

AN ENGINEERED SOIL COMPOSITION AND A METHOD OF PREPARING THE SAME

5

TECHNICAL FIELD

Various embodiments relate to engineered soil compositions and method of preparing the engineered soil compositions.

10

BACKGROUND

Besides being an essential element required for life, water is a useful
15 resource which plays an important role in numerous activities such as industrial, agricultural, and environmental activities. The natural environment provides, for example, wetlands with naturally existing filtering mechanisms capable of treating water for recycled use. However, as populations expand with increasing levels of development, industrial and agricultural activities, anthropogenic
20 degradation of the natural environment has caused stress and eventual loss of these naturally existing filtering mechanisms. Such loss has led to the loading of excess nutrients and pollutants into water bodies causing water quality degradation.

25 In an effort to improve water quality and mitigate losses of naturally existing filtering mechanisms, engineering / low impact technologies are being hybridized with natural resources to form water treatment systems to effect treatment of polluted discharges and attenuate undesirable hydrology changes.

An example of a conventional hybridized water treatment system is a bioretention system, or sometimes referred to as a rain garden.

Typically, bioretention systems used in tropical climates are subjected to higher rainfall every year, hence increasing the peak runoff into the waterways and reservoirs. Particularly for Singapore which aims to to maximize the urban catchment area, such rainfall events can result in high amounts of runoff (containing pollutants) entering local waterways and reservoirs. The influx of pollutants into reservoirs may result in consequences such as eutrophication and silting, affecting the aquatic species.

In bioretention, the physical, chemical, and biological properties of plants, microbes and soils are utilized in removal and transformation of pollutants and nutrients from stormwater runoff, as well as transformation of pollutants and nutrients found in wastewater treatment practices. Processes of sedimentation, adsorption, filtration, volatilization, decomposition, and bioremediation are typically carried out in a bioretention system.

However, due to the non-homogenous nature of the sand and potting soil that are commercially available, the implementation of a bioretention system with consistent soil mix for the use as the planting / filter media proves to be challenging.

Further, in conventional methods of preparing a bioretention system, top soil from the site where the bioreention system is set up, is usually removed to form a recess in the ground that serves as reservoir and to be filled with a fresh layer of soil (e.g., filter media) for planting and filtration. The removed top soil requires proper disposal, which incurs increased cost for implementing the bioretention system.

In certain preparations of bioretention systems, a large amount of sand may be used as an important part of a filtering bed. However, in Singapore and many other countries, sand is one of the natural materials that is scarce and has to be imported. For example, due to rapid developments in the construction industry, sand is perpetually in high demand and the situation may be aggravated by shortage of sand supply in nearby countries. Sand is typically obtained from dredging river banks, the processes of which add on to the cost for constructing and implementing the bioretention system.

Moreover, in some known soil mixes which are considered for use in bioretention, the filtration property of such mixes are insufficient to effectively remove pollutants such as dissolved phosphates, ammonium, nitrites, nitrates and organic nitrogen from the effluent, especially for tropical climates such as Singapore where rainfall can be high and frequent. Typically, fines are chemically active and hence promote the removal of dissolved ions such as phosphates, nitrates and nitrites. Conversely, such soil mixes with high contents of fines may also have low hydraulic conductivities which do not satisfy requirements for bioretention systems and are not suitable for supporting certain plant growth, particularly of plant species of the tropical climate and thus not desirable for use in the tropical climate. The soil mixes to be used in bioretention therefore have to satisfy conflicting requirements of suitable hydraulic conductivity and pollutant removal that satisfies guidelines, for example, provided in Singapore.

Thus, there is a need for an engineered soil composition for bioretention systems that addresses or at least ameliorates the problems mentioned above.

SUMMARY

According to one aspect, there is provided an engineered soil composition comprising a natural occurring soil component in an amount ranging from 30 wt% to 60 wt% of the total dry weight of the composition; a sand component in an amount ranging from 25 wt% to 55 wt% of the total dry weight of the composition; and a waste component in an amount of more than 0 wt% and no more than 15 wt% of the total dry weight of the composition, wherein a total amount of clay and silt derived from the natural occurring soil component is in an amount of more than 0 wt% and no more than 15 wt% of the total dry weight of the composition.

In various embodiments, the engineered soil composition is a substantially homogeneous mixture of the natural occurring soil component, the sand component, and the waste component.

In various embodiments, the waste component comprises water treatment residues.

In various embodiments, the engineered soil composition has a hydraulic conductivity of no less than 20 mm/hr.

In various embodiments, the engineered soil composition has a hydraulic conductivity in a range from 50 mm/hr to 450 mm/hr.

In various embodiments, the engineered soil composition has a hydraulic conductivity in a range from 50 mm/hr to 200 mm/hr.

In various embodiments, the engineered soil composition has a hydraulic conductivity in a range from 200 mm/hr to 400 mm/hr.

5 In various embodiments, the engineered soil composition has a pH level in a range from 5.5 to 8.5.

In various embodiments, the engineered soil composition has an electrical conductivity of no less than 0.1 mS/cm and not more than 0.3 mS/cm.

10 In various embodiments, the clay, or the silt or both have a particle size distribution of no more than 0.075 mm.

In various embodiments, the engineered soil composition further comprises an organic carbon-containing component that is different from the
15 natural occurring soil component, the organic carbon-containing component being present in an amount of more than 0 wt% and no more than 35 wt% of the total dry weight of the composition.

In various embodiments, the organic carbon-containing component
20 comprises a plant-based compost.

In one embodiment, the plant-based compost is selected from the group consisting of coconut fibres, palm fibres, rice husk, jute fibres, wood chips and mixtures thereof.
25

In various embodiments, each of the components is derived from a different source.

In various embodiments, the natural occurring soil component is derived
30 from a top layer of soil that is no more than 1.5 m from ground.

In various embodiments, the natural occurring soil component is derived from a site at which the engineered soil composition is to be used.

5 In various embodiments, the sand component comprises sand particles having a particle size distribution in a range from 0.2 mm to 0.6 mm.

In various embodiments, the sand component comprises sand particles that have been pre-washed and cleaned.

10

In various embodiments, the waste component is derived from a water treatment plant.

15 In various embodiments, the waste component comprises particles having grain sizes in a range from 0.10 mm to 1.20 mm.

In various embodiments, the engineered soil composition is capable of supporting growth of one or more plant species.

20 In one embodiment, the one or more plant species is selected from the group consisting of *Clerodendrum inerme*, *Cordyline fruticosa*, *Codiaeum variegatum*, *Iris domestica*, *Iris domestica*, *Murraya paniculata*, *Ophiopogon jaburan*, *Premna serratifolia*, *Sanchezia oblonga*, *Scaevola taccada*, *Sphagneticola trilobata*, *Sphagneticola trilobata*, *Syzygium myrtifolium*, *Tarenna*
25 *odorata* and *Trimezia steyermarkii*.

In various embodiments, the engineered soil composition is capable of supporting growth of one or more plant species such that the plant stress Fv/Fm ratio of the one or more plant species during growth is from 0.79 to 0.84.

30

In various embodiments, the engineered soil composition is capable of supporting growth of one or more plant species such that the chlorophyll content SPAD value index of the one or more plant species during growth indicates healthy plant growth.

5

In various embodiments, the engineered soil composition is capable of removing no less than 80% of Total Suspended Solids (TSS) from a TSS-containing influent water stream passing through the engineered soil composition.

10

In various embodiments, the engineered soil composition is capable of removing no less than 45% of Total Nitrogen (TN) from a TN-containing influent water stream passing through the engineered soil composition.

15

In various embodiments, the engineered soil composition is capable of removing no less than 45% of Total Phosphorus (TP) from a TP-containing influent water stream passing through the engineered soil composition.

According to another aspect, there is provided an engineered soil composition consisting essentially of a natural occurring soil component in an amount ranging from 35 wt% to 55 wt% of the total dry weight of the composition; a sand component in an amount ranging from 30 wt% to 50 wt% of the total dry weight of the composition; a water treatment residue component in an amount of more than 0 wt% and less than 10 wt% of the total dry weight of the composition; and an organic carbon-containing component in an amount of more than 0 wt% and less than 10 wt% of the total dry weight of the composition, wherein a total amount of clay and silt derived from the natural occurring soil component is in an amount of more than 0 wt% and no more than 10 wt% of the total dry weight of the composition.

30

According to yet another aspect, there is provided a method of preparing an engineered soil composition in accordance with various embodiments as described herein, the method comprising determining a desired hydraulic conductivity range for the engineered soil composition to be obtained; obtaining
5 an amount of natural occurring soil from a source; determining a measure of silt and/or clay present in the amount of natural occurring soil from the source; based on the determined measure of silt and/or clay, mixing the natural occurring soil obtained from the source in an amount ranging from 30 wt% to 60 wt% of the total dry weight of the composition with, a sand component in an
10 amount ranging from 30 wt% to 50 wt% of the total dry weight of the composition, and with a waste component in an amount of more than 0 wt% and no more than 15 wt% of the total dry weight of the composition to form the engineered soil composition, such that the total amount of clay and silt derived from the natural occurring soil is in an amount of more than 0 wt% and no more
15 than 15 wt% of the total dry weight of the engineered soil composition and wherein the engineered soil composition has a hydraulic conductivity value within the desired hydraulic conductivity range.

In various embodiments, the engineered soil composition obtained from
20 the mixing step is a substantially homogeneous mixture of the natural occurring soil, the sand component, and the waste component.

In various embodiments, the step of mixing the natural occurring soil with the sand component and the waste component further comprises mixing the
25 natural occurring soil, the sand component and the waste component with an organic carbon-containing component in an amount of more than 0 wt% and no more than 35 wt% of the total dry weight of the composition.

In one embodiment, the organic carbon-containing component comprises
30 a plant-based compost.

In one embodiment, the plant-based compost is selected from the group consisting of coconut fibres, palm fibres, rice husk, jute fibres, wood chips and mixtures thereof.

5

In various embodiments, the desired hydraulic conductivity range is at or within a range from 50 mm/hr to 450 mm/hr.

10 In various embodiments, the method further comprises prior to the mixing step, the step of determining a desired pH range for the engineered soil composition to be obtained such that the mixing step forms the engineered soil composition having a pH value within the desired pH range.

15 In one embodiment, the desired pH range is at or within a range from 5.5 to 8.5.

In various embodiments, the method further comprises the step of determining a desired electrical conductivity limit for the engineered soil composition prior to the mixing step such that the mixing step forms the
20 engineered soil composition having an electrical conductivity value not more than the desired electrical conductivity limit.

In one embodiment, the desired electrical conductivity limit is 0.1 mS/cm.

25 In various embodiments, the step of determining the desired hydraulic conductivity range for the engineered soil composition to be obtained comprises determining at least one of a desired removal rate of Total Suspended Solids (TSS), a desired removal rate of Total Nitrogen (TN) or a desired removal rate of Total Phosphorus (TP) from an influent water stream passing through the
30 engineered soil composition.

In various embodiments, the clay, or the silt or both have a particle size distribution of no more than 0.075 mm.

5 In various embodiments, the natural occurring soil is derived from a top layer of soil that is no more than 1.5 m from ground.

In various embodiments, the natural occurring soil is derived from a site at which the engineered soil composition is to be used.

10

In various embodiments, the sand component comprises sand particles having a particle size distribution in a range from 0.2 mm to 0.6 mm.

15 In various embodiments, the method further comprises, prior to the mixing step, the steps of providing sand particles; and washing and cleaning the sand particles to form the sand component.

In various embodiments, the waste component comprises water treatment residues.

20

In various embodiments, the method further comprises, prior to the mixing step, the steps of providing a waste material having particles therein; and sieving the waste material to obtain the waste component having particle grain sizes in a range from 0.10 mm to 1.20 mm.

25

In one embodiment, the method further comprises, prior to the sieving step, the step of pulverizing the waste material.

30 According to another aspect, there is provided a water treatment system for simultaneously supporting plant growth and filtering stormwater, the system

comprising an engineered soil composition in accordance with various embodiments as described herein.

5 In one embodiment, the water treatment system is a bioretention system or a rain garden.

DEFINITIONS

10 The term “engineered soil composition” as used herein broadly refers to a composition that is formulated by human intervention as opposed to a composition found in nature. For example, the engineered soil composition may also interchangeably be referred to as a soil mix, an engineered soil mix, or engineered soil.

15 The terms “natural occurring soil component” and “natural occurring soil” as used herein broadly refer to a soil that is formed by cycles of nature. The natural occurring soil component or the natural occurring soil is different from an engineered soil and does not involved a designed mixture which is formulated by human
20 intervention to provide a desired effect, for example, to enhance plant growth. The contents of the natural occurring soil component or the natural occurring soil may be in random proportions.

The term “sand component” as used herein broadly refers to a naturally
25 occurring granular material composed of finely divided rock and mineral particles. For example, the sand component may include sand or medium sand.

The term “water treatment residues” as used herein broadly refers to any form of material unwanted from a water treatment source, for example, an industrial water
30 treatment plant. The water treatment residues may include organic materials from a

biological source, non-bio organic material such as exemplified in the form of organic plastic material, organic polymeric material of any kind, and inorganic materials from any source.

5 The term “waste material” as used herein broadly refers to any form of unwanted material, whether pre-processed or unprocessed, from any source (e.g., being household, landfill, industrial, agricultural, marine, municipal, sewer, drain and so forth) or a processing facility. The waste material includes but is not limited to water treatment residues. The waste material may include the waste component as
10 disclosed herein. The waste component disclosed herein may be a component of the waste material that has undergone further processing.

 The term “total dry weight” as used herein broadly refers to a weight measure of a substance when the substance has less than 2% moisture content.

15

 The term “derived” as used herein is to be interpreted broadly to mean directly or indirectly obtained. In some cases, the term “derived” may interchangeably be but is not limited to being referred to as “obtained”, “extracted”, “being originated”, or “resulted”.

20

 The term “hydraulic conductivity” as used herein broadly refers to a property of soil or rock that describes the ease with which a fluid can move through pore spaces or fractures under the influence of water pressure difference. The term “hydraulic conductivity may interchangeably be referred to as “permeability” and may
25 be symbolically represented as K.

 The term “water treatment plant” as used herein broadly refers to an industrial plant or system for water treatment or water filtration, for example, for drinking purposes. The water treatment plant focuses on removing pollutants from water and
30 may not promote ecological growth, for example, plant growth in any way. The water

treatment plant functions in absence of any hybridization with an ecological system. For example, a water treatment plant may perform treatment of reservoir water into drinking water and may include carrying out a series of processes such as screening, coagulation, flocculation, sedimentation, filtration, and disinfection. Water treatment residue may be obtained due to the processes from coagulation, flocculation, sedimentation and filtration. For example, all these processes may be carried out in drinking water treatment in the water treatment plant in Singapore (i.e., under the Public Utilities Board). In this context, the water treatment plant may be different from a wastewater treatment plant.

The term “plant stress Fv/Fm ratio” as used herein broadly refers to a plant stress measurement quantifying environmental effects on photochemical efficiency of photosynthesis (the maximum quantum yield of photosystem II), and, hence, plant health. For example, the plant stress Fv/Fm ratio may refer to a photochemical efficiency.

The term “Total Suspended Solids” as used herein broadly refers to a parameter used for quantifying total amount of suspended matter in a liquid, which may be retained on a filter paper and dried at about 103-105°C.

The term “Total Nitrogen” as used herein with reference to a volume of water broadly refers to a sum of nitrate-nitrogen ($\text{NO}_3\text{-N}$), nitrite-nitrogen ($\text{NO}_2\text{-N}$), ammonia-nitrogen ($\text{NH}_3\text{-N}$) and organically bonded nitrogen in that volume of water.

The term “Total Phosphorus” as used herein with reference to a volume of water broadly refers to a sum of reactive, condensed and organic phosphorous, which may be in dissolved form (orthophosphate), inorganic form (reactive plus condensed or acid hydrolyzable phosphate) and organically bound forms in that volume of water.

The term “organic carbon-containing component” as used herein broadly refers to matter containing carbon and being derived from living organisms.

5 The term “determining” as used herein is to be broadly interpreted as the act of finding out. It may include but is not limited to steps such as evaluating, establishing, formulating, computing, deciding, or measuring.

10 The term “removing” as used herein is to be broadly interpreted as the act of taking something away. It may include but is not limited to steps such as as filtering, or seperating.

15 The term “providing” as used herein is to be broadly interpreted as the act of giving something. It may include but is not limited to steps such as obtaining or acquiring.

20 The term “mixing” as used herein broadly refers to putting two or more separate components, which can be same or different such that they are not immediately or easily separable to their respective pre-mixed components. Mixing can be manually putting the components together or using a motorized device, for example, a mixer or a blender.

The term “micro” as used herein is to be interpreted broadly to include dimensions from about 1 micron to about 1000 microns.

25 The term “nano” as used herein is to be interpreted broadly to include dimensions less than about 1000 nm.

30 The term “particle” as used herein broadly refers to a discrete entity or a discrete body. The particle described herein can include an organic, or an inorganic particle. The particle used described herein may also be a macro-particle that is

formed by an aggregate of a plurality of sub-particles or a fragment of a small object. The particle of the present disclosure may be spherical, substantially spherical, or non-spherical, such as irregularly shaped particles or ellipsoidally shaped particles. The term "size" when used to refer to the particle broadly refers to the largest dimension of the particle. For example, when the particle is substantially spherical, the term "size" can refer to the diameter of the particle; or when the particle is substantially non-spherical, the term "size" can refer to the largest length of the particle.

The term "and/or", e.g., "X and/or Y" is understood to mean either "X and Y" or "X or Y" and should be taken to provide explicit support for both meanings or for either meaning.

Further, in the description herein, the word "substantially" whenever used is understood to include, but not restricted to, "entirely" or "completely" and the like. In addition, terms such as "comprising", "comprise", and the like whenever used, are intended to be non-restricting descriptive language in that they broadly include elements/components recited after such terms, in addition to other components not explicitly recited. Further, terms such as "about", "approximately" and the like whenever used, typically means a reasonable variation, for example a variation of +/- 5% of the disclosed value, or a variance of 4% of the disclosed value, or a variance of 3% of the disclosed value, a variance of 2% of the disclosed value or a variance of 1% of the disclosed value.

Furthermore, in the description herein, certain values may be disclosed in a range. The values showing the end points of a range are intended to illustrate a preferred range. Whenever a range has been described, it is intended that the range covers and teaches all possible sub-ranges as well as individual numerical values within that range. That is, the end points of a range should not be interpreted as inflexible limitations. For example, a description of a range of 1% to 5% is intended

to have specifically disclosed sub-ranges 1% to 2%, 1% to 3%, 1% to 4%, 2% to 3% etc., as well as individually, values within that range such as 1%, 2%, 3%, 4% and 5%. The intention of the above specific disclosure is applicable to any depth/breadth of a range.

5

Additionally, when describing some embodiments, the disclosure may have disclosed a method and/or process as a particular sequence of steps. However, unless otherwise required, it will be appreciated the method or process should not be limited to the particular sequence of steps disclosed. Other sequences of steps may be possible. The particular order of the steps disclosed herein should not be construed as undue limitations. Unless otherwise required, a method and/or process disclosed herein should not be limited to the steps being carried out in the order written. The sequence of steps may be varied and still remain within the scope of the disclosure.

15

DESCRIPTION OF EMBODIMENTS

Exemplary, non-limiting embodiments of an engineered soil composition, a method of preparing the engineered soil composition, and a water treatment system are disclosed hereinafter.

In various embodiments, an engineered soil composition is provided. The engineered soil composition may comprise a natural occurring soil component in an amount ranging from 30 wt% to 60 wt% of the total dry weight of the composition; a sand component in an amount ranging from 25 wt% to 55 wt% of the total dry weight of the composition; and a waste component in an amount of more than 0 wt% and no more than 15 wt% of the total dry weight of the composition, wherein a total amount of clay and silt derived from the natural occurring soil component is in an amount of more than 0 wt% and no more than

15 wt% of the total dry weight of the composition. In various embodiments, the natural occurring soil component, the sand component and the waste component are different from one another. The engineered soil may be for the use as a soil media to be placed inside a bioretention system, which may be referred to as a rain garden or a bioretention cell or a biofiltration system, or an equivalent such as exemplified in but not limited to a bioswale, a biostrip, a treatment pond, a green belt, or a stormwater treatment system.

In one embodiment, there is provided an engineered soil composition comprising a natural occurring soil component in an amount ranging from 30 wt% to 60 wt% of the total dry weight of the composition; a sand component in an amount ranging from 25 wt% to 55 wt% of the total dry weight of the composition; and a waste component in an amount of more than 0 wt% and no more than 15 wt% of the total dry weight of the composition, wherein a total amount of clay and silt in the composition is in an amount of more than 0 wt% and no more than 15 wt% of the total dry weight of the composition. For example, the amount of clay and silt may be derived from at least one of the natural occurring soil component or the waste component.

The natural occurring soil component in the amount ranging from 30 wt% to 60 wt% of the total dry weight of the composition may be, for example, but is not limited to a natural occurring soil component in an amount ranging from 30 wt% to 40 wt%, from 30 wt% to 50 wt%, from 35 wt% to 40 wt%, from 35 wt% to 45 wt%, from 35 wt% to 50 wt%, from 35 wt% to 55 wt%, from 35 wt% to 60 wt%, from 40 wt% to 45 wt%, from 40 wt% to 50 wt%, from 40 wt% to 55 wt%, from 40 wt% to 60 wt%, from 45 wt% to 50 wt%, from 45 wt% to 55 wt%, from 45 wt% to 60 wt%, from 50 wt% to 55 wt%, from 50 wt% to 60 wt%, or from 55 wt% to 60 wt% of the total dry weight of the composition. In one embodiment, the natural occurring soil component is in the amount ranging from 35 wt% to 55 wt% of the total dry weight of the composition. In some embodiments, the natural

occurring soil component may be about 85 wt%, or about 80 wt%, or about 75 wt%, or about 70 wt%, or about 65 wt% of the total dry weight of the composition, for example, where the natural occurring soil component may be sandy.

5

In various embodiments, the natural occurring soil component is derived from a top layer of soil that is no more than or less than 1.5 m from ground. The top layer of soil may be interchangeably referred to as top soil. It should be appreciated and understood that the ground described herein generally refers to a ground level that is substantially flat and is a surface layer of earth that may be influenced by plant roots, or may have been filled previously, and that the top layer of soil starts from the ground level to a depth of no more than 1.5 m underneath the ground level.

For example, the natural occurring soil component may be, but is not limited to being, derived from a top layer of soil that is no more than or less than 1.2 m, no more or less than 1.0 m, no more than or less than 0.5 m, or no more than or less than 0.2 m from the ground.

In various embodiments, the natural occurring soil component is derived from a site at which the engineered soil composition is to be used or from a site that contains suitable top soil that is available for use, for example, in a bioretention system. For example, the natural occurring soil component may be obtained or extracted from a project site for a bioretention system or an equivalent at which the engineered soil composition is to be used or is used. For the bioretention system or equivalent at which the engineered soil composition is used, the natural occurring soil component may also be referred to as in-situ soil.

The inclusion of the natural occurring soil component in the amount ranging from 30 wt% to 60 wt% of the total dry weight of the composition may

enable existing in-situ soil, for example, top soil, at or near the project site to be reused. For example, since the amount of existing soil reused may be as high as 60 wt%, there may be significant savings in terms of not having the need to buy new top soil and/or to transport the in-situ soil out of the site.

5

In another example, the natural occurring soil component may be obtained or extracted from a different project site for a bioretention system or an equivalent at which a soil composition different from the engineered soil composition, in accordance with various embodiments, is used or is to be used.

10

In yet another example, the natural occurring soil component may be obtained or extracted from any earth's surface containing organic material for plant growth that has not been hybridized or prepared by engineering technologies for the purpose of performing water treatment.

15

The sand component in the amount ranging from 25 wt% to 55 wt% of the total dry weight of the composition may be, for example, but is not limited to a sand component in an amount ranging from 25 wt% to 30 wt%, from 25 wt% to 35 wt%, from 25 wt% to 40 wt%, from 25 wt% to 45 wt%, from 25 wt% to 50 wt%, from 30 wt% to 35 wt%, from 30 wt% to 40 wt%, from 30 wt% to 45 wt%, from 30 wt% to 55 wt%, from 35 wt% to 40 wt%, from 35 wt% to 45 wt%, from 35 wt% to 50 wt%, from 45 wt% to 50 wt%, from 45 wt% to 55 wt%, or from 50 wt% to 55 wt% of the total dry weight of the composition. In one embodiment, the sand component is in the amount ranging from 30 wt% to 50 wt% of the total dry weight of the composition. In some embodiments, the sand component may be in an amount that is more than 0 wt% but no more than 50 wt% of the total dry weight of the composition. In one embodiment, the sand component may be 0 wt%, or about 10 wt%, or about 20 wt%, or about 30 wt% of the total dry weight of the composition.

30

In various embodiments, the sand component comprises sand particles having a particle size distribution in a range from 0.2 mm to 0.6 mm. For example, the sand component may be referred to as medium sand. For example, the sand component may comprise but is not limited to sand particles having a particle size distribution in a range from 0.2 mm to 0.6 mm, from 0.3 mm to 0.6 mm, from 0.4 mm to 0.6 mm, from 0.2 mm to 0.3 mm, from 0.2 mm to 0.4 mm, or from 0.3 mm to 0.4 mm.

In various embodiments, the sand component comprises sand particles that have been pre-washed and cleaned. For example, the sand particles may have been pre-washed and cleaned prior to inclusion into the engineered soil composition.

The inclusion of the sand component in the amount ranging from 25 wt% to 55 wt% of the total dry weight of the composition may enable use of sand in the engineering soil composition to be reduced. This may be significantly lower than the amount used in conventional bioretention systems. For example, the use of sand may be reduced from about 50 wt% of the weight of the typical soil mix to about 25 wt% of the total dry weight of the composition in accordance to various embodiments. In another example, the use of sand may be reduced from about 80 wt% of the weight of the typical soil mix to about 40 wt% of the total dry weight of the composition in accordance to various embodiments. The engineered soil composition may advantageously reduce the usage of sand in the composition by maximizing the reuse of existing in-situ soil at a site for a bioretention system or an equivalent at which the engineered soil composition is to be used or is used.

The waste component in the amount of more than 0 wt% and no more or less than 15 wt% of the total dry weight of the composition may be, for example,

but is not limited to a waste component in an amount ranging from 1 wt% to 15 wt%, from 1 wt% to 10 wt%, from 1 wt% to 5 wt%, from 3 wt% to 15 wt%, from 3 wt% to 10 wt%, from 3 wt% to 5 wt%, from 5 wt% to 15 wt%, from 5 wt% to 10 wt%, or from 10 wt% to 15 wt% of the total dry weight of the composition. In
5 some embodiments, the component is in the amount of less than 10 wt% of the total dry weight of the composition.

In one embodiment, the total amount of natural occurring soil component and sand component is about 85% of the total dry weight of the composition.

10 In various embodiments, the engineered soil composition is a substantially homogeneous mixture comprising the natural occurring soil component, the sand component, and the waste component. In various embodiments, the engineered soil composition further comprises an organic carbon-containing component that
15 is different from the natural occurring soil component, the organic carbon-containing component being present in an amount of more than 0 wt% and no more than or less than 35 wt% of the total dry weight of the composition. Therefore, in some embodiments, the engineered soil composition is a substantially homogeneous mixture comprising the natural occurring soil
20 component, the sand component, the waste component and the organic carbon-containing component.

The engineered soil composition in accordance with various embodiments, with its homogeneous mix of the various components may
25 advantageously provide for enhanced Total suspended solids (TSS) removal. For example, both Total Phosphorus (TP) and TSS removals may far exceed the typical removal requirements even from the initial operation phase of the engineering soil composition.

For example, the organic carbon-containing component may be, but is not limited to being, present in an amount ranging from 1 wt% to 34 wt%, from 5 wt% to 30 wt%, from 5 wt% to 25 wt%, from 5 wt% to 20 wt%, from 5 wt% to 15 wt%, from 5 wt% to 10 wt%, from 10 wt% to 34 wt%, from 10 wt% to 30 wt%, from 10 wt% to 25 wt%, from 10 wt% to 20 wt%, from 10 wt% to 15 wt%, from 15 wt% to 34 wt%, from 15 wt% to 30 wt%, from 15 wt% to 25 wt%, from 15 wt% to 20 wt%, from 20 wt% to 34 wt%, from 20 wt% to 30 wt%, from 20 wt% to 25 wt%, from 25 wt% to 34 wt%, from 25 wt% to 30 wt%, or from 30 wt% to 34 wt% of the total dry weight of the composition. In some embodiments, the organic carbon-containing component is present in an amount ranging from 5 wt% to 30 wt% of the total dry weight of the composition.

In various embodiments, the organic carbon-containing component comprises a plant-based compost. For example, the plant-based compost may contain humic acids.

In various embodiments, the plant-based compost is selected from the group consisting of coconut fibres, palm fibres, rice husk, jute fibres, wood chips and mixtures thereof.

For example, the types of organic carbon-containing component may affect the hydraulic conductivity. Fibreous carbon sources may help to maintain the structure of the engineered soil component, therefore providing / maintaining good hydraulic conductivity of the engineered soil composition (or mix).

In various embodiments, the waste component is derived from a water treatment plant. The water treatment plant may be different from a bioretention system or equivalent. For example, the water treatment plant may include a septic tank for holding an influent to be treated and a treatment tank such as exemplified in an absorption tank coupled in series to the septic tank. The water

treatment plant may be an industrialized apparatus different from a hybridized system such as a bioretention system as described herein.

In various embodiments, the waste component comprises particles having grain sizes in a range from 0.10 mm to 1.20 mm. For example, the waste component may comprise particles having grain sizes in a range from 0.10 mm to 0.25 mm, from 0.10 mm to 0.50 mm, from 0.10 mm to 0.75 mm, from 0.10 mm to 1.00 mm, from 0.25 mm to 0.50 mm, from 0.25 mm to 0.75 mm, from 0.25 mm to 1.00 mm, from 0.25 mm to 1.20 mm, from 0.50 mm to 0.75 mm, from 0.50 mm to 1.00 mm, from 0.50 mm to 1.20 mm, from 0.75 mm to 1.00 mm, from 0.75 mm to 1.20 mm, or from 1.00 mm to 1.20 mm. In some embodiments, the waste component comprises particles having grain sizes in a range from 0.15 mm to 1.18 mm.

In various embodiments, the waste component comprises water treatment residues. The term "water treatment residue" may be interchangeably referred to as water treatment residual or abbreviated as WTR. For example, WTR may be obtained from a water treatment plant. In some embodiments, the WTR are in the form of pellets.

Without being bound by theory, it is believed that the waste component with different sizes or different size ranges may affect the 'lifespan' of the waste component. For example, smaller sizes relate to large surface area-to-volume ratios and therefore this may provide for larger surface areas for dissolved phosphates to adsorb as compared to a larger WTR size. The particle size of WTR may depend largely on the grinding method. For example, long durations of grinding may result in large amounts of fines. In various embodiments, the size of WTR is controlled. For example, the waste component may comprise particles having grain sizes in the range of 0.10 mm to 1.20 mm may be considered as having no fine material.

For example, WTR may be obtained from a water treatment plant managed by the Public Utilities Board (Singapore). For example, the WTR may comprise aluminium-based or ferric-based components. The active component
5 of the WTR may be aluminium hydroxide or ferric hydroxide which provides adsorption of dissolved phosphates.

The inclusion of the waste component in the amount of more than 0 wt% and no more or less than than 15 wt% of the total dry weight of the composition
10 may enable waste material, including and not limited to WTR from water treatment plants to be reused.

Waste material such as WTR may be specially added as an amendment into the engineered soil composition in accordance to various embodiments at a
15 specified weight percentage so as to provide for enhanced Total Phosphorus (TP) removal.

In various embodiments, the engineered soil composition is capable of removing no less than or more than 45% of TP from a TP-containing influent
20 water stream passing through the engineered soil composition. For example, the engineered soil composition may be capable of removing from 45% to 100% of TP, from 45% to 90% of TP, from 45% to 80% of TP, from 45% to 70% of TP, from 45% to 60% of TP, from 45% to 50% of TP, from 50% to 100% of TP, from 50% to 90% of TP, from 50% to 80% of TP, from 50% to 70% of TP, from 50% to
25 60% of TP, from 60% to 100% of TP, from 60% to 90% of TP, from 60% to 80% of TP, from 60% to 70% of TP, from 70% to 100% of TP, from 70% to 90% of TP, from 70% to 80% of TP, from 80% to 100% of TP, from 80% to 90% of TP, from 90% to 100% of TP from a TP-containing influent water stream. In one embodiment, the engineered soil composition is capable of removing no less

than or more than 92% of TP from a TP-containing influent water stream passing through the engineered soil composition.

WTR (for example, with grain size of between 0.1 mm to 1.2 mm) may provide for intrinsically high surface-area-to-volume ratio, hence providing superior adsorption capabilities. The grain size may have been optimized to provide sufficient surface-area for adsorption while maintaining a desired hydraulic conductivity of the entire engineered soil composition. For example, waste materials (such as WTR) enhance dissolved phosphate removal via adsorption. Particulate phosphorus may also be removed via the filtration and sorption mechanism. This advantageously results in an added overall TP removal from polluted stormwater runoff and cleaner filtered effluent entering drains/waterways. With the higher surface-area-to-volume ratio provided by WTR, it may provide for higher amounts of dissolved phosphate removal which hence may increase the lifespan of the bioretention system in terms of satisfying the guidelines for phosphorus removal.

TP removal by a mix without waste materials amendment may gradually reduce over time as the volume of runoff filtered increases due to the saturation of adsorption sites on sand or soil particles. In contrast, the engineered soil composition in accordance with various embodiments amended with a specific percentage (e.g. 10%) of WTR may have sustained TP removal at more than 90% over a predetermined period of time.

In one example, secondary effluent from wastewater treatment plants may be used to pass through the engineered soil composition in accordance with various embodiments amended with a specific percentage (e.g. 10%) of WTR. Such secondary effluent possesses TP concentrations of at least 2 times that of typical stormwater runoff. Despite the high concentrations of TP associated, the

engineered soil composition in accordance with various embodiments amended with 10% WTR displays significant TP removal of more than 80%.

5 In various embodiments, the amount of WTR is limited to 10%, as higher percentage of WTR may result in leaching of other compounds that is existed in the WTR, such as aluminum.

10 In another example, baseline stormwater runoff may be collected to test the efficacy of the engineered soil composition in accordance with various embodiments in pollutant removal. Dissolved phosphate and total suspended solids may be spiked or added into the baseline stormwater runoff so as to reflect typical concentrations present in urban stormwater runoff, for example, in Singapore. The engineered soil composition in accordance with various
15 embodiments enables high TP removals of more than 83%, more specifically, averaging at 89%. With relatively high adsorptive capacity provided by the presence of WTR, 100% dissolved phosphate may be removed via adsorption while particulate removal by the engineered soil composition in accordance with various embodiments may dictate changes in overall TP removal.

20 The total amount of clay and silt from the natural occurring soil component being in the amount of more than 0 wt% and no more than or less than 15 wt% of the total dry weight of the composition may be, for example, but is not limited to a total amount of clay and silt in the composition being in an amount ranging from 1 wt% to 15 wt%, from 1 wt% to 10 wt%, from 1 wt% to 5 wt%, from 3 wt%
25 to 15 wt%, from 3 wt% to 10 wt%, from 3 wt% to 5 wt%, from 5 wt% to 15 wt%, from 5 wt% to 10 wt%, or from 10 wt% to 15 wt% of the total dry weight of the composition.

In various embodiments, the total amount of silt and sand (for example, fine sand) is in an amount of no less than or more than 30 wt% of the natural occurring soil component.

5 For example, the clay and the silt may separately or collectively be referred to as fines.

In various embodiments, the clay, or the silt or both have a particle size distribution of no more than or less than 0.080 mm. For example, the clay, or the silt or both may have a particle size distribution ranging from 0.020 mm to 0.075
 10 mm, from 0.020 mm to 0.070 mm, from 0.020 mm to 0.065 mm, from 0.020 mm to 0.060 mm, from 0.020 mm to 0.055 mm, from 0.020 mm to 0.050 mm, from 0.020 mm to 0.045 mm, from 0.020 mm to 0.040 mm, from 0.020 mm to 0.035 mm, from 0.020 mm to 0.025 mm, from 0.025 mm to 0.075 mm, from 0.025 mm to 0.070 mm, from 0.025 mm to 0.065 mm, from 0.025 mm to 0.060 mm, from
 15 0.025 mm to 0.055 mm, from 0.025 mm to 0.050 mm, from 0.025 mm to 0.045 mm, from 0.025 mm to 0.040 mm, from 0.025 mm to 0.035 mm, from 0.030 mm to 0.075 mm, from 0.030 mm to 0.070 mm, from 0.030 mm to 0.065 mm, from 0.030 mm to 0.060 mm, from 0.030 mm to 0.055 mm, from 0.030 mm to 0.050 mm, from 0.030 mm to 0.045 mm, from 0.030 mm to 0.040 mm, from 0.030 mm
 20 to 0.035 mm, from 0.035 mm to 0.075 mm, from 0.035 mm to 0.070 mm, from 0.035 mm to 0.065 mm, from 0.035 mm to 0.060 mm, from 0.035 mm to 0.055 mm, from 0.035 mm to 0.050 mm, from 0.035 mm to 0.045 mm, from 0.035 mm to 0.040 mm, from 0.040 mm to 0.075 mm, from 0.040 mm to 0.070 mm, from 0.040 mm to 0.065 mm, from 0.040 mm to 0.060 mm, from 0.040 mm to 0.055 mm,
 25 mm, from 0.040 mm to 0.050 mm, from 0.040 mm to 0.045 mm, from 0.045 mm to 0.075 mm, from 0.045 mm to 0.070 mm, from 0.045 mm to 0.065 mm, from 0.045 mm to 0.060 mm, from 0.045 mm to 0.055 mm, from 0.045 mm to 0.050 mm, from 0.050 mm to 0.075 mm, from 0.050 mm to 0.070 mm, from 0.050 mm to 0.065 mm, from 0.050 mm to 0.060 mm, from 0.050 mm to 0.055 mm, from
 30 0.055 mm to 0.075 mm, from 0.055 mm to 0.070 mm, from 0.055 mm to 0.065

mm, from 0.055 mm to 0.060 mm, from 0.060 mm to 0.075 mm, from 0.060 mm to 0.070 mm, from 0.060 mm to 0.065 mm, from 0.065 mm to 0.075 mm, or from 0.065 mm to 0.070 mm. In some embodiments, the clay, or the silt or both have a particle size distribution of no more than or less than 0.063 mm. In other
5 embodiments, the clay, or the silt or both have a particle size distribution of no more than or less than 0.075 mm.

For example, the clay and the silt may relate to the mineralogy of the soil particle, and the size of the particle. Clay may be, for example, any particle
10 smaller than 0.002 mm, and silt may be, for example, any particle between 0.002 mm to 0.075 mm.

In the engineered soil composition in accordance with various embodiments, the percentage of fines (silt and clay) may be capped at 15 wt% of
15 the total dry weight of the composition). These fines may be, for example, the existing components in the in-situ soil or top soil in Singapore.

In various embodiments, the engineered soil composition is capable of removing no less than or more than 80% of Total suspended solids (TSS) from a
20 TSS-containing influent water stream passing through the engineered soil composition. For example, TSS may be the suspended solids retained on a 2.0 µm glass fibre filter, dried to constant weight at about 103 – 105 °C. In other words, the engineered soil composition in accordance with various embodiments, for example, may achieve TSS removal far exceeds the TSS
25 requirements of more than 80% removal or TSS in treated water being less than 10 ppm (for about 90% of storm events). For example, the engineered soil composition may be capable of achieving TSS removals of more than 92%, averaging at about 96% where an influent runoff has TSS concentrations ranging from 44 to 90 ppm. TSS concentrations in the filtrate emerging from the

engineered soil composition in accordance with various embodiments may be in the range of 1 to 8.5 ppm, averaging at a relatively low level of about 2.2 ppm.

The use of in-situ soil / top soil with about 10 wt% of fines may be advantageous for Total Nitrogen (TN) removal. For example, enhanced TN as well as enhancement of TP removal may be achieved using the engineered soil composition in accordance with various embodiments with about an additional 5 wt% of silts as compared to a similar soil mix without the presence of silt.

In various embodiments, the engineered soil composition is capable of removing no less than or more than 45% of TN from a TN-containing influent water stream passing through the engineered soil composition. In one embodiment, the engineered soil composition is capable of removing about 68.8% of TN from a TN-containing influent water stream passing through the engineered soil composition.

For example, despite the presence of compost, WTR and sand, an additional 5 wt% fines in the engineered soil composition may provide for enhanced TN removal due to the removal of nitrates. Nitrates emerging from the engineered soil composition with about 5 wt% fines averaged at about 0.03 ppm in contrast to about 0.22 ppm from the soil mix without any fines. Consequently, the respective average TN removals may be, for example, about 41% and about 67%, respectively for the soil mix without fines and the engineered soil composition with about 5% fines addition.

Due to the complexities of TN due to its wide variety of speciation as ammonium, nitrites, nitrates and organic nitrogen, removal of TN on the whole may be relatively challenging. However, without being bound by theory, it is believed that with the presence of substantially small amounts of fines (for example, no more than 10 wt% of the composition), anoxic pockets formed

within the soil column, coupled with the presence of organic matter from the compost, may constitute suitable environments for conversion of nitrates to nitrogen gas, which is referred to as denitrification. Denitrification mediated by denitrifying bacteria, may therefore lead to a reduction in TN concentration as the nitrates may be converted to nitrogen gas which is removed from a system comprising the engineered soil composition in accordance with various embodiments.

Unlike the significant (high) TSS and TP removal from the initial operation phase of the engineered soil composition in accordance with various embodiments, initial TN removals may not be evident. This may be due to a natural phenomenon in most water treatment systems whereby nitrate leaching may be typically predominant. However, without being bound by theory, it is believed that with the presence of anoxic micropockets within the engineered soil composition and the subsequent development of denitrifying bacteria, denitrification may enhance overall TN removal. Initial leaching of TN may be subsequently characterized by gradual reductions in TN concentrations in the effluent as runtime increases. The presence of fines may be crucial during the dry periods where nitrate leaching, which relates to reduced TN removal may be intensified during the first rainfall following prolonged dry period. With the presence of fines creating anoxic submerged micro-pockets within the engineered soil composition, continual denitrification may still take place during dry weather.

For example, the organic carbon-containing component may include any other carbon sources.

In various embodiments, each of the components, that is each of the natural occurring soil component, the sand component, and the waste component, is derived from a different source.

In various embodiments, each of the components, that is each of the natural occurring soil component, the sand component, the waste component, and the organic carbon-containing component, is derived from a different source.

5

For example, the natural occurring soil component may be derived from a site for a bioretention system or equivalent at which the engineered soil component may or may not be used. The sand component may be imported or retrieved from a river bank. The waste component may be obtained from a water
10 treatment plant, for example, managed by the PUB (Singapore). The organic carbon-containing component may be obtained, for example, from a plantation or other agricultural processes.

The engineered soil composition in accordance with various embodiments
15 is capable of consistent performance in terms of maintaining desirable levels of hydraulic conductivity, sustaining healthy plant growth and achieving water quality improvement requirements.

In one embodiment, the engineered soil composition has a hydraulic
20 conductivity of no less than or more than 20 mm/hr.

In another embodiment, the engineered soil composition has a hydraulic conductivity in a range from 50 mm/hr to 500 mm/hr.

25 In a different embodiment, the engineered soil composition has a hydraulic conductivity in a range from 50 mm/hr to 200 mm/hr.

In yet another embodiment, the engineered soil composition has a hydraulic conductivity in a range from 200 mm/hr to 400 mm/hr.

30

For example, the engineered soil composition may have a hydraulic conductivity in a range from 20 mm/hr to 100 mm/hr, from 30 mm/hr to 150 mm/hr, from 40 mm/hr to 250 mm/hr, from 50 mm/hr to 300 mm/hr, from 50 mm/hr to 350 mm/hr, from 50 mm/hr to 400 mm/hr, from 50 mm/hr to 450 mm/hr, from 100 mm/hr to 150 mm/hr, from 100 mm/hr to 200 mm/hr, from 100 mm/hr to 250 mm/hr, from 100 mm/hr to 300 mm/hr, from 100 mm/hr to 350 mm/hr, from 100 mm/hr to 400 mm/hr, from 100 mm/hr to 450 mm/hr, from 100 mm/hr to 500 mm/hr, from 150 mm/hr to 200 mm/hr, from 150 mm/hr to 250 mm/hr, from 150 mm/hr to 300 mm/hr, from 150 mm/hr to 350 mm/hr, from 150 mm/hr to 400 mm/hr, from 150 mm/hr to 450 mm/hr, from 150 mm/hr to 500 mm/hr, from 200 mm/hr to 250 mm/hr, from 200 mm/hr to 300 mm/hr, from 200 mm/hr to 350 mm/hr, from 250 mm/hr to 300 mm/hr, from 250 mm/hr to 350 mm/hr, from 250 mm/hr to 400 mm/hr, from 250 mm/hr to 450 mm/hr, from 250 mm/hr to 500 mm/hr, from 300 mm/hr to 350 mm/hr, from 300 mm/hr to 400 mm/hr, from 300 mm/hr to 450 mm/hr, from 300 mm/hr to 500 mm/hr, from 350 mm/hr to 400 mm/hr, from 350 mm/hr to 450 mm/hr, from 350 mm/hr to 500 mm/hr, from 400 mm/hr to 450 mm/hr, from 400 mm/hr to 500 mm/hr, or from 450 mm/hr to 500 mm/hr.

For example, the engineered soil composition may have a specified hydraulic conductivity range. For example, the range of hydraulic conductivity of an engineered soil composition for use in Singapore and Australia may be between 50 to 200 mm/hr.

The engineered soil composition in accordance with various embodiments meets the specified requirements of 50 to 200 mm/hr for hydraulic conductivity. This may be important as use of such engineered soil composition generally affects both plant growth and pollutant removal.

A significantly high hydraulic conductivity, for example, of more than 500 mm/hr may consequently lead to poorer pollutant removal and poor plant growth due to rapid draining of moisture from the surface of a soil mix into subsoil drainage pipes and groundwater.

5

With the rapid infiltration of runoff through the soil mix, the retention of TSS may highly likely be reduced and nitrate removal may be minimized using such a free-draining soil. Likewise, dissolved phosphate adsorption may also be hindered due to insufficient contact time with the soil media.

10

However on the other hand, an significantly low hydraulic conductivity, for example, of less than 20 mm/hr may promote pollutant (TSS, TN and TP) removal but may lead to damages to plant roots due to prolonged wetting period of the soil.

15

The engineered soil composition of various embodiments uniquely and advantageously performs consistent in striking a balance for appropriate pollutant removal and healthy plant growth.

20

In various embodiments, the engineered soil composition has a pH level in a range from 5.5 to 8.5. This allows for suitable plant growth.

For example, the engineered soil composition may have but is not limited to having a pH level in a range from 5.5 to 8.5, from 5.5 to 8, from 5.5 to 7.5, from 5.5 to 7, from 5.5 to 6.5, from 5.5 to 6, from 6 to 8.5, from 5.5 to 8, from 6 to 7.5, from 6 to 7, from 6 to 6.5, from 6.5 to 8.5, from 6.5 to 8, from 6.5 to 7.5, from 6.5 to 7, from 7 to 8.5, from 7 to 8, from 7 to 7.5, from 7.5 to 8.5, from 7.5 to 8, or from 8 to 8.5.

In various embodiments, the engineered soil composition has an electrical conductivity of no less than or more than 0.1 mS/cm, and and not more than 0.3

30

mS/cm. Electrical conductivity (EC) of a solution is a measure of the ability of the solution to conduct electricity. For example, when ions (salts) are present in the solution, the EC of the solution increases. For example, the engineered soil composition may have an electrical conductivity ranging from 0.1 mS/cm to 0.3 mS/cm, 0.1 mS/cm to 0.2 mS/cm, or from 0.2 mS/cm to 0.3 mS/cm.

In various embodiments, the engineered soil composition is capable of supporting growth of one or more plant species.

The engineered soil composition in accordance with various embodiments has a predetermined amount of organic content, which is important for plant growth. The engineered soil composition demonstrates capacity to sustain plant growth.

In various embodiments, the one or more plant species is selected from the group consisting of *Clerodendrum inerme*, *Codiaeum variegatum*, *Cordyline fruticosa*, *Iris domestica*, *Murraya paniculata*, *Ophiopogon jaburan*, *Premna serratifolia*, *Sanchezia oblonga*, *Scaevola taccada*, *Sphagneticola trilobata*, *Syzygium myrtifolium*, *Tarenna odorata*, and *Trimezia steyermarkii*.

For example, the one or more plant species may be *Cordyline fruticosa* 'Firebrand'.

One of the indicators that may show a healthy plant growth is a Soil Plant Analysis Development (SPAD) value. The SPAD value, which is a measure of the greenness of leaves, and is related to chlorophyll content.

In various embodiments, the engineered soil composition is capable of supporting growth of one or more plant species such that the chlorophyll content

SPAD value index of the one or more plant species during growth indicates healthy plant growth.

The maintenance or increase in SPAD values of the leaves over time is an indication of healthy leaves and hence healthy plant growth. Over the course of growth in the engineered soil composition of various embodiments, the SPAD values of *Iris domestica* and *Trimezia steyermarkii* using the engineered soil composition increased over time while that for *Cordyline fruticosa* 'Firebrand' remained relatively constant. The engineered soil composition of various embodiments does not negatively affect plant growth and plant health. In various embodiments, the engineered soil composition is capable of maintaining healthy plant growth in a bioretention system.

Another indication that may be used to determine whether or not the plants are stressed or growing unhealthily is the photochemical efficiency of photosynthesis (for example, the maximum quantum yield of photosystem II).

In various embodiments, the engineered soil composition is capable of supporting growth of one or more plant species such that the plant stress F_v/F_m ratio of the one or more plant species during growth is from 0.79 to 0.84.

For example, the plant stress F_v/F_m ratio of the one or more plant species during growth may be from 0.79 to 0.80, from 0.79 to 0.81, from 0.79 to 0.82, from 0.79 to 0.83, from 0.80 to 0.81, from 0.80 to 0.82, from 0.80 to 0.83, from 0.80 to 0.84, from 0.81 to 0.82, from 0.81 to 0.83, from 0.81 to 0.84, from 0.82 to 0.83, from 0.82 to 0.84, or from 0.83 to 0.84.

For example, F_v/F_m allows determination of whether or not plant stress affects photosystem II (or water-plastoquinone oxidoreductase) in a dark adapted state. F_v/F_m ratios of 0.79 to 0.84 are indications of unstressed plants. Based on

respective SPAD values and Fv/Fm ratios, *Cordyline fruticosa* 'Firebrand', *Iris domestica*, and *Trimezia steyermarkii* plants display healthy growth in the engineered soil composition in accordance with various embodiments. Fv/Fm ratios of plants obtained throughout its growth in the engineered soil composition of various
5 embodiments may be averaged at about 0.8.

Various embodiments may provide an engineered soil composition for use in a bioretention system or equivalent to provide consistent performance of a bioretention system or equivalent in terms of the hydraulic conductivity and water
10 quality improvement.

For example, besides providing nutrients in sustaining healthy plant growth, the engineered soil composition in accordance to various embodiments provides sufficient filtration and nutrient removing capabilities. This is an important factor
15 particularly for the engineered soil composition to act as a filter media of a bioretention system or equivalent.

A bioretention system has a primary function of serving as a nonpoint source treatment for pollutant removal from stormwater runoff before it enters local
20 waterways. The filter media, for example, the engineered soil composition of various embodiments plays the dominant role in pollutant removal. The engineered soil composition of various embodiments may include various components constituting specific functions for pollutant removal from stormwater runoff. The engineered soil composition of various embodiments may be a homogeneous mix, therefore, as a
25 whole, may provide significantly high level of filtration function and significantly high level of removal capabilities of various pollutant (e.g. Total suspended solids TSS, Total Nitrogen TN, and Total Phosphorus TP) as described herein with reference to specific examples. The engineered soil composition of various embodiments may allow significantly high level of removal of the pollutants, therefore minimizing
30 negative impacts on receiving waterbodies/reservoirs. The engineered soil

composition of various embodiments may be appropriate for use particularly in tropical climates such as Singapore with average annual rainfall of more than 2,300 mm.

5 The engineered soil composition of various embodiments, with reduced amount of sand needed, coupled with the re-use of existing in-situ soil and the reuse of waste material (for e.g.WTR) may substantially minimize the cost of the engineered soil composition. In addition, under normal circumstances, waste materials such as WTR from water treatment plants typically have to be treated and
10 disposed off into landfills with cost. Therefore, reusing waste materials such as WTR reduces the overall costs and the amount of waste disposed off into the landfill, which in turn, enhances and contributes towards environmental friendliness.

15 One particular example of the engineered soil at a site with in-situ soil including or consisting of more than 30% of silt and sand, and having a desired output, for example, in terms of hydraulic conductivity being more than 50 mm/hr may include or consist of the following:-

- 20 (a) sand – 30% to 50% of total dry weight of the composition
- (b) in-situ soil – 35% to 55% of total dry weight of the composition
- (c) water treatment residual (WTR) – less than 10% of total dry weight of composition; and
- (d) compost – 5% of total dry weight of the composition.

25 Various embodiments may provide an engineered soil composition consisting essentially of or consisting of a natural occurring soil component in an amount ranging from 35 wt% to 55 wt% of the total dry weight of the composition; a sand component in an amount ranging from 30 wt% to 50 wt% of the total dry weight of the composition; a water treatment residue component in an amount of more than 0
30 wt% and less than 10 wt% of the total dry weight of the composition; and an organic

carbon-containing component in an amount of more than 0 wt% and less than 10 wt% of the total dry weight of the composition, wherein a total amount of clay and silt in the composition is in an amount of more than 0 wt% and no more than 10 wt% of the total dry weight of the composition.

5

Various embodiments may provide a method of producing the engineering soil composition as described herein to provide consistent performance of a bioretention system or equivalent in terms of hydraulic conductivity and water quality improvement. Various embodiments of the method disclosed herein may allow the engineered soil composition to be prepared while adhering to parameters provided in guidelines, for example, in terms of the range of hydraulic conductivity of the engineered soil composition for use in Singapore being between 50 to 200 mm/hr.

10

15

Various embodiments provide a method of preparing an engineered soil composition for use in a bioretention system or equivalent, the method involving at least four major considerations, which are as described hereinabove:-

(a) reusing of available top soil / insitu soil;

20

(b) reduction of amount of sand;

(c) reuse of waste material, including but not limited to water treatment residual (WTR); and

25

(d) addition of other components for carbon sources, including but not limited to compost and/or coconut fibres and/or palm fibres and/or rice husk and/or jute fibres and/or woodchips and/or any other carbon sources.

The method may also involve providing flexibility of determining an appropriate or optimum use of various components according to the available top soil / in-situ soil properties, which maybe varied at different sites.

5 Further, the method may enable flexibility of determining an appropriate or optimum proportion of various components to achieve the site specific hydraulic conductivity and water retention capability, in order to further support plant growth and optimize water quality improvement, according to the specific weather and runoff characteristic at the site.

10

The method may also allow flexibility of determining an appropriate or optimum percentage and type of carbon source components, to suit the water quality improvement required, with respect to the variation of water quality of incoming flow of the bioretention system or equivalent.

15

Various embodiments provide a method of preparing an engineered soil composition, the method comprising determining a desired hydraulic conductivity range for the engineered soil composition to be obtained; obtaining an amount of natural occurring soil from a source; determining a measure of silt and/or clay
20 present in the amount of natural occurring soil from the source; based on the determined measure of silt and/or clay, mixing the natural occurring soil obtained from the source in an amount ranging from 30 wt% to 60 wt% of the total dry weight of the composition with, a sand component in an amount ranging from 30 wt% to 50 wt% of the total dry weight of the composition, and with a waste component in an
25 amount of more than 0 wt% and no more than 15 wt% of the total dry weight of the composition to form the engineered soil composition, such that the total amount of clay and silt from the natural occurring soil is in an amount of more than 0 wt% and no more than 15 wt% of the total dry weight of the engineered soil composition and wherein the engineered soil composition has a hydraulic conductivity value within the
30 desired hydraulic conductivity range.

For example, the engineering soil composition may be described in the context of the engineering soil composition in accordance with various embodiments as described herein.

5

The terms “natural occurring soil”, “sand component”, “waste component”, “silt”, “clay” and “hydraulic conductivity value” may comprise one or more characteristics as described above.

10

In an embodiment, the engineered soil composition obtained from the mixing step is a substantially homogeneous mixture of the natural occurring soil, the sand component, and the waste component.

15

In various embodiments, the step of mixing the natural occurring soil with the sand component and the waste component further comprises mixing the natural occurring soil, the sand component and the waste component with an organic carbon-containing component in an amount of more than 0 wt% and no more than 35 wt% of the total dry weight of the composition.

20

The term “organic carbon-containing component” may comprise one or more characteristics as described above.

25

In various embodiments, the organic carbon-containing component comprises a plant-based compost.

In various embodiments, the plant-based compost is selected from the group consisting of coconut fibres, palm fibres, rice husk, jute fibres, wood chips and mixtures thereof.

In various embodiments, the desired hydraulic conductivity range is at or within a range from 50 mm/hr to 500 mm/hr. The desired hydraulic conductivity may be determined by a scientific professional in accordance to requirements of, for example, a bioretention system or equivalent.

5

In various embodiments, the method further comprises prior to the mixing step, the step of determining a desired pH range for the engineered soil composition to be obtained such that the mixing step forms the engineered soil composition having a pH value within the desired pH range.

10

In various embodiments, the desired pH range is at or within a range from 5.5 to 8.5. The desired pH range may be determined by a scientific professional in accordance to requirements of, for example, a bioretention system or equivalent.

15

In various embodiments, the method further comprises the step of determining a desired electrical conductivity limit for the engineered soil composition prior to the mixing step such that the mixing step forms the engineered soil composition having an electrical conductivity value not more than the desired electrical conductivity limit.

20

In various embodiments, the desired electrical conductivity limit is 0.1 mS/cm. The desired electrical conductivity limit may be determined by a scientific or engineering professional in accordance to requirements of, for example, a bioretention system or equivalent to perform water treatment in a safe manner.

25

In various embodiment, the step of determining the desired hydraulic conductivity range for the engineered soil composition to be obtained comprises determining at least one of a desired removal rate of Total Suspended Solids (TSS), a desired removal rate of Total Nitrogen (TN) or a desired removal rate of Total

Phosphorus (TP) from an influent water stream passing through the engineered soil composition.

5 In various embodiments, the clay, or the silt or both have a particle size distribution of no more than 0.075 mm.

In various embodiments, the natural occurring soil is derived from a top layer of soil that is no more than 1.5 m from ground.

10 In various embodiments, the natural occurring soil is derived from a site at which the engineered soil composition is to be used.

15 In various embodiments, the sand component comprises sand particles having a particle size distribution in a range from 0.2 mm to 0.6 mm.

In various embodiments, the method further comprises prior to the mixing step, providing sand particles; and washing and cleaning the sand particles to form the sand component.

20 In various embodiments, the waste component comprises water treatment residues.

The term "water treatment residues" may comprise one or more characteristics as described above.

25 In various embodiments, the method further comprises prior to the mixing step, the steps of providing a waste material having particles therein; and sieving the waste material to obtain the waste component having particle grain sizes in a range from 0.10 mm to 1.20 mm.

30

In one embodiment, the method further comprises prior to the sieving step, the step of pulverizing the waste material. For example, the waste material may be grinded or crushed to an average size of about 0.1 mm, about 0.2 mm, about 0.3 mm, about 0.4 mm, or about 0.5 mm. In some examples, a predetermined
5 percentage of the waste material may be grinded or crushed to an average size of less than 0.075 mm.

Various embodiments provide a water treatment system comprising an engineered soil composition capable of simultaneously supporting plant growth and
10 filtering stormwater. For example, the engineering soil composition may be described in the context of the engineering soil composition in accordance with various embodiments as described herein.

For example, the water treatment system may support plant growth and filter
15 stormwater at the same time. In another example, the water treatment system having the capability of filtering stormwater may support plant growth or the water treatment system having the capability of supporting plant growth may filter stormwater.

In various embodiments, the water treatment system is a bioretention system
20 or a rain garden.

BRIEF DESCRIPTION OF FIGURES

25 Fig. 1A is a flowchart of a method of preparing an engineered soil composition in accordance with some embodiments disclosed herein.

Fig. 1B is a flowchart of a method of preparing an engineered soil composition in accordance with other embodiments disclosed herein.

Fig. 2A is a perspective view of an apparatus for determining the percentage of fines and the hydraulic conductivity of in-situ soil.

Fig. 2B is a front view of Fig. 2A.

5

Fig. 3 is a graph showing the removal efficiency of Total Suspended Solids (TSS) in a bioretention soil column comprising an engineered soil composition Mix 1 in accordance with one embodiment disclosed herein.

10

Fig. 4 is a graph showing the effluent concentration of TSS in a bioretention soil column comprising an engineered soil composition Mix 1 in accordance with one embodiment disclosed herein.

15

Fig. 5 is a graph showing the removal efficiency of Total Nitrogen (TN) in a bioretention soil column comprising an engineered soil composition Mix 1 in accordance with one embodiment disclosed herein.

20

Fig. 6 is a graph showing the effluent concentration of TN in a bioretention soil column comprising an engineered soil composition Mix 1 in accordance with one embodiment disclosed herein.

25

Fig. 7 is a graph showing the removal efficiency of Total Phosphorus (TP) in a bioretention soil column comprising an engineered soil composition Mix 1 in accordance with one embodiment disclosed herein.

Fig. 8 is a graph showing the effluent concentration of TP in a bioretention soil column comprising an engineered soil composition Mix 1 in accordance with one embodiment disclosed herein.

Fig. 9 is a graph showing the removal efficiency of TSS in a bioretention soil column comprising an engineered soil composition Mix 2 in accordance with one embodiment disclosed herein.

5 Fig. 10 is a graph showing the effluent concentration of TSS in a bioretention soil column comprising engineered soil composition Mix 2 in accordance with one embodiment disclosed herein. Wet period condition is simulated here.

10 Fig. 11 is a graph showing the effluent concentration of TSS in a bioretention soil column comprising engineered soil composition Mix 2 in accordance with one embodiment disclosed herein. Dry period condition is simulated here.

15 Fig. 12 is a graph showing the removal efficiency of TN in a bioretention soil column comprising an engineered soil composition Mix 2 in accordance with one embodiment disclosed herein.

20 Fig. 13 is a graph showing the effluent concentration of TN in a bioretention soil column comprising engineered soil composition Mix 2 in accordance with one embodiment disclosed herein. Wet period condition is simulated here.

Fig. 14 is a graph showing the effluent concentration of TN in a bioretention soil column comprising engineered soil composition Mix 2 in accordance with one embodiment disclosed herein. Dry period condition is simulated here.

25 Fig. 15 is a graph showing the removal efficiency of TP in a bioretention soil column comprising an engineered soil composition Mix 2 in accordance with one embodiment disclosed herein.

Fig. 16 is a graph showing the effluent concentration of TP in a bioretention soil column comprising engineered soil composition Mix 2 in accordance with one embodiment disclosed herein. Wet period condition is simulated here.

Fig. 17 is a graph showing the effluent concentration of TP in a bioretention soil column comprising engineered soil composition Mix 2 in accordance with one embodiment disclosed herein. Dry period condition is simulated here.

DETAILED DESCRIPTION OF FIGURES

Referring to Fig. 1A, there is shown a flow chart 100 of a method of preparing an engineered soil composition in accordance with various embodiments. In 102, a desired hydraulic conductivity range is determined for the engineered soil composition to be obtained. In 104, an amount of natural occurring soil is obtained from a source. In 106, the composition of silt and/or clay present in the amount of natural occurring soil from the source is determined. In 108, the natural occurring soil obtained from the source is mixed with a sand component and a waste component such that the total amount of clay and silt derived from the naturally occurring soil is in an amount of more than 0% and no more than 15 wt% of the total dry weight of the engineered soil composition and wherein the engineered soil composition has a hydraulic conductivity value within the desired range.

Referring to Fig. 1B, there is shown a flow chart 120 of a method of preparing an engineered soil composition in accordance with another embodiment. In 122, a catchment area of which the water is required to be treated by a bioretention system is determined. This may be broadly classified into urban and sub-urban. For urban classification, the catchment area may be further divided into roof run-off and road run-off. For sub-urban classification, the catchment area may be natural (or of the nature). In 124, an amount of water sample is collected from the catchment area and the pollutant load level in the sample is determined to establish the runoff quality

of the catchment area. For example, the types of pollutants may include TSS, TN and TP. In 126, the requirement of the hydraulic conductivity is determined based on the treatment level that is required on the water (qualitative) and also the amount of water to be treated by the system (quantitative). In 128, the natural occurring soil
5 obtained from the source is sampled and the soil quality is determined. Particle size distribution, moisture content and hydraulic conductivity of the soil are tested to determine the amount of the soil that may be reused. In 130, a test method may be performed at site to determine the hydraulic conductivity and estimate the fines percentage of the in-situ soil. The suitability of the in-situ soil to be reused may be
10 quickly determined using this test method. In 132, the amount of additional sand that is required to be brought into the site for the preparation of engineered soil is determined. For example, this value may depend on the amount of natural occurring soil quantity that may be reused. In 134, the amount of WTR and carbon sources to be added is determined based on the conditions determined in Steps 122, 124 and
15 126. In 136, the mixing of natural occurring soil obtained from the source with additional sand component, a waste component and a carbon source is performed such that the total amount of clay and silt derived from the natural occurring soil is more than 0% and no more than 15 wt% of the total dry weight of the engineered soil composition and wherein the engineered soil composition has a hydraulic
20 conductivity value within the desired range. In 138, checks are performed on the engineered soil to determine the hydraulic conductivity (K), pH, and/or electrical conductivity ranges are within the desired values.

EXAMPLES

25 Example embodiments of the disclosure will be better understood and readily apparent to one of ordinary skill in the art from the following examples, and if applicable, in conjunction with the figures.

Example 1: Preparation of engineered soil composition and its individual components

The engineered soil composition prepared according to embodiments of the methods disclosed herein can be modified according to the requirements of a site. Firstly, the runoff quality from the catchment area of the bioretention area should be determined. Runoff quality can be determined in terms of the Total Suspended Solids (TSS), Total Nitrogen (TN) and Total Phosphorus (TP). Alternatively, the runoff quality can be estimated based on the type of catchment / landuse (i.e. roof runoff or road runoff). For roof runoff / runoff with low pollutant, the engineered soil composition can have a higher range of hydraulic conductivity value, which is between 200 – 400 mm/hr and type 1 engineered soil may be used. For road runoff / runoff with high pollutant, the engineered soil composition will have a lower range of hydraulic conductivity value, which is between 50 – 200 mm/hr and type 2 engineered soil may be used.

For roof runoff, engineered soil composition of type 1 is used: Sand + Top soil (85%), Compost as an organic carbon-containing component (5%), Water treatment residue (WTR) (10%)

For road runoff, engineered soil composition of type 2 is used: Sand + Top soil (85%), Coconut fibre as an organic carbon containing component (5%), WTR (10%)

Secondly, the amount of natural occurring soil such as in-situ soil or top soil that can be reused should be determined. The percentage of in-situ soil that may be reused is determined based on the criteria stated below under “Preparation of top soil” and “Preparation of engineered soil composition”.

Method of preparation:

Preparation of Water treatment residues (WTR)

1. WTR was obtained from a water treatment plant managed by the Public Utilities Board (PUB).
- 5 2. WTR was crushed to smaller sizes
3. WTR was oven dried at 50 degree Celsius for at least 24 hours, or the WTR can be sun dried for 24 hours.
4. WTR was crushed or blended.
5. WTR was further dried at 50 degree Celsius or under the sun, where
10 necessary.
6. Dried WTR was sieved to the size of between 0.10mm and 1.2mm.
7. WTR was weighed and marked as the 'dry weight'.
8. If required, the WTR may be grinded to sizes smaller than 0.075 mm, to
15 compensate for the lack of fines in a situation where the top soil may contain significantly high sand percentage.

Preparation of compost

1. The compost used was the commonly used type of compost that was being used for gardening purposes.
- 20 2. The moisture content of the compost was determined using oven-drying method in accordance to BS1377-2:1990.
3. The organic content of the compost was determined using Method C as stated in ASTM D 2974 – 97. This method involves igniting an oven-dried sample from the moisture content test in a muffle furnace at 440 degree Celsius.

25

Preparation of sand

1. The sand type used was medium sand, which was cleaned and washed.
2. The moisture content of the sand was determined using oven-drying method in accordance to BS1377-2:1990.

30

Preparation of top soil

1. The top soil here refers to the top layer (0.5m from ground) of soil at an intended project site for a rain garden/bioretention system.

2. A sample of top soil (weight of 1kg) was obtained from the project site for laboratory testing.

3. The moisture content of the top soil was determined using oven-drying method in accordance to BS1377-2:1990.

4. The organic content of the top soil was determined using Method C as stated in ASTM D 2974 – 97. This method involves igniting an oven-dried sample from the moisture content test in a muffle furnace at 440 degree Celsius.

5. Particle size distribution of top soil was determined using dry sieving method in accordance to BS1377-2:1990.

6. From the particle size distribution, the percentage of fines (<0.063mm) in the top soil is determined.

Preparation of engineered soil composition

1. The percentage of fines in the engineered soil composition had to be less than 10% of the total dry weight of the engineered soil composition.

2. Based on the existing percentage of fines, the percentage of top soil to be used into the engineered soil composition was adjusted.

3. The mix ratio of top soil to sand was adjusted so that the percentage of fines was less than 10%.

4. The total weight of top soil and sand consisted 85% of the total required engineered soil composition.

5. The required weight for top soil and sand (wet weight) was calculated, based on the moisture content results obtained earlier.

6. The top soil and sand were mixed thoroughly, and then followed by adding in WTR (10% of total dry weight) and compost (5% of total dry weight).

7. After mixing the engineered soil composition thoroughly, the engineered soil composition was filled into the bioretention system to form its filter layer.

8. Proper care was given to not compact the engineered soil composition during mixing process and the pouring process.

The characteristics of the engineered soil composition that was prepared comprised the following characteristics:

1. Hydraulic conductivity is 50mm/hr to 200 mm/hr
2. Water quality improvement:
 - a. Total suspended solids (TSS) removal > 80%
 - b. Total phosphorus (TP) removal > 45%
 - c. Total nitrogen (TN) removal > 45%

For example, the method of preparing an engineered soil composition in accordance with various embodiments may include determining incoming run-off quality from a catchment area in terms of the Total Suspended Solids (TSS), Total Nitrogen (TN) and Total Phosphorus (TP).

For example, the TSS value may be measured by pouring a substantially precisely measured volume of water (typically one litre) through a pre-weighed filter of a specified pore size, then weighing the filter again after drying at 103-105°C to remove all moisture. For example, the TN value may be measured using a Total organic carbon/Total nitrogen analyzer. For example, the TP value may be determined after digestion and measuring using the ascorbic acid method.

For example, the method may also include determining a measure of fines (e.g. silt and clay) in in-situ soil of an intended bioretention system area and obtaining the particle size distribution of the in-situ soil.

For example, the particle size distribution may be measured by using a dry sieving method. A series of sieve sizes may be used to perform the particle size

distribution. From the test, the percentage of fines is determined by calculating the ratio of soil that passed through the 0.063mm sieve to the total weight of soil.

For example, the percentage of fines and the hydraulic conductivity of the in-situ soil may be determined by using a test method. Figs. 2A and 2B show an example of a simple apparatus 200 fabricated for this purpose. The apparatus 200 includes a body 202 having an open end 204 and an opposing end 206 which is covered by a cover 208. The apparatus 200 further includes an outlet 210 located near the cover 208. Two set of the apparatus (for example, the apparatus 200) are required for the above tests. For example, in one set, the percentage of fines may be estimated by placing 500g of the soil sample and followed by adding 800 ml of water. The top of the apparatus 200 is covered and the soil and water is mixed by shaking the apparatus rigourously. After that, the apparatus 200 is placed onto a flat ground and allow the soil mixture in the water to settle naturally. The proportion of the sand, silt and clay may be estimated based on the height of the respective sediment.

For example, in the other set of the apparatus (for example, the apparatus 200), about 300g of the soil sample is placed. A falling head test may be performed using the apparatus 200 to determine the hydraulic conductivity of the soil sample.

For example, upon the determination of the TSS, TP, TN values of the runoff, the measure of fines and the particle size distribution, the method may also include establishing a minimum required (or desired) hydraulic conductivity, and TSS, TP, TN removal rates of the bioretention system based on output requirements for the site.

For example, with the analysis of the particle size distribution of the in-situ soil, the method may also include adjusting a proportion of in-situ soil, sand, water treatment residual (WTR) and compost based on the in-situ particle size distribution.

In one example for illustration purpose, the TSS, TP, and TN values of the runoff may be about 100 mg/l, about 2 mg/l, and about 0.350 mg/l, respectively, and the measure of fines may be about 5 wt% of the total dry weight of the in-situ soil. The desired hydraulic conductivity of the resultant engineered soil composition may be in the higher range, for example, about 200 to 400 mm/hr, with TSS, TN, TP removal rates of, for example, about 95%, about 75%, and about 97%, respectively.

Based on the above illustrative example, in order to prepare 1000 kg of engineered soil, 100 kg of WTR (10 wt%) and 50 kg (5 wt%) of compost is added into 667 kg of natural occurring soil (which has 15% fines). Another 183 kg of additional sand is required to make up the mix to a total of 1000 kg.

The mixture may be checked so that the mixture does not exceed the following mix proportion:

a. The total percentage of fines in the engineered soil mix is limited to or capped at 10 wt% for controlling hydraulic conductivity.

b. WTR limited to less than 10% for preventing leaching of other compounds from the WTR material.

c. pH being more than 5.5 but less than 8.5 for healthy plant growth.

d. Electrical conductivity being more than 0.1 mS/cm.

If any of the above (a) to (d) is not satisfied, more sand may be added in portions of about 10 kg and/or more waste component may be added in portions of 1 kg with intervals of checking the mix proportion as described above in order to prepare an appropriate or optimum engineered soil composition based on the above conditions so as to meet the output (desired) requirements.

The amount of various components in the engineered soil composition may be expressed in percentage or wt% or in other metric measurements such as exemplified in terms of density (kg/m^3), weight (kg), volume (m^3), or % volume, for example, as shown in Table 1.

Table 1

	Percentage	Density (kg/m^3)	weight, kg	volume, m^3	% volume
WTR	10%	1500	100	0.067	9.7%
fibre	5%	950	50	0.053	7.7%
Sand	50%	1500	500	0.333	48.6%
Top Soil	35%	1500	350	0.233	34.0%
	100%		1000	0.686	100%

Example 2: Performance of engineered soil composition under conditions of wet and dry period

Two engineered soil compositions prepared according to embodiments of the methods disclosed herein were tested extensively in the laboratory. These compositions were:

Type 1: Sand (35%), Top soil (50%), Compost (5%), WTR (10%)

Type 2: Sand (35%), Top soil (50%), Coconut fibre (5%), WTR (10%)

Baseline stormwater flow was collected from a local canal and spiked with various chemicals and soil as shown in Table 2 to achieve concentration ranges which are representative of typical urban stormwater runoff. Other pollutant concentrations present in the collected runoff was representative of typical pollutant concentrations and were therefore not spiked into the simulated runoff.

Table 2. Targeted concentrations of spiked chemicals

Chemicals	Targeted concentration (mg/L)
H ₂ KO ₄ P	1.8 (PO ₄ ³⁻)
Copper (II) sulphate	0.241 (Cu)
Lead (II) nitrate	0.09025 (Pb)
Zinc chloride	1.127 (Zn)
Cadmium nitrate	0.00457 (Cd)
Sand and silt	100 (TSS)

The bioretention soil columns were subjected to both wet and dry periods to simulate weather conditions in Singapore. During wet period, each rainfall event was simulated once every 2-3 days while that for the dry period was simulated once every 5-7 days. Moisture levels within the soil were monitored using a calibrated moisture probe (Flexrake, FY-901, USA).

Water quality analyses were conducted in accordance to the Standard Methods for the examination of Water and Wastewater Analysis (American Public Health Association (APHA), 1999). Total Organic Carbon (TOC) and TN were measured using the TOC Analyzer (Shimadzu, TOC-L, USA) and ion concentrations were determined using Dionex ion chromatography system (Dionex LC20, USA). Prior to ion chromatography, runoff samples were filtered using a 0.45 µm pore size filter paper (Pall Corporation, GN-6, USA).

Physical parameters such as pH (Horiba, F-54 BW, Japan) and Turbidity (Hach, 2100N, USA) were also monitored for all samples. TSS was measured using the gravimetric method and glass-fibre filter papers (Whatman, GF/F, UK) were used for filtration. TP was measured using PhosVer® 3 with Acid Persulfate Digestion Method (Hach method 8190).

Averaged TSS removal efficiencies were the highest for Column 1 (96%) and 2 (94%). Both efficiencies exceeded the stormwater treatment objectives of 80% TSS removal or less than 10 mg/L (90% of all storm events), which are specified in the ABC Waters Design Guidelines. The corresponding TSS concentrations in treated runoff were 1.8 and 2.5 mg/L for type 1 and 2, respectively.

TP removal obtained in this study was higher than the stormwater treatment objectives of 45% TP removal or less than 0.08 mg/L (90% of all storm events). Average TP removals were at 92%, and 91% for type 1 and 2 respectively. Averaged effluent TP concentrations for Columns 1 and 2 were lower than the stormwater treatment objectives of 0.08 mg/L. TP removal remained consistently high from the start of the rainfall simulation period and no stabilization phase was required.

TN removal in this engineered soil composition required a stabilization phase. After a stabilization phase of about 20 bed volumes (BV), in which the soil was flushed with deionized water, the TN removal for type 2 was at 68% but type 1 has demonstrated much slower stabilization phase. Type 1 engineered soil composition has shown leaching of N but its TN removal capability was slowly increasing towards the end of the laboratory study. It was important to note that the type 1 soil in this study has been tested with higher than intended hydraulic conductivity. The leaching of N in type 1 proved that there was insufficient contact time for the nitrate conversion to occur. However, the type 1 soil has been tested in another tank study, with the correct hydraulic conductivity value, the TN removal capability was shown to be 68.8%. This finding further emphasized the importance of this engineered soil composition in maintaining the correct hydraulic conductivity range for proper water quality improvement.

The results obtained from the performance test are shown in Figs. 3 to 17. Referring to Figs. 3 to 8, there is shown the removal efficiencies and effluent concentrations of pollutants of water samples containing high TP, low TN and 40% silt that were treated by Mix 1. TSS removal was more than 90% and the TSS effluent concentration measured was 4.5 mg/L (Figs. 3 and 4). TN removal was more than 65% and the TN effluent concentration measured was less than 0.8 mg/L (Figs. 5 and 6). TP removal was more than 94% and the TP effluent concentration measured was less than 0.06 mg/L (Figs. 7 and 8).

Referring to Figs. 9 to 17, there is shown the removal efficiencies and effluent concentrations of pollutants of water samples containing high TP, high TN and 40% silt that were treated by Mix 2. For Mix 2, the effluent concentrations of pollutants for wet and dry periods were calculated. During wet period, each rainfall event was simulated once every 2-3 days while that for the dry period was simulated once every 5-7 days. To interpret the data depicted on the graphs for effluent concentration, reference is made to Fig. 10 as an example. In Fig. 10, there are different measurement values of the effluent concentration, namely the maximum concentration 1002, minimum concentration 1010, 90th percentile concentration 1004, 10th percentile concentration 1008 and the median concentration 1006.

TSS removal was more than 90% when Mix 2 was used. For the 90th percentile, the TSS effluent concentration during the wet period was 5 mg/L while the dry period measured 4.5 mg/L. TN removal was more than 65%. For the 90th percentile, the TN effluent concentration during the wet period was 0.6 mg/L while the dry period measured 0.8 mg/L. TP removal was more than 65%. For the 90th percentile, the TP effluent concentration during the wet period was 0.10 mg/L while the dry period measured 0.09 mg/L.

APPLICATIONS

Embodiments of the engineered soil composition disclosed herein may be capable of achieving consistent performance in terms of maintaining good hydraulic conductivity, sustaining healthy plant growth and achieving water quality improvement requirements. Accordingly, embodiments of the engineered soil composition disclosed herein may be suitable for use in bioretention systems or its equivalent, wastewater and/or stormwater treatment in Singapore and other places in the region.

Embodiments of the engineered soil composition disclosed herein utilizes water treatment residue (WTR). This solves the need to find a proper disposal ground for WTR produced by a water treatment plant. By reusing the WTR in an engineered soil composition, the amount of WTR to be disposed may be drastically reduced when this engineered soil composition is widely used in bioretention systems.

Embodiments of the engineered soil composition disclosed herein may reduce the dependency on sand usage in an engineered soil composition for bioretention system. At the same time, the engineered soil composition resuses the top soil at the site location. These advantageously translate into cost savings for the construction material cost and transportation cost in a bioretention system construction project.

Embodiments of the engineered soil composition disclosed herein comprise components which are capable of acting as a filter and removing pollutants from water. This advantageously allows the composition to be used in bioretention systems for pollutant removal from stormwater runoff before it enters the local runways.

In some embodiments, the filtration function and pollutant removal capabilities of the engineered soil composition have proved to be effective in tropical climates like Singapore where the average annual rainfall is more than 2300 mm. Since higher rainfall translates to higher hydraulic loads, the engineered soil composition disclosed herein may be capable of handling higher hydraulic loads yet may still provide for high pollutant removal.

In some embodiments, the pollutant removal capabilities of the engineered soil composition is effective for high annual pollutant loads (for example, in Singapore, with more than 2300 mm rainfall but where pollutant load level is lower), as compared to other systems operating in other climates (for example, in other countries with much lesser annual rainfall but where pollutant load level is higher).

Embodiments of the methods of making an engineered soil composition disclosed herein may be carried out in such a way that its components may be modified according to the requirements of a site. Advantageously, even though the conditions at different sites may be different, embodiments of the method disclosed herein will still allow a user to prepare an engineered soil composition with the desired characteristics.

Embodiments of the methods of preparing an engineered soil composition disclosed herein may also provide a consistent and established method of preparation which overcomes the challenges in obtaining a good and consistent soil mix for use as planting/filter media. Embodiments of the methods disclosed herein also address the issue of the non-homogenous nature of soil. Advantageously, the performance of the engineered soil composition used in a bioretention system may be capable of consistently achieving the desired levels of hydraulic conductivity and pollutant removal.

Embodiments of the methods of making an engineered soil composition disclosed herein may also be applied to preparing media compositions for wastewater and/or stormwater treatment.

- 5 It will be appreciated by a person skilled in the art that other variations and/or modifications may be made to the embodiments disclosed herein without departing from the spirit or scope of the disclosure as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. An engineered soil composition comprising:

5 a natural occurring soil component in an amount ranging from 30 wt% to 60 wt% of the total dry weight of the composition;

 a sand component in an amount ranging from 25 wt% to 55 wt% of the total dry weight of the composition; and

10 a waste component in an amount of more than 0 wt% and no more than 15 wt% of the total dry weight of the composition,

 wherein a total amount of clay and silt derived from the natural occurring soil component is in an amount of more than 0 wt% and no more than 15 wt% of the total dry weight of the composition.

- 15 2. The engineered soil composition of claim 1, wherein the engineered soil composition is a substantially homogeneous mixture of the natural occurring soil component, the sand component, and the waste component.

- 20 3. The engineered soil composition of any one of claims 1 or 2, wherein the waste component comprises water treatment residues.

- 25 4. The engineered soil composition of any one of claims 1 to 3, wherein the engineered soil composition has a hydraulic conductivity of no less than 20 mm/hr.

- 30 5. The engineered soil composition of any one of claims 1 to 3, wherein the engineered soil composition has a hydraulic conductivity in a range from 50 mm/hr to 450 mm/hr.

6. The engineered soil composition of any one of claims 1 to 3, wherein the engineered soil composition has a hydraulic conductivity in a range from 50 mm/hr to 200 mm/hr.
- 5 7. The engineered soil composition of any one of claims 1 to 3, wherein the engineered soil composition has a hydraulic conductivity in a range from 200 mm/hr to 400 mm/hr.
8. The engineered soil composition of any one of claims 1 to 7, wherein the
10 engineered soil composition has a pH level in a range from 5.5 to 8.5.
9. The engineered soil composition of any one of claims 1 to 8, wherein the engineered soil composition has an electrical conductivity of no less than 0.1 mS/cm and not more than 0.3 mS/cm.
- 15 10. The engineered soil composition of any one of claims 1 to 9, wherein the clay, or the silt or both have a particle size distribution of no more than 0.075 mm.
- 20 11. The engineered soil composition of any one of claims 1 to 10, further comprising an organic carbon-containing component that is different from the natural occurring soil component, the organic carbon-containing component being present in an amount of more than 0 wt% and no more than 35 wt% of the total dry weight of the composition.
- 25 12. The engineered soil composition of claim 11, wherein the organic carbon-containing component comprises a plant-based compost.
- 30 13. The engineered soil composition of claim 12, wherein the plant-based compost is selected from the group consisting of coconut fibres, palm fibres, rice husk, jute fibres, wood chips and mixtures thereof.

14. The engineered soil composition of any one of claims 1 to 13, wherein each of the components is derived from a different source.

5 15. The engineered soil composition of any one of claims 1 to 14, wherein the natural occurring soil component is derived from a top layer of soil that is no more than 1.5 m from ground.

10 16. The engineered soil composition of any one of claims 1 to 15, wherein the natural occurring soil component is derived from a site at which the engineered soil composition is to be used.

15 17. The engineered soil composition of any one of claims 1 to 16, wherein the sand component comprises sand particles having a particle size distribution in a range from 0.2 mm to 0.6 mm.

18. The engineered soil composition of any one of claims 1 to 17, wherein the sand component comprises sand particles that have been pre-washed and cleaned.

20 19. The engineered soil composition of any one of claims 1 to 18, wherein the waste component is derived from a water treatment plant.

25 20. The engineered soil composition of any one of claims 1 to 19, wherein the waste component comprises particles having grain sizes in a range from 0.10 mm to 1.20 mm.

30 21. The engineered soil composition of any one of claims 1 to 20, wherein the engineered soil composition is capable of supporting growth of one or more plant species.

22. The engineered soil composition of claim 21, wherein the one or more plant species is selected from the group consisting of *Clerodendrum*

inerme, *Cordyline fruticosa*, *Codiaeum variegatum*, *Iris domestica*, *Iris domestica*, *Murraya paniculata*, *Ophiopogon jaburan*, *Premna serratifolia*, *Sanchezia oblonga*, *Scaevola taccada*, *Sphagneticola trilobata*, *Sphagneticola trilobata*, *Syzygium myrtifolium*, *Tarenna odorata* and *Trimezia steyermarkii*.

23. The engineered soil composition of any one of claims 1 to 22, wherein the engineered soil composition is capable of supporting growth of one or more plant species such that the plant stress Fv/Fm ratio of the one or more plant species during growth is from 0.79 to 0.84.

24. The engineered soil composition of any one of claims 1 to 23, wherein the engineered soil composition is capable of supporting growth of one or more plant species such that the chlorophyll content SPAD value index of the one or more plant species during growth indicates healthy plant growth.

25. The engineered soil composition of any one of claims 1 to 24, wherein the engineered soil composition is capable of removing no less than 80% of Total Suspended Solids (TSS) from a TSS-containing influent water stream passing through the engineered soil composition.

26. The engineered soil composition of any one of claims 1 to 25, wherein the engineered soil composition is capable of removing no less than 45% of Total Nitrogen (TN) from a TN-containing influent water stream passing through the engineered soil composition.

27. The engineered soil composition of any one of claims 1 to 26, wherein the engineered soil composition is capable of removing no less than 45% of Total Phosphorus (TP) from a TP-containing influent water stream passing through the engineered soil composition.

28. An engineered soil composition consisting essentially of:

a natural occurring soil component in an amount ranging from 35 wt% to 55 wt% of the total dry weight of the composition;

a sand component in an amount ranging from 30 wt% to 50 wt% of the total dry weight of the composition;

a water treatment residue component in an amount of more than 0 wt% and less than 10 wt% of the total dry weight of the composition; and

an organic carbon-containing component in an amount of more than 0 wt% and less than 10 wt% of the total dry weight of the composition,

wherein a total amount of clay and silt derived from the natural occurring soil component is in an amount of more than 0 wt% and no more than 10 wt% of the total dry weight of the composition.

29. A method of preparing an engineered soil composition of any one of claims 1 to 28, the method comprising:

determining a desired hydraulic conductivity range for the engineered soil composition to be obtained;

obtaining an amount of natural occurring soil from a source;

determining a measure of silt and/or clay present in the amount of natural occurring soil from the source;

based on the determined measure of silt and/or clay, mixing the natural occurring soil obtained from the source in an amount ranging from 30 wt% to 60 wt% of the total dry weight of the composition with, a sand component in an amount ranging from 30 wt% to 50 wt% of the total dry weight of the composition, and with a waste component in an amount of more than 0 wt% and no more than 15 wt% of the total dry weight of the composition to form the engineered soil composition, such that the total amount of clay and silt derived from the natural occurring soil is in an

amount of more than 0 wt% and no more than 15 wt% of the total dry weight of the engineered soil composition and wherein the engineered soil composition has a hydraulic conductivity value within the desired hydraulic conductivity range.

5

30. The method of claim 29, wherein the engineered soil composition obtained from the mixing step is a substantially homogeneous mixture of the natural occurring soil, the sand component, and the waste component.

10

31. The method of claim 29 or 30, wherein the step of mixing the natural occurring soil with the sand component and the waste component further comprises mixing the natural occurring soil, the sand component and the waste component with an organic carbon-containing component in an amount of more than 0 wt% and no more than 35 wt% of the total dry weight of the composition.

15

32. The method of claim 31, wherein the organic carbon-containing component comprises a plant-based compost.

20

33. The method of claim 32, wherein the plant-based compost is selected from the group consisting of coconut fibres, palm fibres, rice husk, jute fibres, wood chips and mixtures thereof.

25

34. The method of any one of claims 29 to 33, wherein the desired hydraulic conductivity range is at or within a range from 50 mm/hr to 450 mm/hr.

30

35. The method of any one of claims 29 to 34, further comprising prior to the mixing step, the step of determining a desired pH range for the engineered soil composition to be obtained such that the mixing step forms the engineered soil composition having a pH value within the desired pH range.

36. The method of claim 35, wherein the desired pH range is at or within a range from 5.5 to 8.5.

5 37. The method of any one of claims 29 to 36, further comprising the step of determining a desired electrical conductivity limit for the engineered soil composition prior to the mixing step such that the mixing step forms the engineered soil composition having an electrical conductivity value not more than the desired electrical conductivity limit.

10 38. The method of claim 37, wherein the desired electrical conductivity limit is 0.1 mS/cm.

15 39. The method of any one of claims 29 to 38, wherein the step of determining the desired hydraulic conductivity range for the engineered soil composition to be obtained comprises determining at least one of a desired removal rate of Total Suspended Solids (TSS), a desired removal rate of Total Nitrogen (TN) or a desired removal rate of Total Phosphorus (TP) from an influent water stream passing through the engineered soil
20 composition.

40. The method of any one of claims 29 to 39, wherein the clay, or the silt or both have a particle size distribution of no more than 0.075 mm.

25 41. The method of any one of claims 29 to 40, wherein the natural occurring soil is derived from a top layer of soil that is no more than 1.5 m from ground.

30 42. The method of any one of claims 29 to 41, wherein the natural occurring soil is derived from a site at which the engineered soil composition is to be used.

43. The method of any one of claims 29 to 42, wherein the sand component comprises sand particles having a particle size distribution in a range from 0.2 mm to 0.6 mm.

5 44. The method of any one of claims 29 to 43, further comprising, prior to the mixing step, the steps of providing sand particles; and washing and cleaning the sand particles to form the sand component.

10 45. The method of any one of claims 29 to 44, wherein the waste component comprises water treatment residues.

15 46. The method of any one claims 29 to 45, further comprising, prior to the mixing step, the steps of providing a waste material having particles therein; and sieving the waste material to obtain the waste component having particle grain sizes in a range from 0.10 mm to 1.20 mm.

20 47. The method of claim 46, further comprising, prior to the sieving step, the step of pulverizing the waste material.

48. A water treatment system for simultaneously supporting plant growth and filtering stormwater, the system comprising an engineered soil composition of any one of claims 1 to 28.

25 49. The water treatment system of claim 48, wherein the water treatment system is a bioretention system or a rain garden.