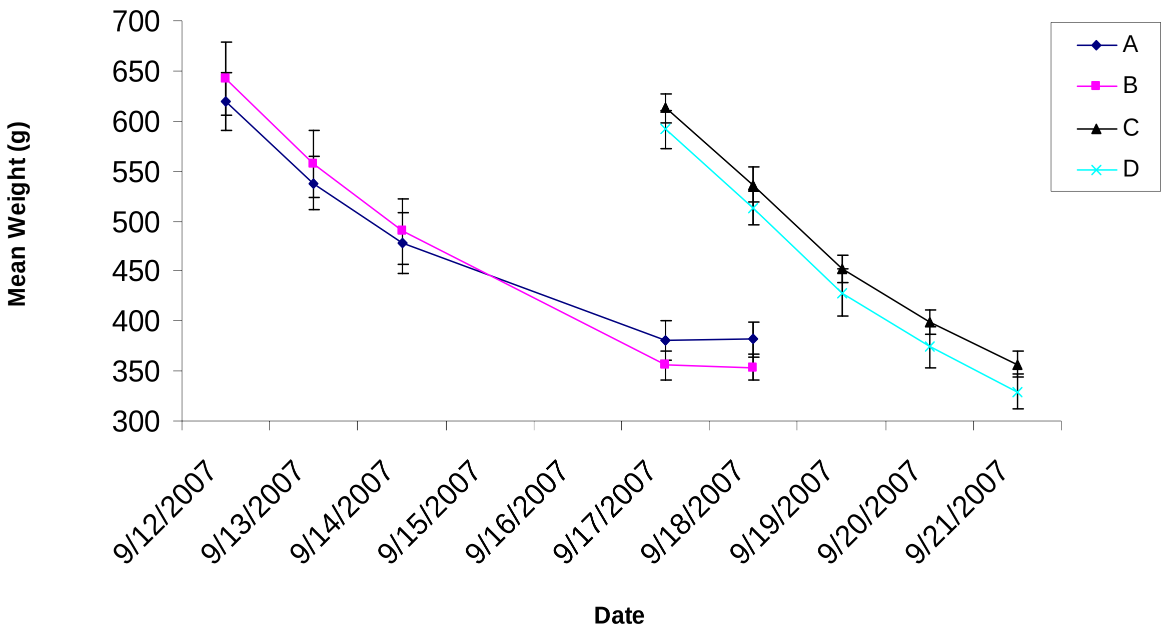

Figure 6: Evaporation rate over time.

Type	Mean dried weight (g)	St Dev. dried weight (g)	Mean saturated weight (g)	St Dev. Saturated weight (g)	Mean W. H. Capacity (g/1000ml)	St Dev. W.H. Capacity
A =100 % Air-crete	372.48	17.44	619.67	29.33	247.19	12.21
B = 90 % Air-crete	342.2	8.76	642.29	36.4	300.1	32.48
C = 70 % Air-crete	290.65	7.04	612.75	14.65	322.2	11.21
D = 50 % Air-crete	232.52	10.70	591.85	19.03	359.33	23.12

Table 4: The mean value and standard deviation of dried weight, saturated weight and water holding capacity (W.H.Capacity) in different types of compositions.

This result is due to the water holding capacity of the organic matter. It indicates that substrate types C and D would be more suitable to support vegetation, especially in dry situations, however, again the amount of shrinkage may present a problem. Further investigation of this issue would be useful to examine the rate of evaporation in greater detail, and the time taken for each type of substrate to become totally dry, as well as to examine the potential issue of shrinkage.

There is a significant difference in the water holding capacity between the substrates with different mixes of organic matter (F= 23.57, n= 5, P= 0.000) with greater retention of water occurring in the substrate with a higher proportion of organic matter.

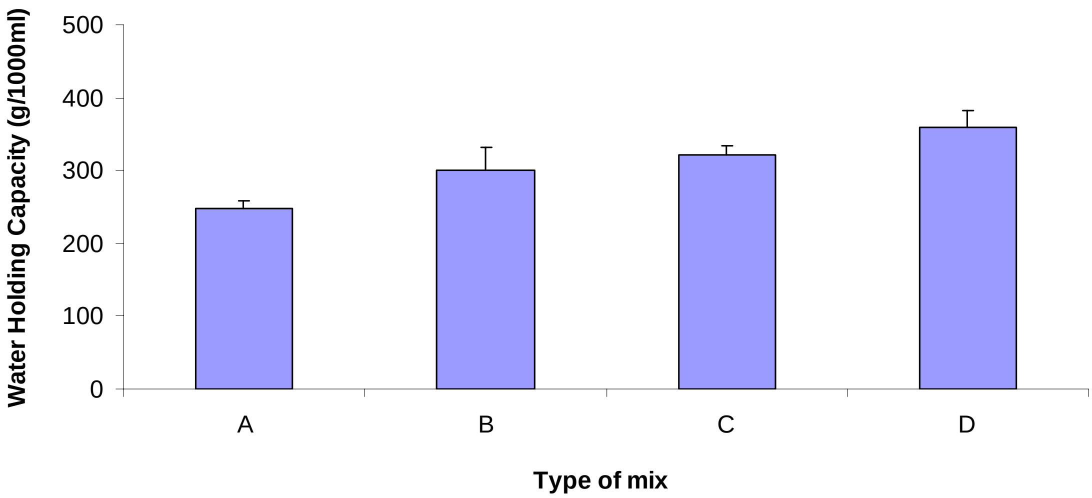

Figure 7: The mean water holding capacity of crushed concrete under four different organic matter regimes.

Figure 7 shows the water holding capacity of crushed concrete with different proportions of organic matter. It is obvious the substrate composition type A has the smallest water holding capacity, whilst D has the highest water holding capacity, supporting the statistics. This also supports the data from the evaporation rates, and also indicates that substrate type D is the best mix for plant growth.

4. Conclusion

The results from this study show that plant growth and coverage were significantly influenced by the amount of organic matter that was mixed with the substrate. Generally the greater the amount of organic matter mixed with Air-crete the higher amount of plant coverage is found.

Additionally according to current research in which the water holding capacity of a number of aggregates such as Crushed Brick, Air-crete and Sand have been investigated, the Air-crete has the lowest water holding capacity when compared with the other materials, whilst sand showed the maximum amount of water holding capacity (Srivastava, 2007). This shows that crushed concrete might not be the best option for areas with long periods of dryness, due to the smaller amount of water it could retain compared with other aggregates. However it could be an appropriate choice when mixed with a small amount of organic matter in some countries with humid climates such as England since it is locally available and is much lighter than the other aggregates specially when loading restrictions exist.

The major conclusion of this study therefore, is that Air-crete could be a suitable option for green roof substrates and does support the plant growth if it mixed with 30% or 50% organic matter. However the Air-crete does not appear to be a suitable option for a meadow grass mixture as the substrate did not support a significant growth of grasses, even when 50% organic matter was added. Further research also needs to be conducted to examine the amount of shrinkage or leaching that takes place when using this substrate under the different organic matter regimes.