Institute of Soil Bioengineering and Landscape Construction
Department of Civil Engineering and Natural Hazards
University of Natural Resources and Applied Life Sciences

Plant compatibility of recycled construction materials for use in gravel turf

Pflanzenveträglichkeit von Recycling Baustoffen für die Verwendung im Schotterrasen

Thesis

for the Degree of

Diplomingenieur

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Vienna, June 2007

Acknowledgements

The following thesis was written at the Institute of Soil Bioengineering and Landscape Construction, Department of Civil Engineering and Natural Hazards at the University of Natural Resources and Applied Life Sciences in Vienna.

My acknowledgements go to:

Simone Längert for all her advice and expertise...

Florin Florineth for giving me the possibility to write this thesis at the institute and opening my eyes to the world of soil bioengineering and landscape construction...

All employees at the institute, especially Ulli Pitha and Bernhard Scharf...

My parents Elizabeth and Udo for enabling me to study at the university...

Finally I would like to thank Nicole for all her support whilst writing this thesis and the final motivation to finish it on time...

Table of contents

Summary

In this thesis, ten recycled construction materials and four natural gravels were tested and evaluated for plant compatibility from December 2006 to January 2007. This research was conducted within the framework of the EU co-financed project "Green Concrete" whose goal is to research the applicability of recycled construction materials for the use in gravel turf. Companies from Austria, Germany and Italy have taken part in the project by providing crushed brick, crushed concrete, and mixed materials from building and road construction.

The growth test with cress was modified from the Austrian ordinance on compost (BGBl-Nr.292, 2001, *Kompostverordnung)* and formatted to assess the plant compatibility of recycled construction materials.

The evaluated parameters were fresh weight plant yield, germination rate, sprout length, plant colour and root growth of the planted cress. These values were set in relation to a reference substrate, consisting of sowing substrate and powdered brick, compared and classified. The modified growth test was proven to be applicable when defining the plant compatibility with recycled construction materials.

The plant compatibility of the crushed brick was classified as "satisfactory", the mixed materials also as "satisfactory". The crushed concrete materials did not achieve good results and were classified as "semi-satisfactory" to "unsatisfactory". The researched natural gravels consistently had "satisfactory" plant compatibility. The recycled building materials were also tested with an addition of 25 % compost. The adding of compost had a positive effect on all researched parameters.

Zusammenfassung

Im Rahmen des EU ko-finanzierten Projektes "Green Concrete", dessen Ziel es ist die Eignung von Recyclingmaterialien für den Aufbau eines Schotterrasens zu untersuchen, wurden im Zeitraum von Dezember 2006 bis Jänner 2007 10 Recycling Baustoffe und 4 Naturschotter teilnehmender Firmen aus Österreich, Deutschland und Italien auf ihre Pflanzenverträglichkeit untersucht. Die Recyclingmaterialien wurden als reiner Ziegelbruch, reiner Betonbruch und gemischte Hochbauabrissmaterialien deklariert.

Der Wachstumstest mit Kresse gemäß der österreichischen *Kompostverordnung* BGBl-Nr.292 (2001) wurde in modifizierter Form für die Untersuchungen angewandt.

Die bewerteten Parameter waren Pflanzenfrischsubstanz, Keimrate, Sprosslänge, Pflanzenfarbe und Wurzelwachstum der angesetzten Kresse. Diese Werte wurden in Relation zu einem Referenzsubstrat, aus Aussaaterde und Ziegelmehl, angegeben und miteinander verglichen und bewertet. Der modifizierte Wachstumstest zeigte sich als geeignet, Auskunft über die Pflanzenverträglichkeit von Recyclingmaterialien zu geben.

Die Pflanzenverträglichkeit des reinen Zeigelbruchs kann man als „gegeben" bezeichnen, die der gebrochenen Hochbauabrissmaterialien ebenfalls als „gegeben". Die reinen Betonbrüche erreichten keine guten Ergebnisse, hier wurde die Pflanzenverträglichkeit als „mäßig gegeben" bis „nicht gegeben" eingestuft. Die untersuchten Naturschotter hatten durchwegs eine gute Pflanzenverträglichkeit. Es wurden die getesteten Recyclingmaterialen auch unter Zusatz von 25 % Kompost untersucht. Die Zumischung von Kompost hatte auf alle Parameter einen positiven Einfluss.

1 Introduction

1.1 Initial position and problem

A change of consumption habits in modern day society has led to higher use of natural resources.

Only a very small part of these are returned to the economic cycle. This not only leads to a shortage of resources and an increase of prices but also to a rise of waste.

After appropriate processing, a part of these resources could be used as valuable materials.

In Vienna there were 4 million tons of construction rubble in 2005. (UMWELTBUNDESAMT, 2006)

Considering the decreasing space for landfills a rise of disposal costs is to be expected. The substitution of natural resources is not only of economical interest, but also an environmental concern. Opencast mining can disclose areas which could enable pollutants to enter into the ground water.

One of the main goals should be to keep resources in the economic system as long as possible. This only can be reached by waste prevention and realization.

A possible use for recycled building materials could be as a growing medium in gravel turf, a surface fortification with a high ecological value. (Chapter 1.3)

1.2 And then objective and approach

The objective of this thesis was to assess the plant compatibility of 14 recycled construction materials, which were to be used in gravel turf.

The topic of this thesis arose within the frame of the "Green Concrete" project as a part of the tests conducted on the recycled construction materials. (Chapter 1.4)

To be able to reach this goal a suitable testing method had to be found. A plant compatibility test was encountered in the Austrian ordinance on compost which will be further described in chapter 2.3.

Since this test method was developed for compost it had to be modified to fit the different characteristics of recycled construction materials. This process will be explained in chapter 2.4.

The results of these tests will be evaluated and used as a basis for the classification of the tested recycled construction materials (chapter 5)

1.3 Gravel turf

When you are writing a thesis about the plant compatibility of recycled construction materials for use in gravel turf it is important to understand what it consists of and how it works.

The following paragraphs give a short overview of the properties and functions of gravel turf.

Gravel turf is a permeable surface fortification with a high ecological value. Its type of construction covered with vegetation enables it to fulfil a row of functions such as a required load bearing capacity, soil-air-exchange, water permeability, water storage capacity and also the infiltration and evaporation of surface water. This is especially important in cities where the sealing of surfaces prevents the natural infiltration of water and strongly reduces the natural evaporation. An increased discharge of surface water which strains the sewerage system, lowering of the ground water level and a degradation of the city climate are only a few problems that can emerge from sealing surfaces. For this reason surfaces should only be sealed in areas of high utilization. In all other places an open soil fortification should be preferred. (FLORINETH, 2004).

The construction of gravel turf consists of 1 or 2 layers depending on the requirements (Figure 1-1 and Figure 1-2). The underground is the naturally occurring soil. The substructure is a layer to improve the level, enhance the load bearing capacity, the water permeability or the water storage capacity. The vegetation base course is the superstructure that is to be planted. It has to have an according grain size distribution, load bearing capacity, water permeability and storage. (FLORINETH, 2004).

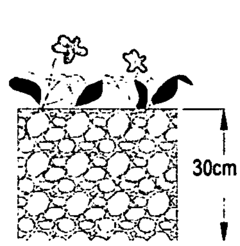


Figure 1-1: Gravel turf 1 layer construction

Source: IBLB, 2005, Grafik LÄNGERT

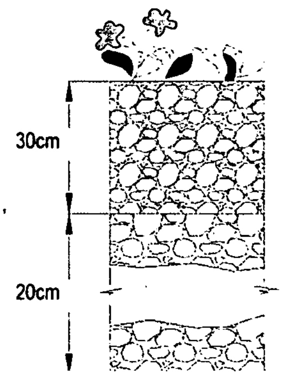


Figure 1-2: Gravel turf 2 layer construction

Source: IBLB, 2005, Grafik LÄNGERT

Gravel is the material that forms the largest part of the vegetation base course. It should have a grain size distribution from very fine to coarse to ensure a certain load bearing capacity and water permeability (0/32 – 0/64 mm). Compost or humus is added to the gravel at volumetric percentages of 15 – 20 to improve the growth of the plants and the water storage capacity. The substrate has to have the right grain size distribution after adding the compost or humus. (FLORINETH, 2004).

The difficulty of finding a suitable grain size distribution lies in complying with demands of parking cars (high density, load bearing capacity and water permeability – fulfilled by coarse material) and the contrasting needs of the plants (pore volume, water storage capacity - fulfilled by fine material). Figure 1-3 shows one of the latest grain size distributions (FLL, 2006) or (FLORINETH, 2004).

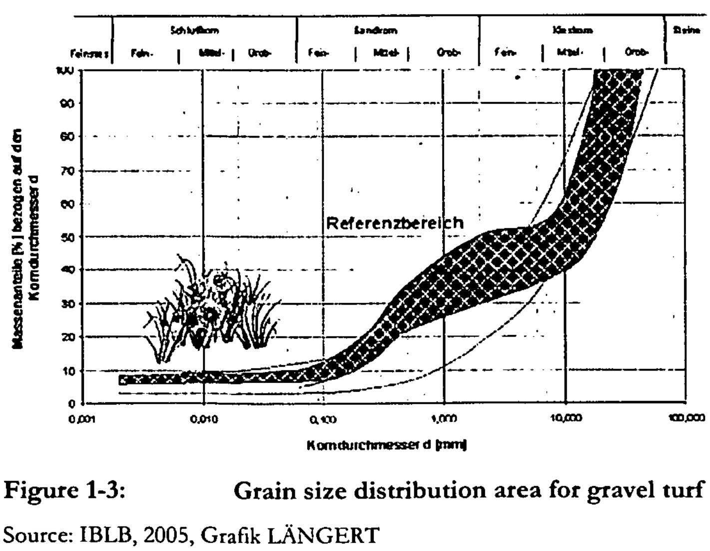


Figure 1-3: Grain size distribution area for gravel turf

Source: IBLB, 2005, Grafik LÄNGERT

The installation method of gravel turf also has a large influence on the properties of gravel turf. If the installation is performed by heavy machinery the soil is compacted, the load bearing capacity improved but the water permeability deteriorated and the conditions for the growth of plants worsened. Successful installations have been achieved with an excavator that doesn't drive on the material, but levels and lightly compacts it with the bucket. Subsequently the gravel is compacted with a non-vibrating roller (8-9 tons of weight) (FLORINETH, 2004).

A drought resistant assortment of seeds which is capable of bearing loads is needed for successful vegetation. This assortment can include grasses and herbs, or be a usual grass mixture for parking lots. The seeds are applied on the compacted vegetation base course and should be watered during the first few weeks of growth. (FLORINETH, 2004).

Gravel turf is a surface fortification which is constantly being researched, modified and developed as it is in the "Green concrete" project.

1.4 The "Green Concrete" project

„Development of gravel turf consisting of recycled construction materials as an economical and ecological method for permeable and absorptive surface consolidation most suitable for parking areas"

This is the projects official definition according to the Institute of Soil Bioengineering and Landscape Construction at the BOKU in Vienna (IBLB, 2007)

The main points of research were:

- Structural stability and material combination
- Infiltration rate, seeping water properties
- Water permeability, water absorption capacity, microclimate effects
- Load bearing capacity, evenness
- Applicability and suitability of plants, development of the vegetation

(IBLB, 2007)

The EU co-financed research project was a cooperation of the Institute of Soil Bioengineering and Landscape Construction at the BOKU in Vienna and the Technical college of Landscape Architecture and Horticulture in Erfurt.

Recycled building material companies taking part in the project were searching for application possibilities for materials which could not be sold. (In Vienna there were 4 million tons of construction rubble in 2005. (UMWELT-BUNDESAMT, 2006)

A consortium of 12 partners from Austria, Germany and Italy took part in the project which was officially launched on September 29. Five scientists were employed at the facilities in Vienna, Erfurt and Veitshöchheim, and were currently working on the project during the writing of this thesis.

Among many other factors there was the necessity of being able to test plant compatibility before defining a final mixture which was to be used during the consequent field testing phase.

This is how the topic of this thesis developed and consists of researching one of the eco tests and applicability of the recycled construction materials.

2 Assessment of plant compatibility

The second part of this thesis illustrates the preparation for the test phase. It begins by explaining the plant compatibility test method this research is based on. The plant compatibility test in accordance with the Austrian ordinance on compost (Kompostverordnung, 2001) was chosen for its reliable results over the past decades (chapter 2.3). The modifications applied to make this method suitable for testing recycled building materials are explained in chapter 2.4.

2.1 Principle of the test method

The cress test part of the eco-tests when analysing compost and is used to determine a possible toxic effect of a test item to the emergence and growth of terrestrial plants. In this case the compost is mixed in different ratios with reference substrate and then compared with a mixture of reference substrate to which no test compost is added. The toxicity of possible residuals of the test item is evaluated by comparing the results on germination and plant yield of test compost to reference substrate. The cress plant is chosen as a representative for dicotyledonous plants and because of its sensitive germination.

2.2 Guidelines used

The test was based on the "Wachstumstest mit Kresse" according to the BGBl.-Ausgegeben 14.August 2001-Nr.292 "*Verordnung des Bundesministers für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft über Qualitätsanforderungen an Komposte aus Abfällen (Kompostverordnung)*".

2.3 Plant compatibility according to the ordinance on compost

(BGBl.-Ausgegeben 14.August 2001-Nr.292 "*Kompostverordnung*")

This testing method has its roots at the agricultural and chemical research center in Linz, where it was developed at the beginning of the eighties under the name of "Linzer Substrat- Test". It was then transferred to the national code "ÖNORM S2023" and subsequently to the Austrian ordinance on compost with only marginal changes.

2.3.1 General procedure

The procedure begins by filling a suitable plant container (for example a Neubauer bowl, d=120mm, h=60mm) with a bottom layer of quartz sand (100ml, grain size ≤ 3mm). Vertically in the middle of this sand layer one must place a watering straw with a diameter of 6 to 8mm. After positioning the straw, 200g of dampened compost substrate is to be filled into the container loosely and compacted down to 1cm beneath the top rim of the container.

The compost substrate is a combination of 0, 15 and 30% (or respectively volume parts of 25 or 50%, to be stated when analysing) of the compost substrate and a substrate of reference. The substrate of reference is a 50/50 mixture of sowing substrate with a defined composition and low nutrient content and fired, powdered clay (also used on tennis courts, grain size ≤ 2mm).

Then one must sew 0,4g of cress seeds (Lepidium Sativum, accuracy of 0,01g) onto the compost substrate and arrange them equally. 50ml of quartz sand are applied as a top layer. By watering via the straw with approximately 100ml of water one must reach water saturation. Until germination of the seeds the container must be covered by a glass plate and a black plastic foil. After germination (with cress normally after 2 days) the cover must be taken off. The compost substrate has to be kept damp by spraying or, in case it is necessary, refilling through the watering straw. The plants are to be kept for 9 to 11 days in a very light room (16 hours of lighting) or in a greenhouse. After this time period the plants are cut closely to the surface of the top sand layer and weighed. Every approach has three parallel test rows, which means that one test consists of 9 plant containers (3x reference substrate, 3x 15% compost substrate, 3x 30% compost substrate).

2.3.2 Researched parameters

The germination rate is stated in percentage compared to the substrate of reference, the value is estimated. The minimum germination rate is 90 %.

The fresh weight plant yield is weighed at a precision of 0.01 g and declared in percentage compared to the substrate of reference. This value is rounded to integral numbers. A statistical method (e.g. Dixon) must be used to determine irregularities. The maximum error of the fresh weight plant yield allowed is

15% of the average weight of the three parallel reference substrate test containers.

The delay of germination is stated in days compared to the substrate of reference. No delay of germination is allowed for the tested compost.

The arithmetic average of all three parallel test rows is used for comparison.

2.4 Modification of the plant compatibility test

The plant compatibility test explained in chapter 2.3 is based on testing compost. To be able to use this method for recycled building materials it was necessary to make modifications. A detailed description of the test setup can be found in chapter 3.4.1

2.4.1 General procedure

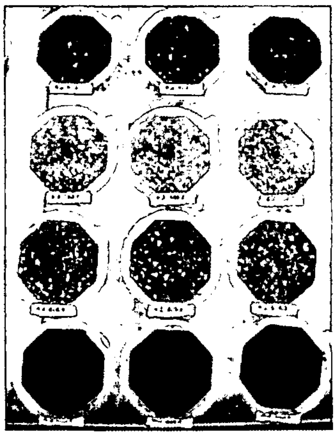
First and foremost the size of the plant container was increased because of the differing characteristics of the tested material. All amounts were then increased in relation to the enlarged volume of the container which was 750 ml (150 ml of quartz sand bottom layer, 100 ml of quartz sand top layer, 600 ml of substrate, 0.5 g of seeds and 200 ml of water).

Instead of using glass to cover the seeds before germination, containers with a lid were used.

The substrate percentages of 0, 15 and 30% were incremented to 0, 75 and 100% for a higher impact of the tested recycled materials. A mixture of 25% compost and 75% recycled material was also added to test if it would cover up possible negative influences of the material. This mixture was also added to simulate an actual gravel turf mixture which consists of 15-20 % compost.

The final test consisted of 12 containers for every tested material (3x reference substrate, 3x 75% recycled material substrate, 3x 100% recycled material substrate, 3x 75% recycled material substrate/25% compost). The mixtures with compost were dismissed for the materials F1_MMT and F2_GRA due to of lack of material. The final setup is illustrated in Figure 2-1

Apart from these changes the test was conducted according to the ordinance on compost "Kompostverordnung".



75% Recycled material substrate/ 25% Compost

100% Recycled material substrate

75% Recycled material substrate/ 25% Ref. substrate

100% Reference substrate

1 2 3

Figure 2-1: Setup of modified plant compatibility test

Source: Alexander Leitner, Vienna 2007

2.4.2 Researched parameters

Changes were also made to the researched parameters. Sprout length, plant colour, and root growth were added as further points in order to achieve clearer results.

Sprout length is a good indicator of plant vitality and is important when modelling plant growth (TRAPP, Mc FARLANE, 1995). Sprout length was stated in percentage compared to the substrate of reference.

The plant colour was added because it was used in the plant compatibility test stated in the ÖNORM S 2023 ("Untersuchungsmethoden und Güteüberwachung von Komposten") and proved to be a useful parameter. Plant colour provides information about nutrients in the soil. The plant was stated in light green and dark green whereas the reference substrate is always light green.

The root growth was added because roots provide anchorage, permit storage of energy-rich molecules, and undergo a physical as well as a chemical interaction with the soil. Roots were proven to be a very useful parameter when researching plant contamination. (TRAPP, McFARLANE, 1995). The root growth was classified in two grades (2=good, 1=bad) according to its characteristics. (Figure 2-2 and Figure 2-3).

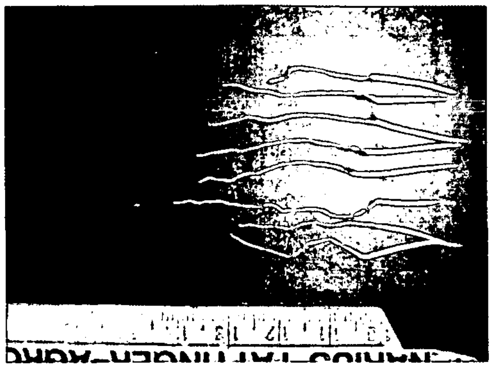


Figure 2-2: Root growth; class 2

Source: Alexander Leitner, Vienna 2007

Figure 2-3: Root growth; class 1

Source: Alexander Leitner, Vienna 2007

Apart from these changes the test was conducted according to the ordinance on compost "Kompostverordnung".

3 Test conditions and setup

3.1 General

The modified plant compatibility test was conducted at the BOKU greenhouse on the Peter Jordan Straße 63, 1180 Vienna. Further analysis, such as the pH-value and the lime content were tested at the laboratory of the institute in the Simony Haus on the Peter Jordan Straße 65, 1180 Vienna.

The plant compatibility was tested in two rounds. The first round included the materials A1_CBR, E1_CBR, A2_CCR, D1_CCR, A3_MMT, D2_MMT, E2_MMT, F1_MMT, G1_MMT, A4_GRA, B2_GRA, C1_GRA and was conducted from December 7th 2006 until December 18th 2006. The second testing phase was tested from January 14th 2007 until January 25th 2007 and included B1_MMT and F2_GRA. An upcoming deadline of the "green concrete" project and delayed material deliveries from some companies were the reasons for having to divide the testing into two phases. Both rounds had identical conditions which were reflected in the same obtained results of the substrate of reference.

3.2 Boundary conditions

3.2.1 Atmospheric environment

There was a constant temperature of approximately 20°C and a humidity of 80% in the greenhouse. The months of December and January had an average daylight of about 8 hours; no additional artificial light was used.

3.2.2 Seeds

The seeds were obtained from a garden store in Vienna and were of simple green garden cress (Lepidium Sativum) for indoor cultivation. The brand name was "SPERLI Grüne, einfache Gartenkresse". Only seeds from the same package were used during the testing phase.

3.2.3 Sowing substrate

The sowing substrate was bought at a local building market in Vienna. The brand name was "OBI Kultursubstrat, Aussaterde"It was for plants with low nutrient demand and was thought to be used as a seed starter mix. The contents were high moor turf, perlites, lime, clay and NPK-fertilizer. The chemical parameters were a pH-value of 5.0-6.0, salt content of 0.5-1.5 g KCl/l, Nitrogen of 50-300mg/l, Phosphate of 40-300 mg/l P_2O_5 and Caliumoxide of 100-500 mg/l K_2O.

3.2.4 Fired, powdered clay

This material was obtained at "WIENERBERGER" in Vösendorf and consisted of finely ground fired clay with a grain size of ≤ 2mm. It was called "Wienerberger Tennismehl"

3.2.5 Compost

The applied compost was a 50/50 mixture of sowing substrate and compost obtained from one of the companies taking part in the "Green Concrete" project. The same compost was used for every sample.

3.2.6 Quartz sand

The quartz sand was obtained at a local building shop in Vienna. It had a grain size of ≤ 2mm.

3.3 Description of the tested recycled construction materials

There were a total of fourteen tested recycled construction materials from Austria, Germany and Italy. They were provided by companies taking part in the "green concrete" project described in chapter 1.4. Due to protection of the companies they will not be named in this thesis.

A numerical identification was used to name the materials and from now on will be used in this thesis.

The materials were delivered by mail, or dropped off at the department by an employee of the company. They were then stored in the cellar of the university building under constant temperature and humidity. The amounts of the delivered materials varied between about 5 and 10kg.

For clarity the materials were divided into four groups according to their definitions by the companies:

- CBR* crushed brick
- CCR* crushed concrete
- MMT* mixed material
  (Combination of building- and road construction material)
- GRA* natural gravel
  (Is not a recycled material, but will be tested and analysed under the same conditions)

Due to our testing method all samples were provided at a grain size of ≤ 10mm To be able to describe the materials they were machine sifted at a facility in the department of Department of Civil Engineering and Natural Hazards. The chosen test sieves were of 8, 4, 2, 1 and 0.5 mm.

The different fractions were weighed after sifting and put in relation to the total weight which was measured before sifting. The weight of the fractions was then added up and compared to the total weight to ensure that there was no loss during sifting. For documentation all fractions were then placed on a scaled matt and subsequently photographed and described.

*These abbreviations are used solely in this thesis.

The bulk density was determined during the planting phase when an exact volumetric amount of material was weighed and subsequently filled into the plant containers. The bulk density was obtained by dividing this weight by the volume.

For the pH-Value the test materials were sifted to under 2mm. An amount of 10ml was then mixed with 25ml of destilled water and poured into a small plastic container, well shaken and then left to sit for 2 hours. The pH-Value was then measured with a pH-meter. (BODENZUSTANDSINVENTUR, 1996)

The lime content was also measured by sifting the material to under 2mm. An amount of 0.5-10g was then filled into a glass container. This small amount was mixed with hydrochloric acid. Through the chemical reaction with the content of lime and the resulting expansion of air in a closed system the content could be read on a scale which was placed on a water column (BODENZUSTANDSINVENTUR, 1996)

The conductivity was measured by mixing 25 g of unsifted material with 250 ml of distilled water in a plastic container. The suspension was then mixed for 15 minutes and left to sit for 2 hours. The conductivity was then measured with an conductivity meter after shaking well for another 30 seconds. (DURNER, NIEDER, 2003)

Every description will begin with a photo of the sifted material and followed by points stating the density, pH Value, conductivity and lime content. Subsequently the weights of the sifted fractions are shown in percentage compared to the total test weight. A written description at the end shows typical characteristics and other contents and impurities which were established in the material.

3.3.1 Material A1_CBR crushed brick

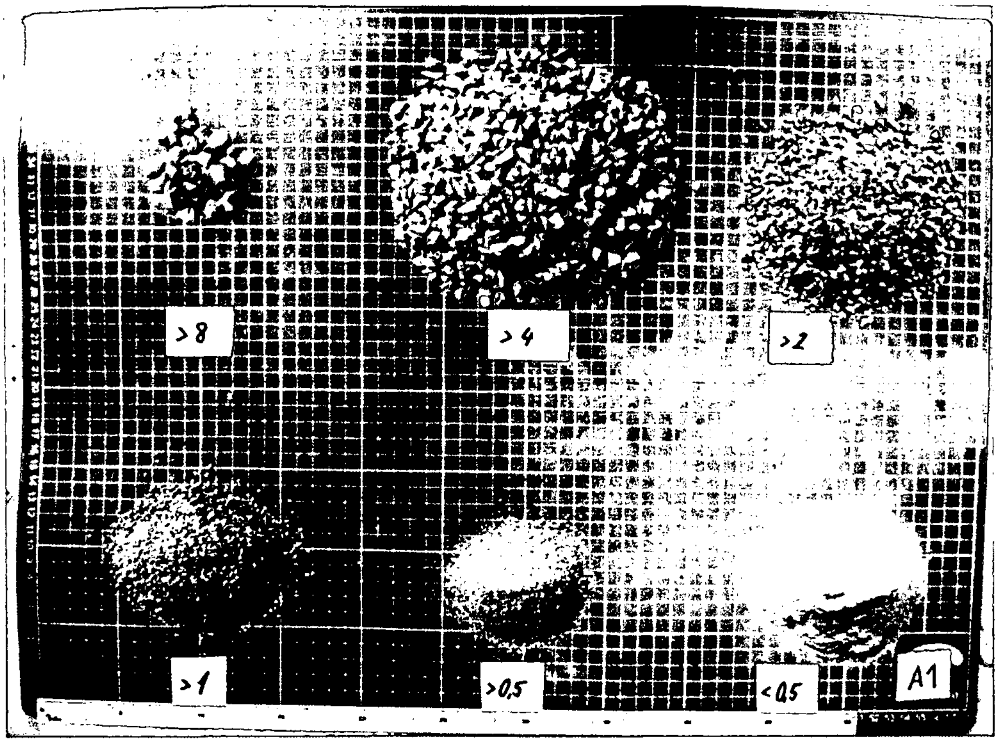


Figure 3-1: Material A1_CBR crushed brick

Source: Alexander Leitner, Vienna 2007

- Bulk density: 1.20 [g/cm³]
- pH Value: 8.53 [1]
- Conductivity: 78 [mS/m]
- Lime content: 6.98 [%]
- Weight of the fractions in percentage of the total test weight (0,90kg):

> 8 mm = 2%   > 4 mm = 51%   > 2 mm = 21%

> 1 mm = 9%   > 0.5 mm = 5%   < 0.5 mm = 11%

- Description:

The material has a low density due to the low weight of the porous brick and its loose layering. The highest content in this crushed brick was the fraction between 8 and 4mm.

The batch made a very pure impression and the only other contents found were 1 piece of plastic, 1 piece of organic matter and a few pieces of natural stone.

3.3.2 Material E1_CBR crushed brick

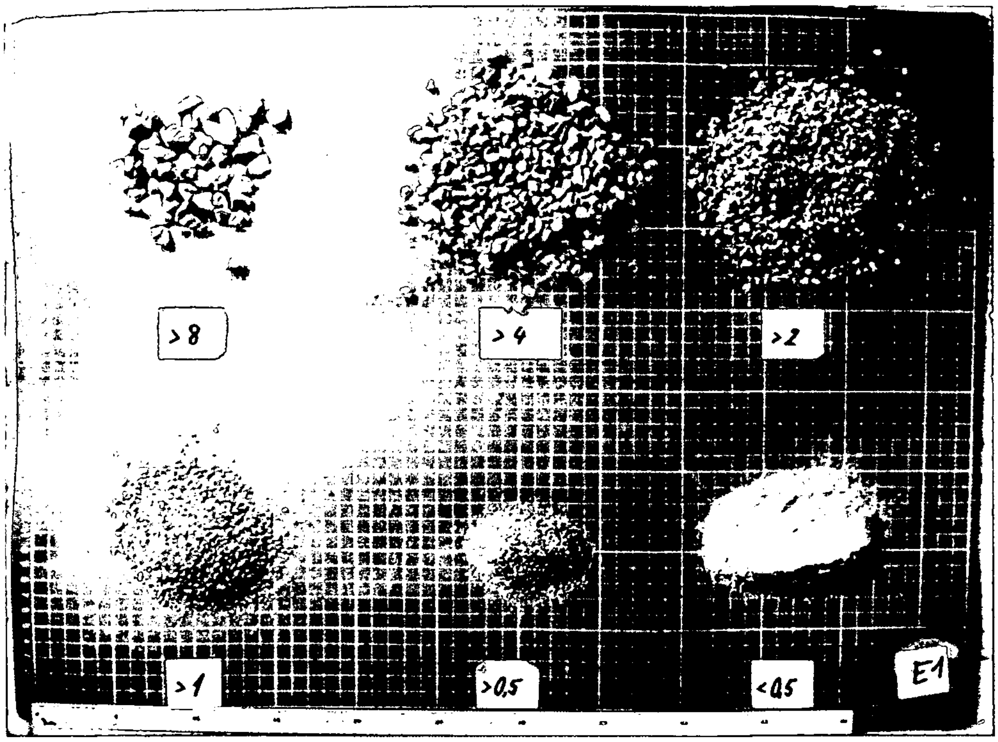


Figure 3-2: Material E1_CBR crushed brick

Source: Alexander Leitner, Vienna 2007

- Bulk density: 1.15 [g/cm³]
- pH Value: 8.62 [1]
- Conductivity: 110 [mS/m]
- Lime content: 10.57 [%]
- Weight of the fractions in percentage of the total test weight (0,43kg):

> 8 mm = 9% > 4 mm = 34% > 2 mm = 28%

> 1 mm = 11% > 0.5 mm = 4% < 0.5 mm = 14%

- Description:

This material had similar results in density and pH than the other crushed brick material. About one third of this crushed brick was between 8 and 4mm. The fractions less than 1mm also made up about a third of this material.

Like the other crushed brick this material made a very clean impression and the only other contents found were a few pieces of natural stone, 1 piece of Styrofoam; and 1 piece of wood.

3.3.3 Material A2_CCR crushed concrete

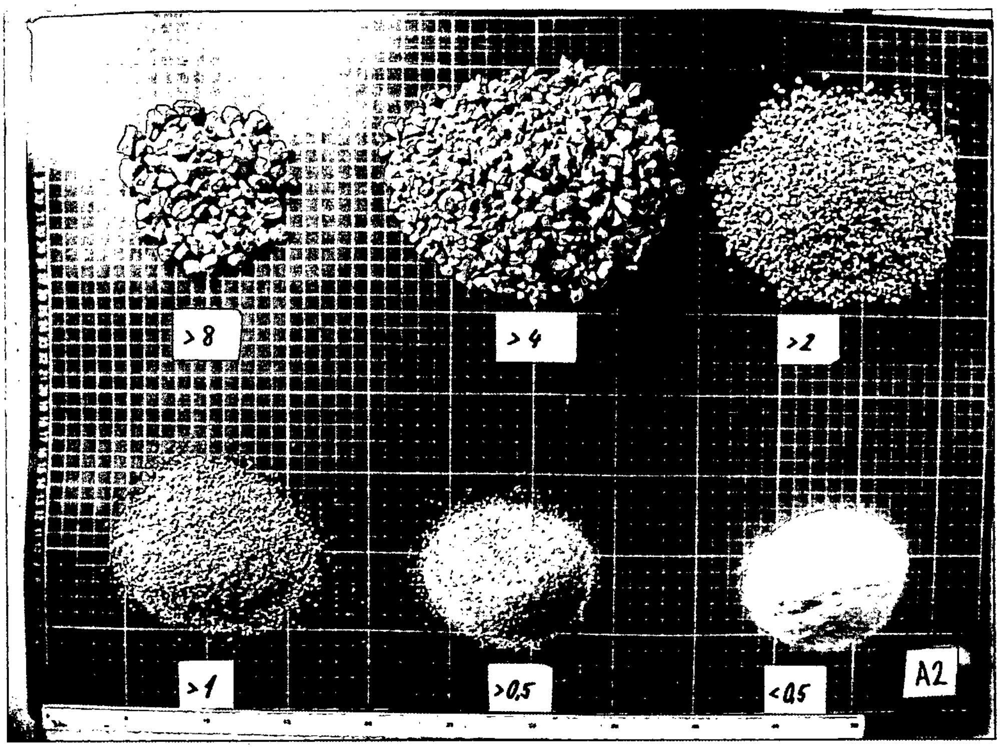


Figure 3-3: Material A2_CCR crushed concrete

Source: Alexander Leitner, Vienna 2007

- Bulk density: 1.59 [g/cm³]
- pH Value: 11.66 [1]
- Conductivity: 132 [mS/m]
- Lime content: 12.33 [%]
- Weight of the fractions in percentage of the total test weight (1.21kg):

> 8 mm = 8% > 4 mm = 40% > 2 mm = 25%

> 1 mm = 12% > 0.5 mm = 8% < 0.5 mm = 7%

- Description:

This material had a high density and a very high pH-value at 11.66. The largest fraction was between 4 and 8 mm. About one third of the weight was of the fractions less than 1mm.

This was a pure crushed concrete material with no other contents found.

3.3.4 Material D1_CCR crushed concrete

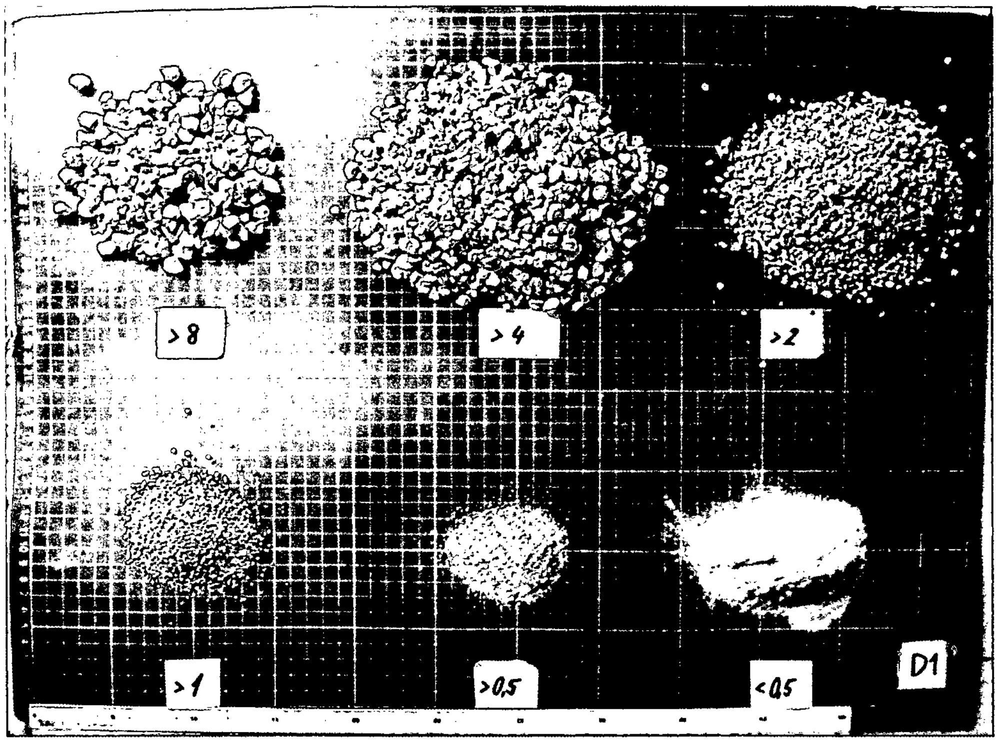


Figure 3-4: Material D1_CCR crushed concrete

Source: Alexander Leitner, Vienna 2007

- Bulk density: 1.50 [g/cm³]
- pH Value: 11.22 [1]
- Conductivity: 94 [mS/m]
- Lime content: 20.97 [%]
- Weight of the fractions in percentage of the total test weight (1.06kg):

> 8 mm = 16% > 4 mm = 50% > 2 mm = 21%

> 1 mm = 4% > 0.5 mm = 2% < 0.5 mm = 7%

- Description:

Similar to the first crushed concrete this material had a high density and a very high pH-Value. One half of this material was between 4 and 8mm. It had a small content of fine material lower than 1mm (13 %).

This was also a pure crushed concrete material with only 1 piece of cloth, 1 piece of Styrofoam and five small pieces of wood found.

3.3.5 Material A3_MMT mixed material

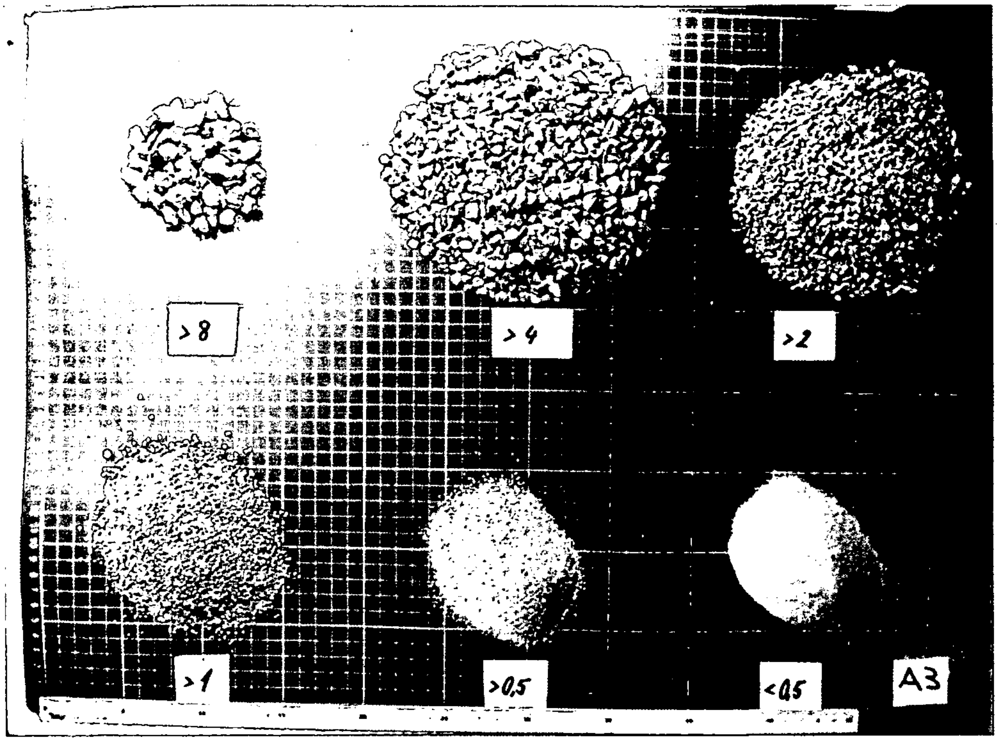


Figure 3-5: Material A3_MMT mixed material

Source: Alexander Leitner, Vienna 2007

- Bulk density: 1.54 [g/cm³]
- pH Value: 11.27 [1]
- Conductivity: 94 [mS/m]
- Lime content: 19.09 [%]
- Weight of the fractions in percentage of the total test weight (1.11kg):

> 8 mm = 6%   > 4 mm = 40%   > 2 mm = 28%

> 1 mm = 13%   > 0.5 mm = 6%   < 0.5 mm = 6%

- Description:

This mixed material was almost a pure crushed concrete material with the same characteristics such as a high density and pH-value. The only indicators of a mixed material were a few pieces of crushed bricks in all fractions.

Other contents found were some natural, 3 pieces of wood and a piece of glass

3.3.6 Material B1_MMT mixed material

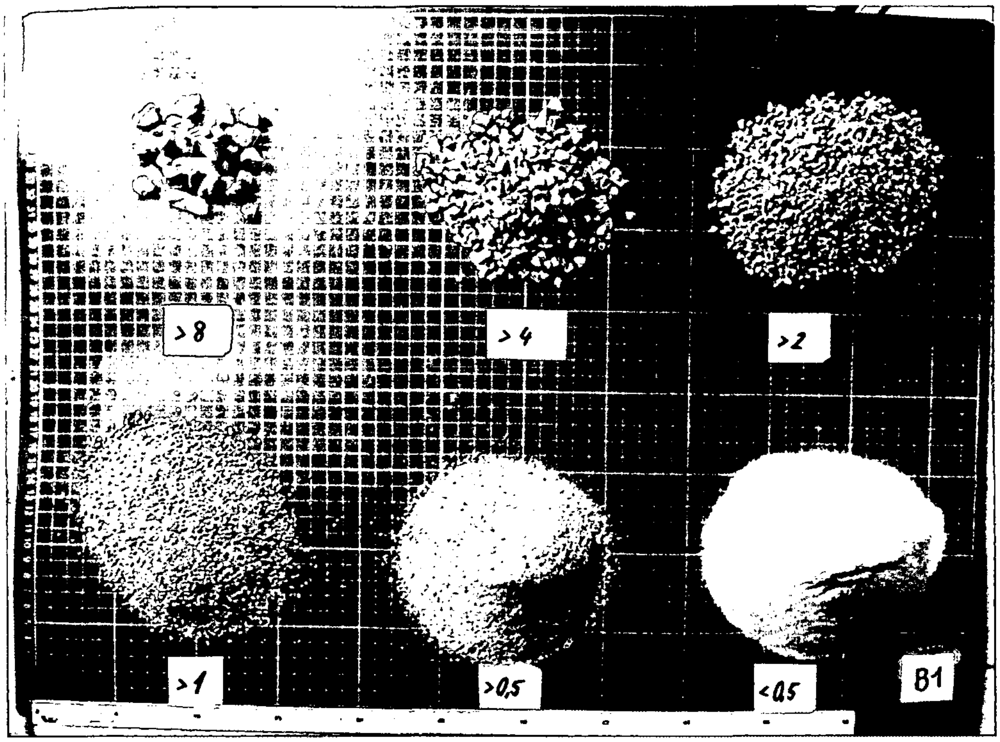


Figure 3-6: Material B1_MMT mixed material

Source: Alexander Leitner, Vienna 2007

- Bulk density: 1.22 [g/cm³]
- pH Value: 7.91 [1]
- Conductivity: 40 [mS/m]
- Lime content: 30.63 [%]
- Weight of the fractions in percentage of the total test weight (1.02kg):

> 8 mm = 3% > 4 mm = 11% > 2 mm = 17%

> 1 mm = 21% > 0.5 mm = 21% < 0.5 mm = 28%

- Description:

The density at 1.22 and the pH-value at 7.91 were similar to the crushed brick materials. This material had a high content of brick in the fractions over 2 mm which made up about one third of the total tested weight. The fractions less than 1 mm made up two thirds of the material which is a high percentage compared to the other materials.

No impurities where found in this mixed material

3.3.7 Material D2_MMT mixed material

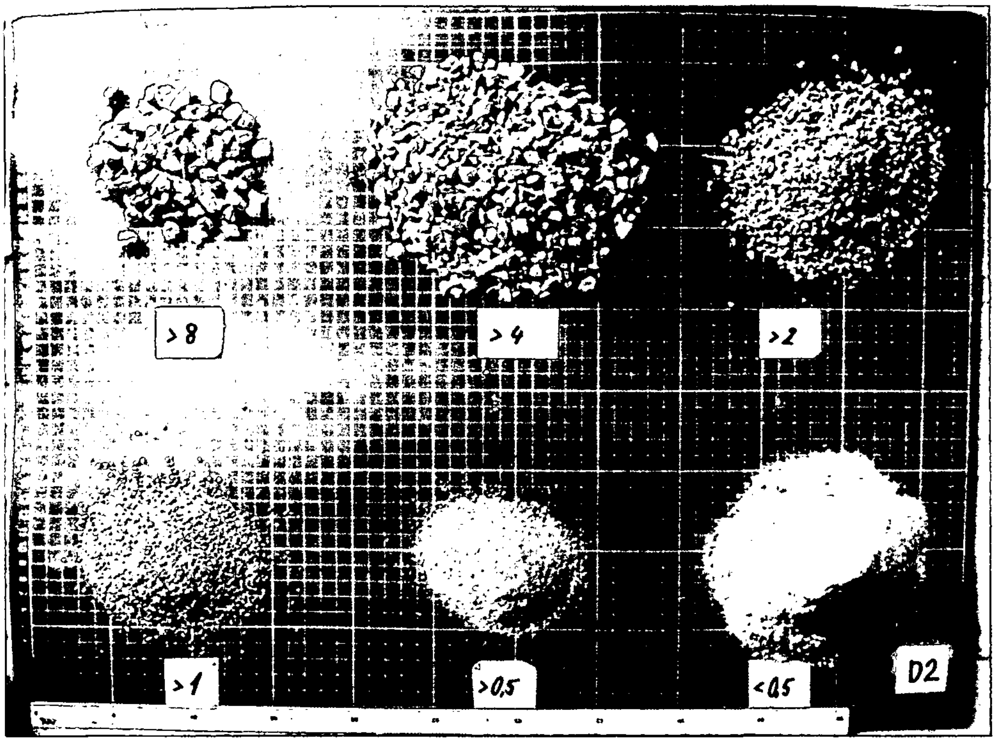


Figure 3-7: Material D2_MMT mixed material

Source: Alexander Leitner, Vienna 2007

- Bulk density: 1.33 [g/cm³]
- pH Value: 9.47 [1]
- Conductivity: 182 [mS/m]
- Lime content: 29.51 [%]
- Weight of the fractions in percentage of the total test weight (0.86kg):

> 8 mm = 9% > 4 mm = 34% > 2 mm = 19%

> 1 mm = 9% > 0.5 mm = 6% < 0.5 mm = 23%

- Description:

This mixed material had a high content of brick in all fractions but a higher density and pH-value compared to the crushed brick materials. One third of the weight was between 4 and 8 mm. The weight of the fractions lower than 1mm was 38% of the total weight.

This was a mixed material with many impurities such as 9 pieces of Styrofoam, 5 pieces of glass and numerous pieces of wood in every fraction.

3.3.8 Material E2_MMT mixed material

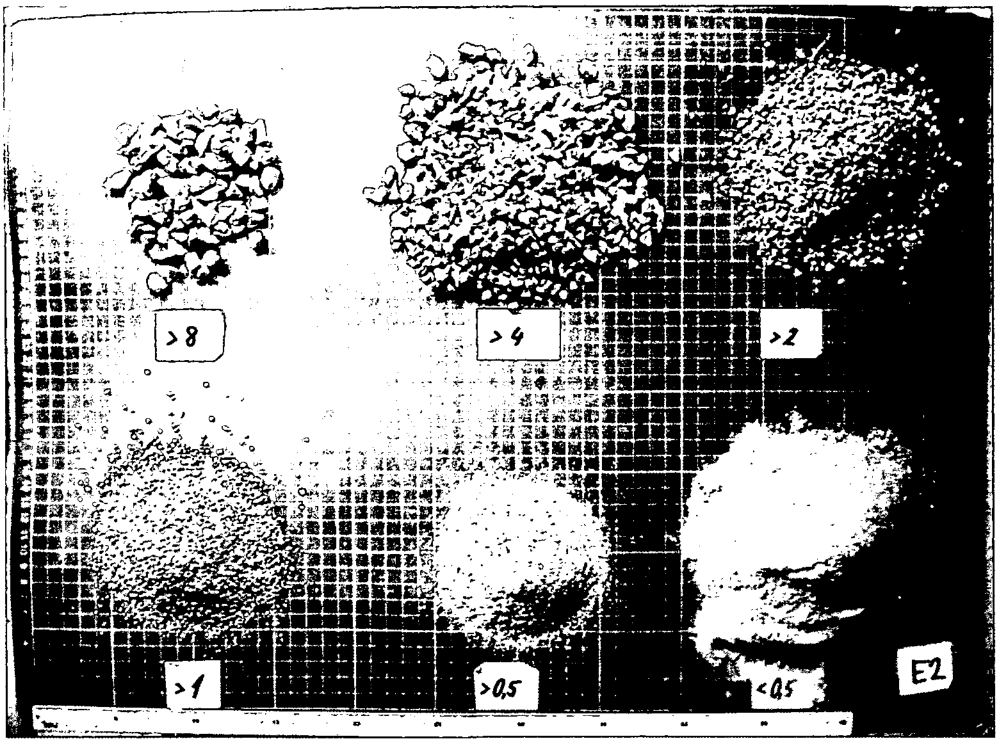


Figure 3-8: Material E2_MMT mixed material

Source: Alexander Leitner, Vienna 2007

- Bulk density: 1.32 [g/cm³]
- pH Value: 8.41 [1]
- Conductivity: 168 [mS/m]
- Lime content: 24.85 [%]
- Weight of the fractions in percentage of the total test weight (1.08kg):

> 8 mm = 5% > 4 mm = 25% > 2 mm = 18%

> 1 mm = 12% > 0.5 mm = 9% < 0.5 mm = 32%

- Description:

This material also had a very high content of crushed brick in all fractions but a slightly higher density and pH-value compared to the crushed bricks. Over half of the weight is in the fractions smaller than 1 mm, lower than 0.5 mm is almost one third of the total weight.

Pieces of wood and Styrofoam were found in every fraction.

3.3.9 Material F1_MMT mixed material

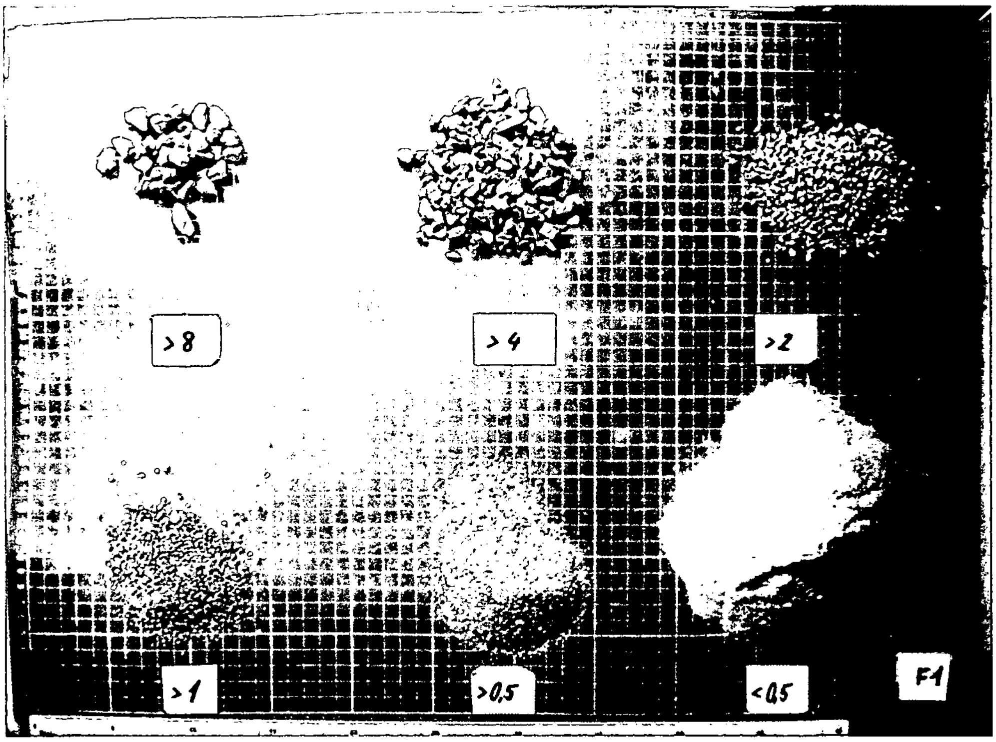


Figure 3-9: Material F1_MMT mixed material

Source: Alexander Leitner, Vienna 2007

- Bulk density: 1.53 [g/cm³]
- pH Value: 9.06 [1]
- Conductivity: 41 [mS/m]
- Lime content: 5.87 [%]
- Weight of the fractions in percentage of the total test weight (0.70kg):

> 8 mm = 5% > 4 mm = 14% > 2 mm = 8%

> 1 mm = 7% > 0.5 mm = 13% < 0.5 mm = 53%

- Description:

This was a mixed material with a low content of brick and relatively high content of natural stone. The density and pH-value were among the highest in the mixed materials. The fraction less than 0.5mm made over half the weight, almost two thirds of the weight were in the fractions under 1 mm.

No impurities where found in this mixed material

3.3.10 Material G1_MMT mixed material

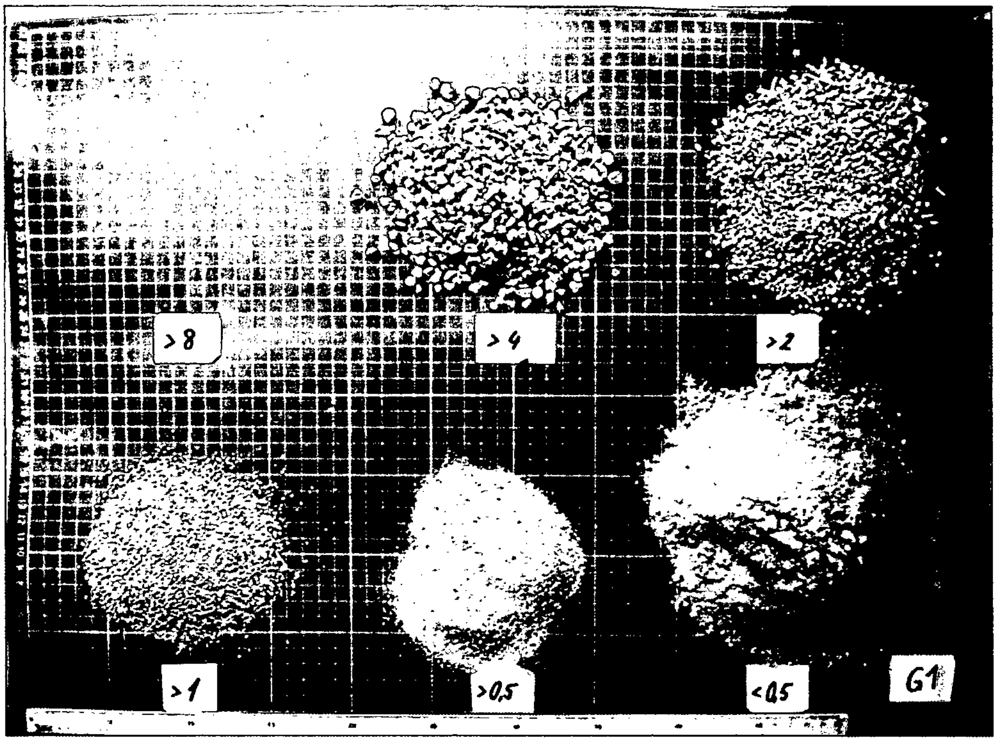


Figure 3-10: Material G1_MMT mixed material

Source: Alexander Leitner, Vienna 2007

- Bulk density: 1.53 [g/cm³]
- pH Value: 8.04 [1]
- Conductivity: 155 [mS/m]
- Lime content: 20.07 [%]
- Weight of the fractions in percentage of the total test weight (1.05kg):

> 8 mm = 0% > 4 mm = 18% > 2 mm = 17%

> 1 mm = 9% > 0.5 mm = 9% < 0.5 mm = 47%

- Description:

A high density, but relatively low pH-value characterized this material with a high content of natural stone. The fraction less than 0.5 mm made almost half the weight, 65% of the weight was in the fractions under 1 mm. There was no material larger than 8 mm.

Two pieces of glass and numerous pieces of wood were found in every fraction.

3.3.11 Material A4_GRA natural gravel

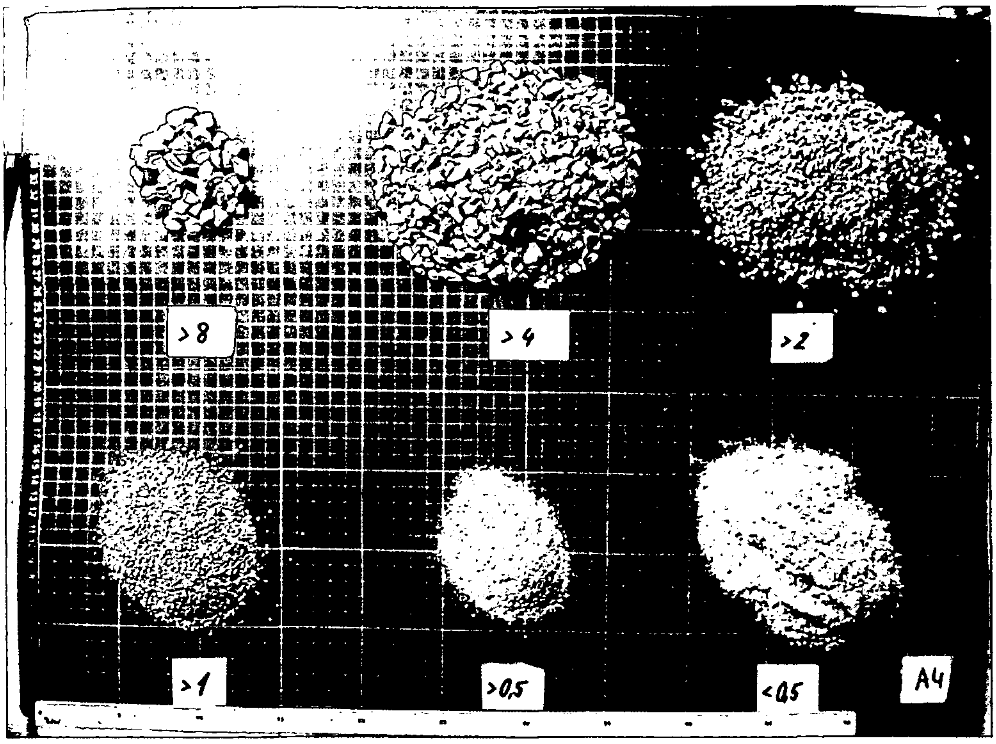


Figure 3-11: Material A4_GRA natural gravel

Source: Alexander Leitner, Vienna 2007

- Bulk density: 1.58 [g/cm³] (moist)
- pH Value: 8.60 [1]
- Conductivity: 22 [mS/m]
- Lime content: 21.86 [%]
- Weight of the fractions in percentage of the total test weight (1.12kg):

> 8 mm = 4% > 4 mm = 40% > 2 mm = 30%

> 1 mm = 11% > 0.5 mm = 5% < 0.5 mm = 11%

- Description:

This natural gravel had typical values for this material, nothing exceptional was noticed.

No impurities where found in this natural gravel.

3.3.12 Material B2_GRA natural gravel

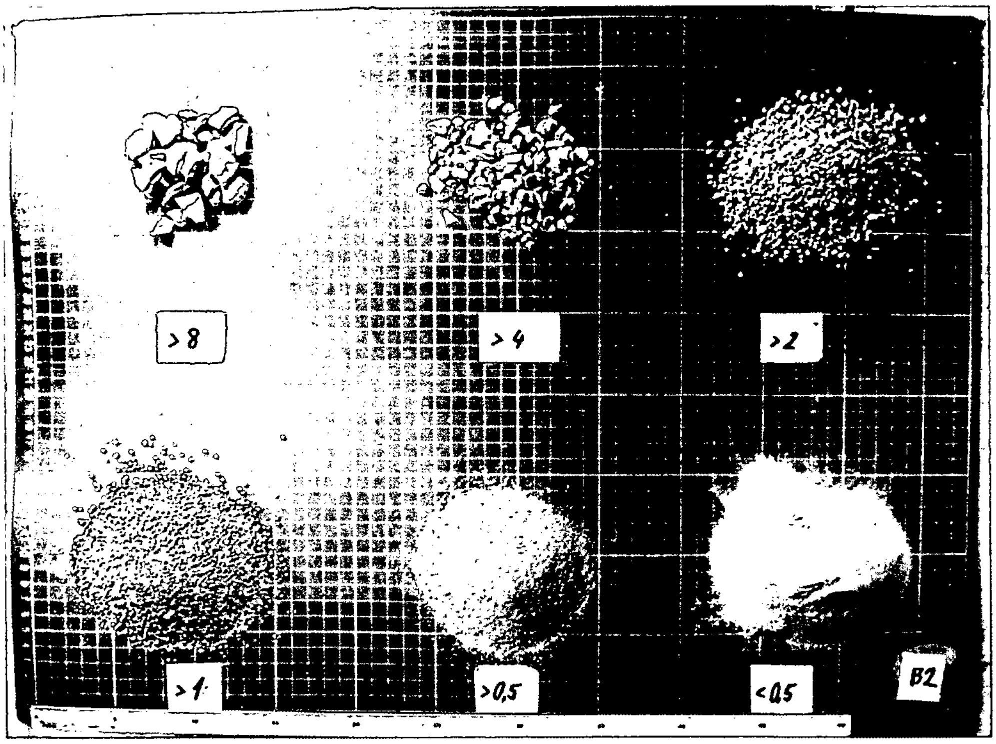


Figure 3-12: Material B2_GRA natural gravel

Source: Alexander Leitner, Vienna 2007

- Bulk density: 1.34 [g/cm³] (moist)
- pH Value: 8.33 [1]
- Conductivity: 9 [mS/m]
- Lime content: 26.78 [%
- Weight of the fractions in percentage of the total test weight (0.64kg):

> 8 mm = 10% > 4 mm = 11% > 2 mm = 17%

> 1 mm = 23% > 0.5 mm = 17% < 0.5mm = 22%

- Description:

Due to the density being measured whilst the material was moist it has a high density. This natural gravel had typical values for this material, nothing exceptional was noticed.

No impurities where found in this natural gravel.

3.3.13 Material C1_GRA natural gravel

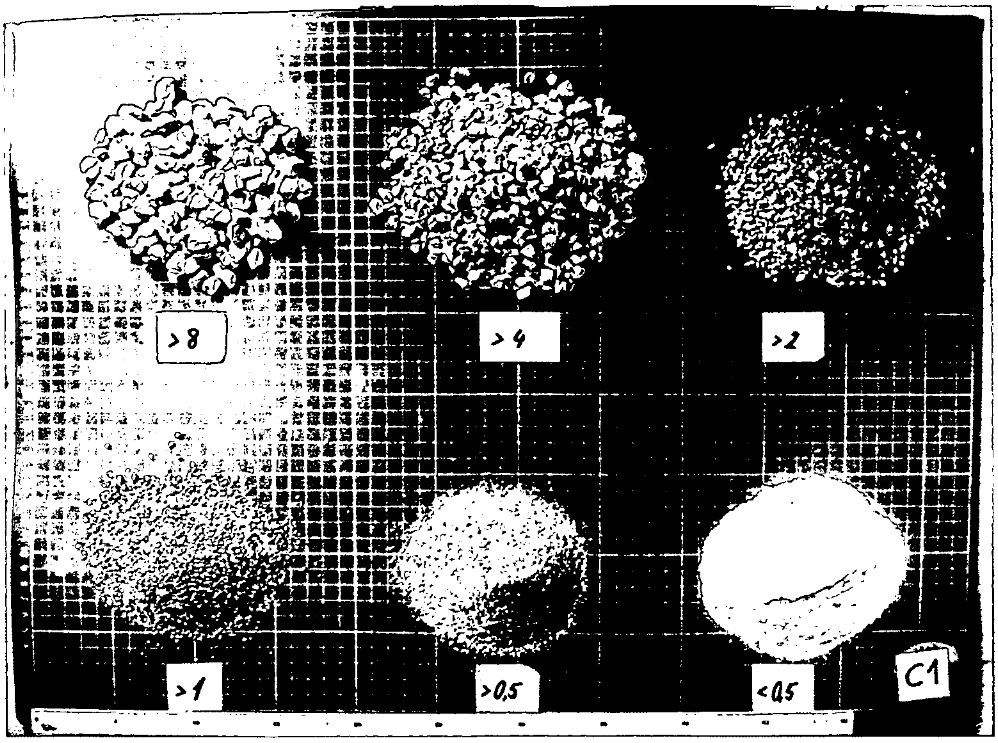


Figure 3-13: Material C1_GRA natural gravel

Source: Alexander Leitner, Vienna 2007

- Bulk density: 1.97 [g/cm³] (moist)
- pH Value: 8.95 [1]
- Conductivity: 6 [mS/m]
- Lime content: 29.03 [%]
- Weight of the fractions in percentage of the total test weight (1.4kg):

> 8 mm = 19% > 4 mm = 28% > 2 mm = 16%

> 1 mm = 12% > 0.5 mm = 10% < 0.5mm = 15%

- Description:

Due to the density being measured whilst the material was moist it has a high density. This natural gravel had typical values for this material, nothing exceptional was noticed.

No impurities where found in this natural gravel.

3.3.14 Material F2_GRA natural gravel

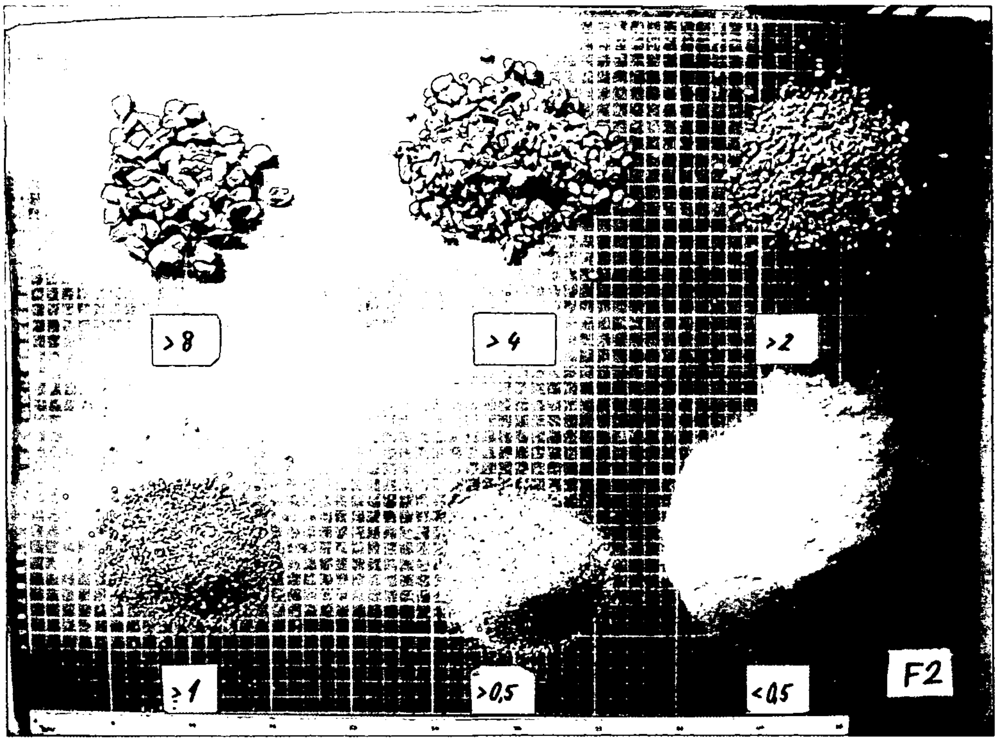


Figure 3-14: Material F2_GRA natural gravel

Source: Alexander Leitner, Vienna 2007

- Bulk density: 1.66 [g/cm³]
- pH Value: 9.03 [1]
- Conductivity: 7 [mS/m]
- Lime content: 2.94 [%]
- Weight of the fractions in percentage of the total test weight (1.05kg):

> 8 mm = 9% > 4 mm = 17% > 2 mm = 9%

> 1 mm = 8% > 0.5 mm = 10% < 0.5 mm = 47%

- Description:

This gravel had a higher pH-value than usual and almost half of the weight was in the fraction under 0.5 mm.

No impurities where found in this natural gravel.

3.4 Conduction of the test phase

The test phase was conducted between December 7th 2006 until December 18th 2006 and January 14th 2007 until January 25th 2007.

The planting took place at the greenhouse on the Peter Jordan Straße 63, 1180 Vienna.

On the following pages the test phase will be explained in detail joined by photos for ease of understanding.

3.4.1 Planting

The planting was realised according to the modified plant compatibility test described under chapter 2.4.

Due to transport some fine material fractions could have settled. Before the planting phase began all materials were homogenised in a mixing machine.

150ml of quartz sand were measured and filled into the plastic plant containers (Figure 3-15). The straw was cut to a length of 60mm and placed in the middle of the quartz sand bed (Figure 3-16).

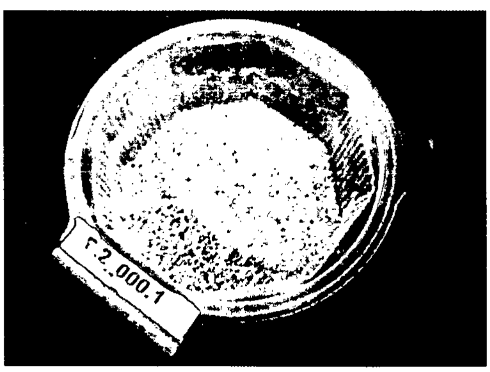


Figure 3-15: Planting; quartz sand ≤ 2 mm

Source: Alexander Leitner, Vienna 2007

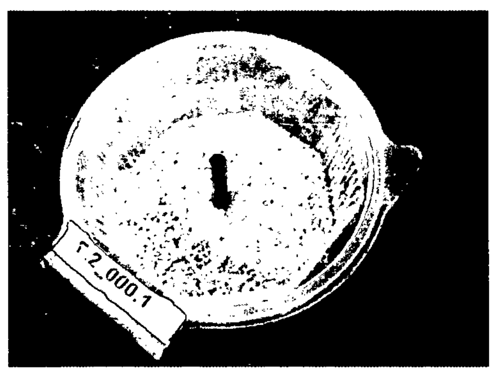


Figure 3-16: Planting; straw 6mm

Source: Alexander Leitner, Vienna 2007

For the 100% recycled material substrate mix 600ml were filled into the container. The other substrate mixtures (75% recycled material substrate and 25% reference substrate or 25% compost) were mixed in relations of 450ml (75%) and 150ml (25%). All substrates were dampened by spraying with water before they were filled into the plant container and then lightly compacted to 1cm under the rim (Figure 3-17). 0.5g of Lepidium Sativum seeds were then weighed and distributed evenly on the surface of the substrates (Figure 3-18)

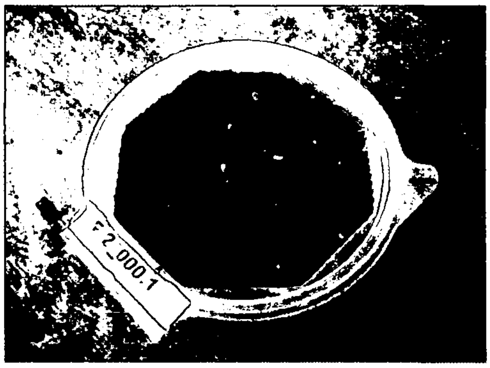


Figure 3-17: Planting; substrate

Source: Alexander Leitner, Vienna 2007

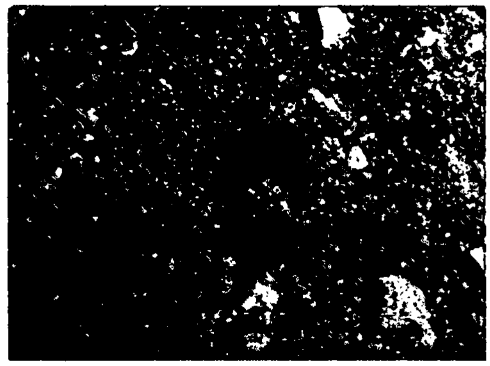


Figure 3-18: Planting; seeds (Lepidium Sativum)

Source: Alexander Leitner, Vienna 2007

100 ml of quartz sand were then used to cover the seeds (Figure 3-19). All substrates were the watered with 200ml of tap water by using a bottle with a spout to fill the container through the watering straw (Figure 3-20).

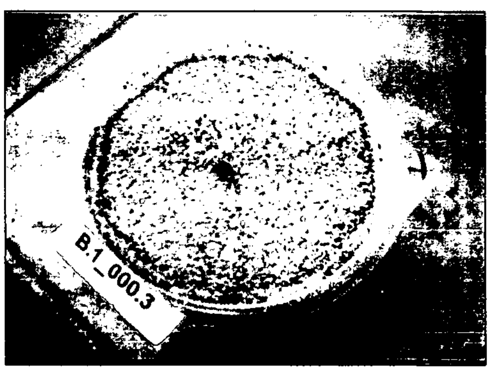


Figure 3-19: Planting; quartz sand ≤ 2 mm

Source: Alexander Leitner, Vienna 2007

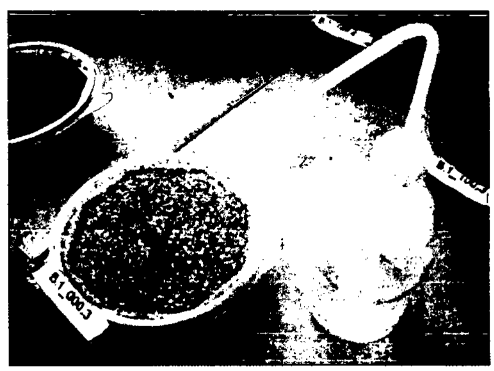


Figure 3-20: Planting; watering bottle

Source: Alexander Leitner, Vienna 2007

After watering all containers they were placed according to their material group and substrate mixture (Figure 3-21). All containers were then put onto a large planting table (Figure 3-22). The containers were then closed by putting on a lid and covered with black plastic foil.

After two days the lid and black plastic foil were taken off. The substrate was held moist by spraying it; no further watering by the watering straw was necessary.

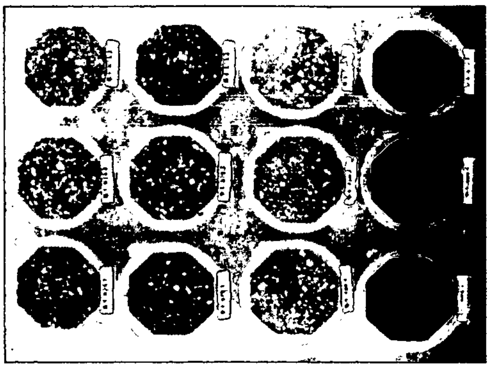


Figure 3-21: Planting; positioning

Source: Alexander Leitner, Vienna 2007

Figure 3-22: Planting; placement

Source: Alexander Leitner, Vienna 2007

3.4.2 Harvesting and documentation

Nine days after removing the lid and black plastic foil the cress had developed sufficiently.

A total of three people were working on the harvest at one time. It consumed a total working day.

A method of the special cutting system with wings on the scissors (DI Ulli Pitha) made sure that no fresh weight plant yield was lost during the process of cutting (Figure 3-23) All cuttings were then transferred into the paper cups which were labelled with the correspondent description (Figure 3-24).

Figure 3-23: Harvest; cutting

Source: Alexander Leitner, Vienna 2007

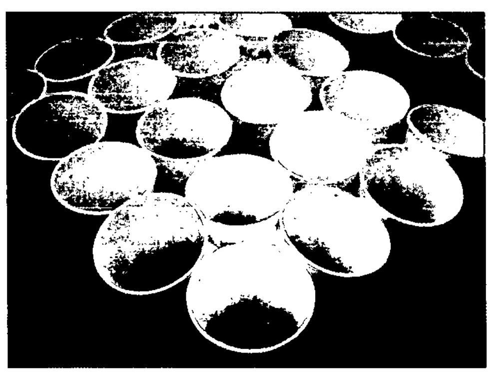


Figure 3-24: Harvest; container

Source: Alexander Leitner, Vienna 2007

All samples where weighed immediately after harvesting. Every cup was weighed before the cress cuttings were placed inside (Figure 3-25). By subtracting this value from the total weight of cup and cuttings the fresh plant weight was obtained. Every weighing was at an accuracy of 0.01g. A Sartorius scale was used for weighing.

One hour before harvesting the germination rate was estimated in comparison to the reference substrate (Figure 3-26)

Figure 3-25: Documentation; fresh weight plant yield after 9 days

Source: Alexander Leitner, Vienna 2007

Figure 3-26: Documentation; germination rate after 9 days

Source: Alexander Leitner, Vienna 2007

The sprout length was also measured shortly before harvesting the cress. By placing a scale next to the sprout which represented the average height the length was obtained (Figure 3-27).

The roots were taken from the most representative plant container of three samples. 8 roots were carefully washed for every container and then photographed (Figure 3-28) and classified according to their growth structure.

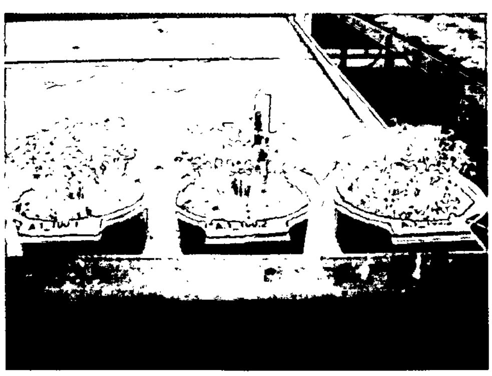


Figure 3-27: Documentation; sprout length after 9 days

Source: Alexander Leitner, Vienna 2007

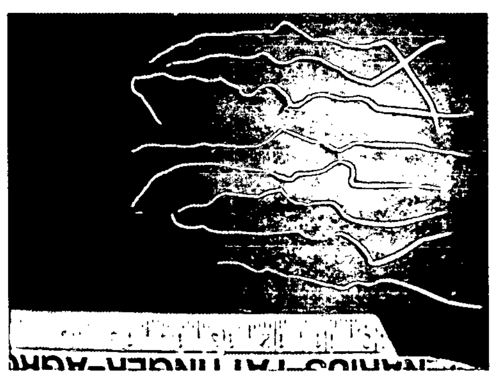


Figure 3-28: Documentation; roots after 9 days

Source: Alexander Leitner, Vienna 2007

4 Results

Both test rounds were harvested nine days after removing the lid and black plastic foil. (09.Dec. – 18.Dec.2006 and 16.Jan. – 25.Jan.2007).

All the documentation was carried out immediately after harvesting, apart from the germination which was recorded shortly before.

The results will be declared in the following order:

- Fresh weight plant yield (4.1)
- Germination rate (4.2)
- Plant colour (4.3)
- Sprout length (4.4)
- Root quality (4.5)

Each description will begin by showing the results on a figure and be followed by a description stating the most important observations.

Material groups are stated together in the result tables due to there similar results (apart from the mixed materials). The Reference material substrate will be illustrated in grey, the crushed brick substrate in red, the crushed concrete in black, the mixed material in green and the natural gravel in blue.

To be able to compare the results they are all set in relation to the reference substrate declared as 100 % at the far left of the figures. For Images of the Reference material refer to Appendix 8.1, 8.2 and 8.3.

For all results obtained refer to Appendix 8.1-Table of results.

4.1 Fresh weight plant yield

The fresh weight yield was the most important research parameter. It is therefore described in three figures. The first shows the 100% Recycled construction material substrates, the second the 75% Recycled material and 25% reference material substrates and the third the 75% Recycled material and 25% compost substrates.

4.1.1 Fresh weight plant yield: 100% Recycled construction material substrate

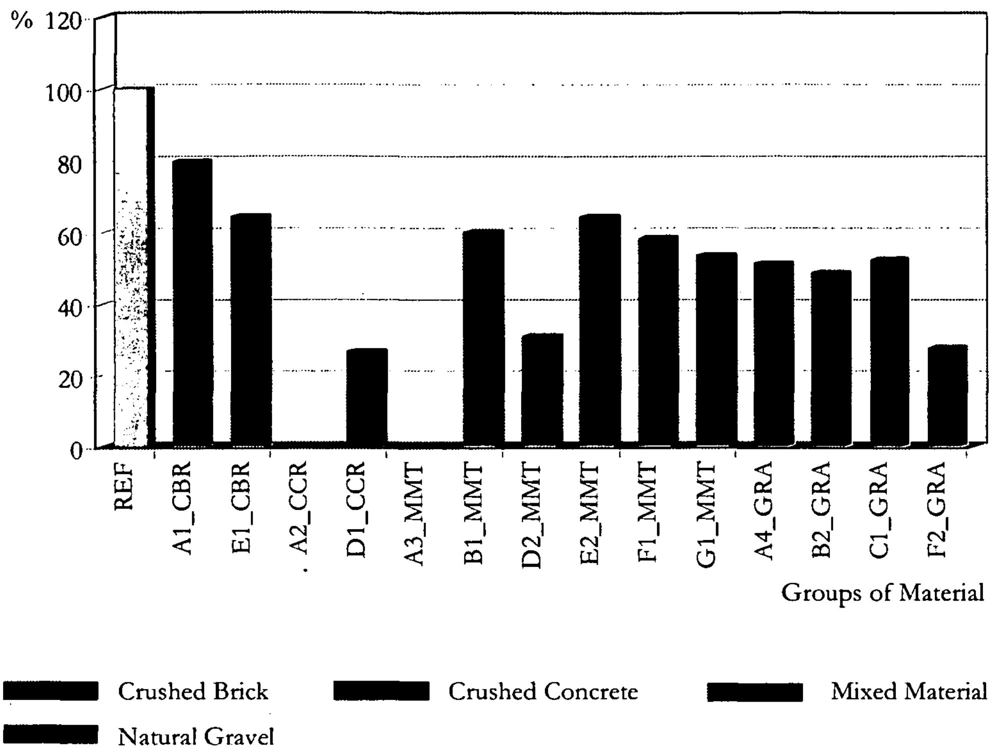


Figure 4-1: **Average fresh weight plant yield of the 100% recycled material substrate as a percentage in relation to the reference substrate**

Source: Alexander Leitner, Vienna 2007

The results in Figure 4-1 show that:

- The substrates A1 (80 %), E1 (65 %) and E2 (65 %) had the best results. A1 and E1 are both pure crushed brick substrates, E2 is a mixed material substrate with a high content of crushed brick.
- A2 and A3 had no fresh weight yield. D1 had a very low yield at 27 %. A2 and D1 are pure crushed concrete substrates; A3 is a mixed material substrate with a high content of crushed concrete.
- The natural gravel substrates and the mixed material substrates were in the centre span between F2 (28 %) and B1 (60 %).
- The mixed material substrates had a large span in their fresh weight yield results between D2 (31 %) and E2 (65 %) due to their different components.

4.1.2 Fresh weight plant yield: 75% Recycled material/25% Reference material

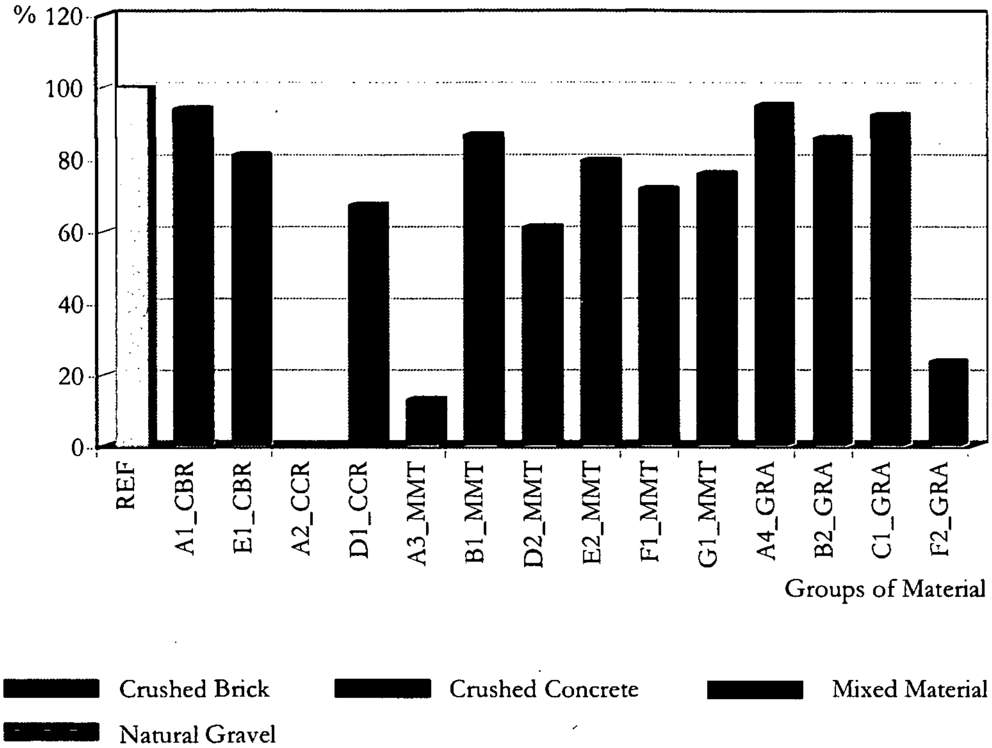


Figure 4-2: **Average fresh weight plant yield of the 75% recycled material substrate/25% reference substrate as a percentage in relation to the reference substrate**

Source: Alexander Leitner, Vienna 2007

The results in Figure 4-2 show that:

- All substrates gained average fresh weight plant yield substantially apart from A2 (0 %) and F2 (24 %)
- Three of the natural gravel substrates (A4, B2 and C1) almost doubled their fresh weight plant yield.
- The natural gravel substrates took over as the strongest group followed by crushed concrete, mixed material and crushed concrete.
- One crushed concrete substrate (D1-68 %) had better results than the weakest mixed material (A3-13 %).

4.1.3 Fresh weight plant yield: 75% Recycled material/ 25% Compost

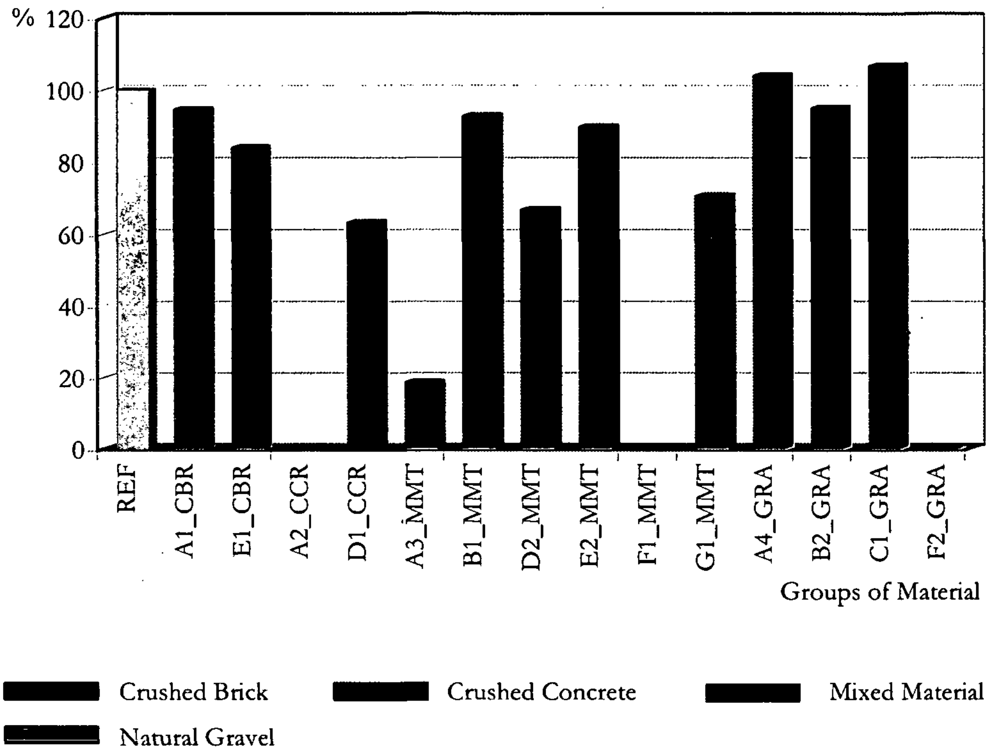


Figure 4-3: **Average fresh weight plant yield of the 75% recycled material substrate/ 25 % compost substrate as a percentage in relation to the reference substrate***

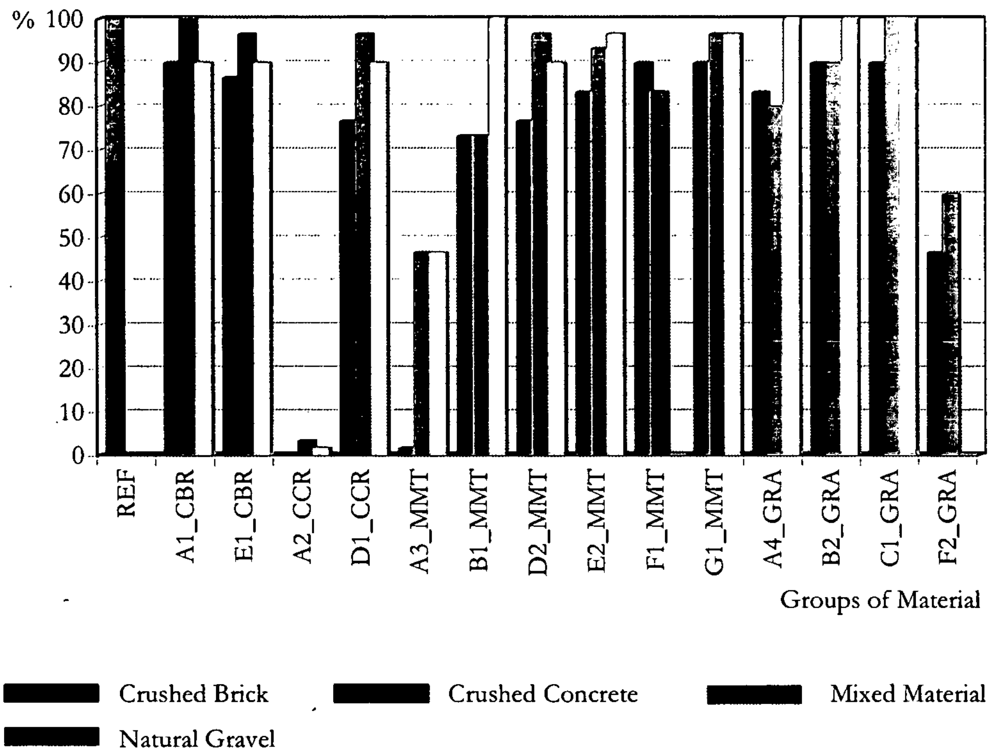
Source: Alexander Leitner, Vienna 2007

The results in Figure 4-3 show that:

- The tested substrates further increased their fresh weight yield, apart from D1 and G1 which dropped slightly.
- A4 and C1 overtook the reference material at 104 % and 107 %.
- There was only a very slight gain of fresh weight yield with the crushed brick substrates (94 and 84 %)

*F1 and F2 where not tested due to lack of substrate

4.2 Germination rate



The dark shade represents the 100 % recycled material substrate
The normal shade represents the 75 % recycled material substrate/ 25 % reference substrate
The light shade represents the 75 % recycled material substrate/ 25 % compost

Figure 4-4: **Average Germination rate of all tested substrates as a percentage in relation to the reference substrate***

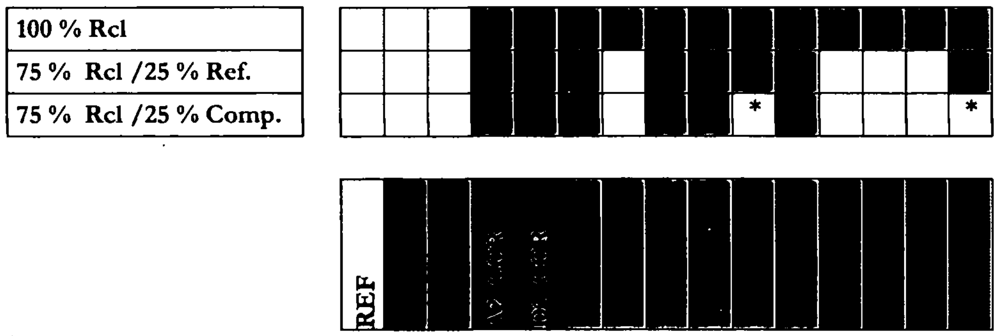
Source: Alexander Leitner, 2007

The results in Table Figure 4-4 show that:

- The best germination rates were achieved by the crushed brick and the natural gravel substrates followed by the mixed materials
- D1 had a very good germination rate compared to the second crushed concrete material A2.
- Apart from A2 and A3 and F2 the germination rate was over 70%.
- The reference material and the compost have a positive influence on the germination rate.

*F1 and F2 in the mixtures with compost were not tested due to lack of substrate

4.3 Plant colour



Rcl: Recyled Material; Ref: Reference Material; Comp: Compost

Crushed Brick Crushed Concrete Mixed Material Natural Gravel

Figure 4-5: Plant colour of all tested substrates in light or dark green*

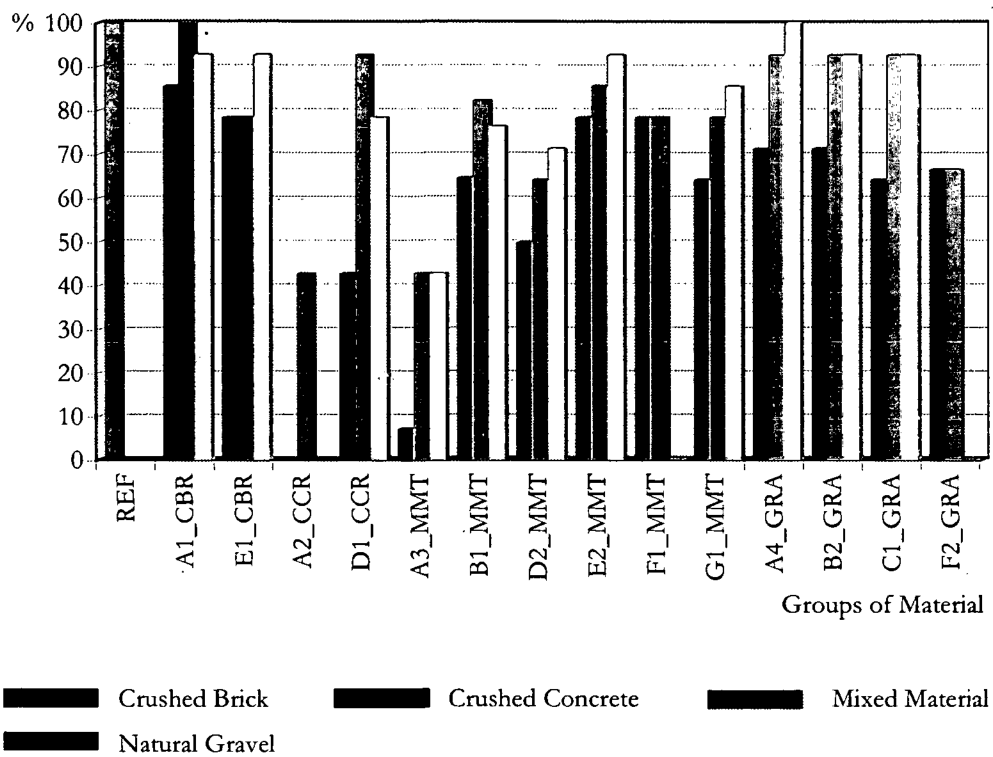
Source: Alexander Leitner, Vienna 2007

The results in Figure 4-5 show that:

- The cress grown on the crushed brick substrates were all light green, the colour of plants grown on the reference material.
- The mixtures of 75 % recycled material/ 25 % reference material and 75 % recycled material/ 25 % compost of B1, A4, B2 and C1 produced plants which were also light green.
- All plants grown on other substrates were dark green.

*F1 and F2 in the mixtures with compost were not tested due to lack of substrate

4.4 Sprout length



The dark shade represents the 100 % recycled material substrate
The normal shade represents the 75 % recycled material substrate/ 25 % reference substrate
The light shade represents the 75 % recycled material substrate/ 25 % compost

Figure 4-6: **Sprout length of all tested substrates as a percentage in relation to the reference substrate***

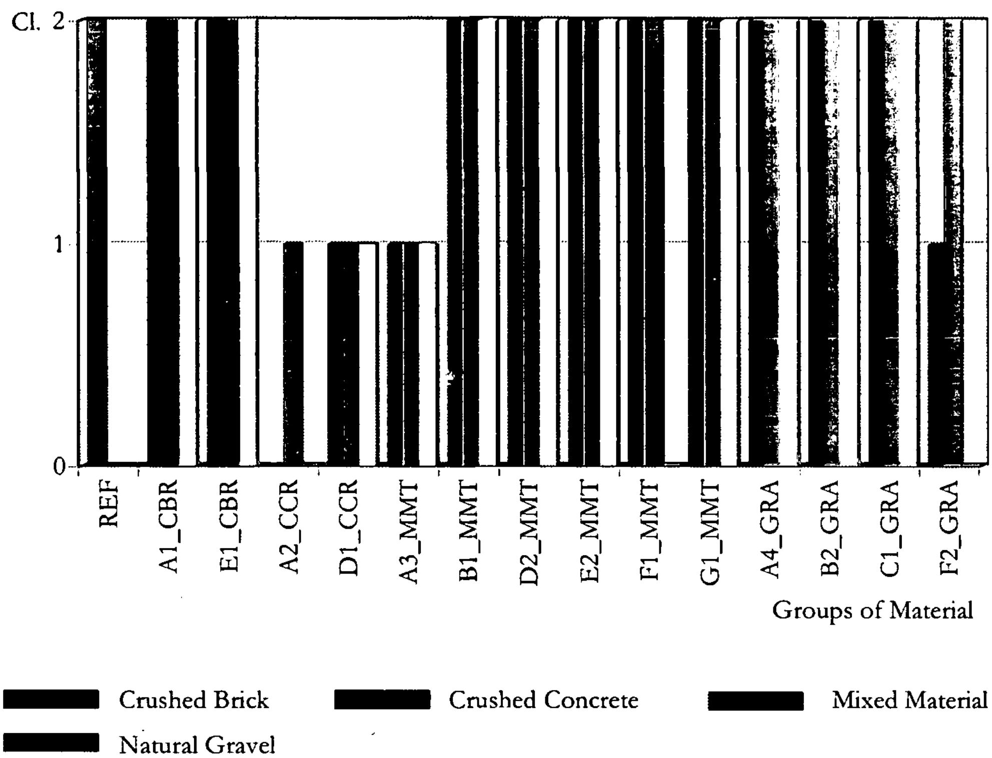
Source: Alexander Leitner, Vienna 2007

The results in Figure 4-6 show that:

- The longest sprouts were achieved on the mixtures of 75 % recycled material/ 25 % reference material and 75 % recycled material/ 25 % compost of A1, E1, E2, A4, B2 and C1.
- The cress grown on A2 and A3 were less than half as long as the ones from the reference material.
- The reference material and the compost have a positive influence on the length of the sprouts.

*F1 and F2 in the mixtures with compost (75/25C) where not tested due to lack of substrate

4.5 Root growth



The dark shade represents the 100 % recycled material substrate
The normal shade represents the 75 % recycled material substrate/ 25 % reference substrate
The light shade represents the 75 % recycled material substrate/ 25 % compost

Figure 4-7: Root growth in two classes: 1-bad growth; 2-normal growth*

Source: Alexander Leitner

The results in Figure 4-7 show that:

- Only A2, D1, A3 and the 100% mixture of the F2 natural gravel clearly different root growth
- The reference material and the compost have only a minor influence on the root growth.

*F1 and F2 in the mixtures with compost (75/25C) where not tested due to lack of substrate

5 Discussion

This chapter discusses the results illustrated in chapter 4.

First coherences will be analysed to be able to evaluate which parameters are most important when classifying the material. (chapter 5.1).

Subsequently the materials will be discussed and the plant compatibility classified (chapter 5.2).

The last point of this discussion will consist of a conclusion bringing together all results and giving recommendations (chapter 5.3).

5.1 Coherences and evaluation of parameters

The conclusions taken from these evaluations were:

- Only the results of the 100% recycled material should be used for a comparison and classification of the materials due to large and differing influence of the reference material and compost on the results
- Fresh weight plant yield, sprout length and germination rate proved to be reliable indicators of the plant compatibility of recycled construction materials due to their coherences
- Root growth also proved to be a indicator of plant compatibility of recycled construction materials but should treated with caution because roots structures can be very differing within one classification.
- The pH-value also proved to be a good indicator, which was shown in the coherence with the Fresh weight plant yield.

Numerous coherences were examined during the analysis of the test results.

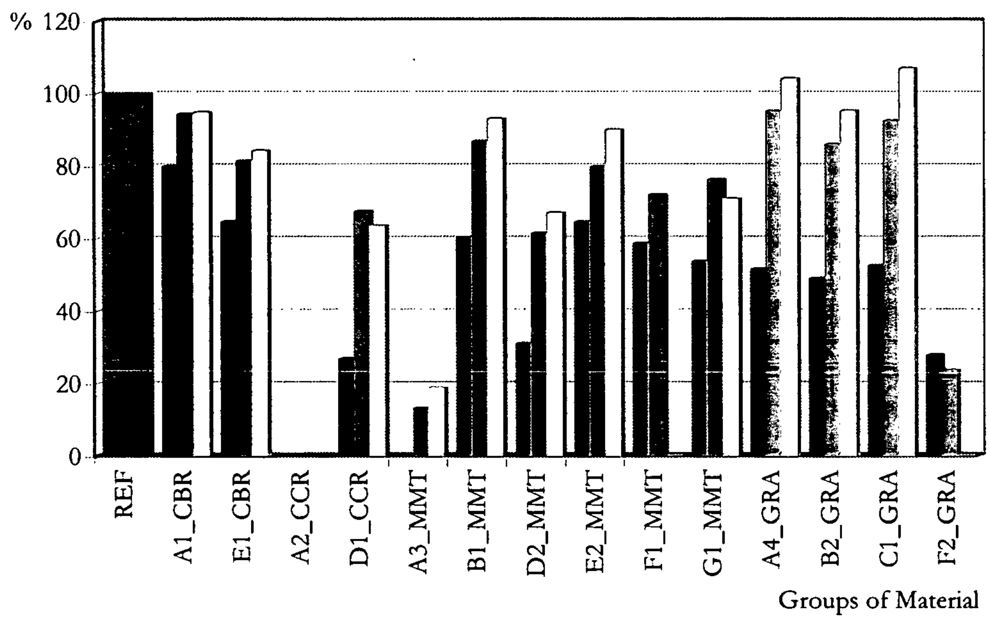
What can be said at first sight from the obtained results is that reference and compost materials have a positive influence on all results.

There were comparisons between material characteristics such as conductivity or pH-value and the results from the plant compatibility test such as sprout length and fresh weight yield. The different results of the plant compatibility test were also compared to evaluate there correlation and importance.

The only comparisons which produced reasonable results for this test of plant compatibility were: fresh weight yield with sprout length, fresh weight yield with germination rate, fresh weight yield with root growth and fresh weight yield with pH-value. These comparisons will be discussed in chapters 0 to 5.1.5.

Each description will begin with a Figure of coherence and be followed by stating the most important characteristics.

5.1.1 Fresh weight yield of all tested substrates



Crushed Brick · Crushed Concrete · Mixed Material · Natural Gravel

The dark shade represents the 100 % recycled material substrate
The normal shade represents the 75 % recycled material substrate/ 25 % reference substrate
The light shade represents the 75 % recycled material substrate/ 25 % compost

Figure 5-1: Average Fresh weight yield of all tested substrates as a percentage in relation to the reference substrate*

Source: Alexander Leitner, 2007

The results in Figure 5-1 show the influence of the reference substrate and the compost on the results of the Fresh weight yield. It is clear that these added substrates have better influence on some materials than others. Crushed brick materials are only influenced lightly whereas the natural gravel almost doubles.

*F1 and F2 in the mixtures with compost (75/25C) where not tested due to lack of substrate

5.1.2 Fresh weight plant yield and sprout length

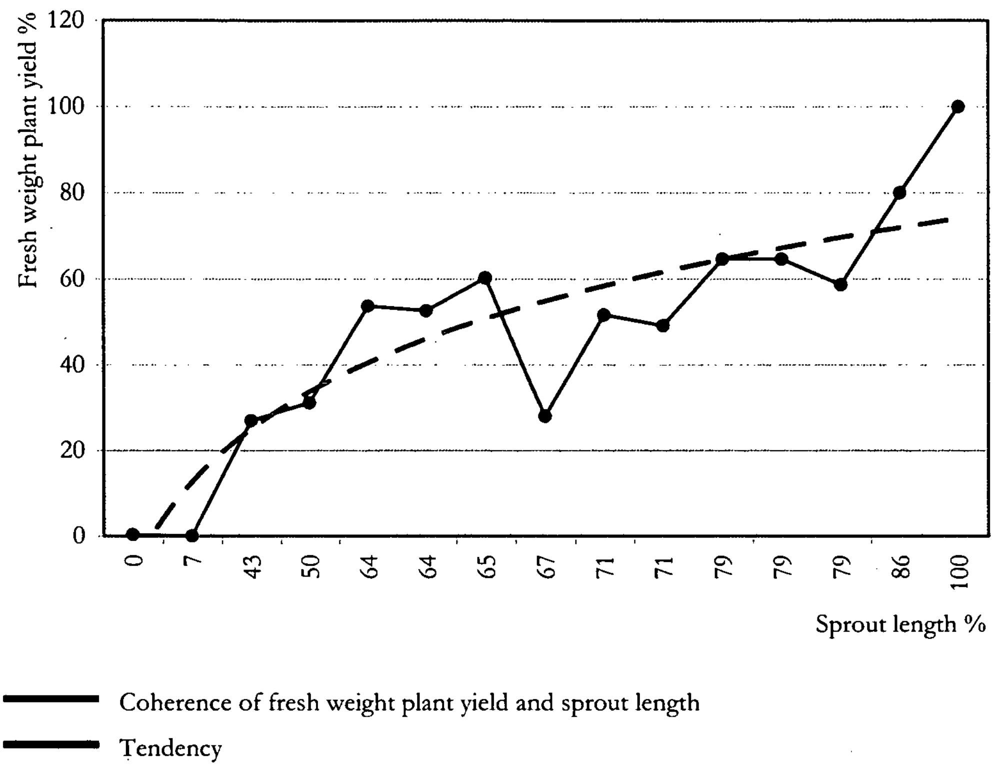


Figure 5-2: Coherence between fresh weight plant yield and sprout length

Source: Alexander Leitner, Vienna 2007

An increasing sprout length was applied on the abscissa (in percentage compared to the reference material) and set in relation to the fresh weight plant yield (in percentage compared to the reference material) on the ordinate. Only results from the 100 % recycled material substrates were used for this figure.

The coherence in Figure 5-2 shows that:

- There was an increasing tendency in the relation of fresh weight yield and sprout length.
- These parameters could be used efficiently to classify the plant compatibility of recycled construction materials
- The largest difference were between the sprout length of 65 % and 67 % (fresh weight yield between 28 % and 60 %

5.1.3 Fresh weight plant yield and germination rate

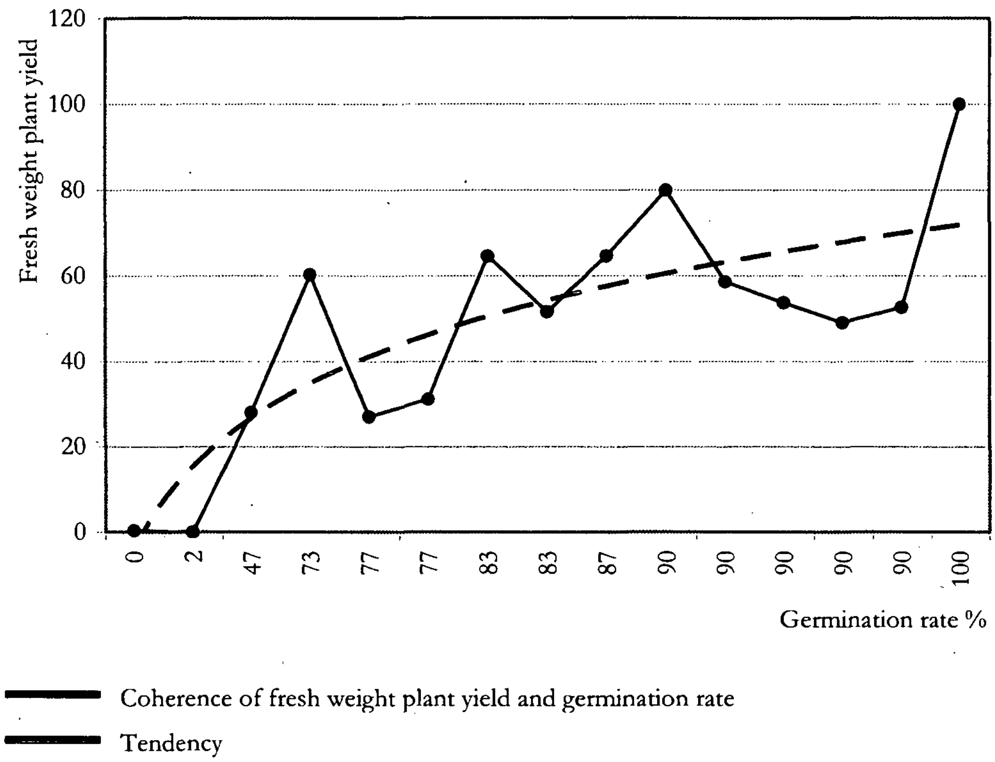


Figure 5-3: Coherence between fresh weight plant yield and germination rate.

Source: Alexander Leitner, Vienna 2007

An increasing germination rate was applied on the abscissa (in percentage compared to the reference material) and set in relation to the fresh weight plant yield (in percentage compared to the reference material) on the ordinate. Only results from the 100 % recycled material substrates were used for this figure

The results in Figure 5-3 show that:

- There was an increasing tendency in the relation of fresh weight yield and germination rate.
- These parameters could be used efficiently to classify the plant compatibility of recycled construction materials.
- The largest differences were at the germination rate of 90 % (fresh weight yield between 49 % and 80 %). This was likely to be caused by an error in estimating the germination rate.

5.1.4 Fresh weight plant yield and root growth

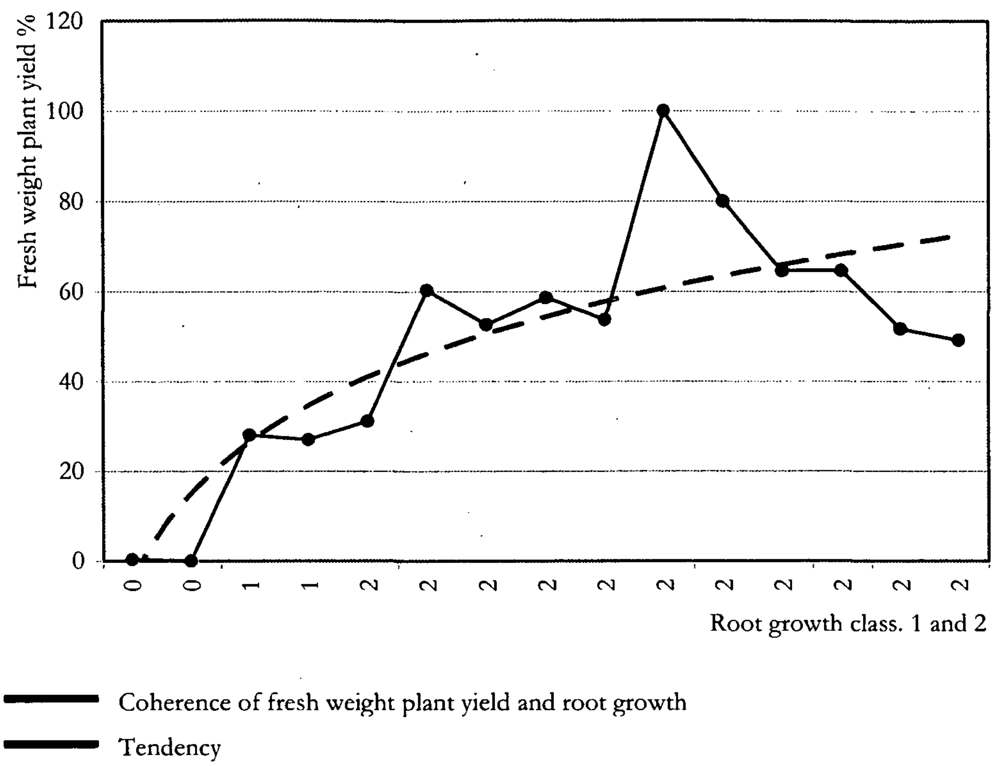


Figure 5-4: Coherence between fresh weight plant yield and root growth.

Source: Alexander Leitner, Vienna 2007

An increasing root growth was applied on the abscissa (in classifications 1 and 2) and set in relation to the fresh weight plant yield (in percentage compared to the reference material) on the ordinate. Only results from the 100 % recycled material substrates were used for this figure.

The results in Figure 5-4 show that:

- There was a increasing tendency in the relation of fresh weight yield and root growth
- There were very large differences in the classification 2 (31 %-100 %) and the values between both groups were very close (27 % and 31 %).
- The root growth could only be used to disqualify a material if the was extremely bad growth but not to classify it because the borders were to close.

5 Discussion

This chapter discusses the results illustrated in chapter 4.

First coherences will be analysed to be able to evaluate which parameters are most important when classifying the material. (chapter 5.1).

Subsequently the materials will be discussed and the plant compatibility classified (chapter 5.2).

The last point of this discussion will consist of a conclusion bringing together all results and giving recommendations (chapter 5.3).

5.1 Coherences and evaluation of parameters

The conclusions taken from these evaluations were:

- Only the results of the 100% recycled material should be used for a comparison and classification of the materials due to large and differing influence of the reference material and compost on the results
- Fresh weight plant yield, sprout length and germination rate proved to be reliable indicators of the plant compatibility of recycled construction materials due to their coherences
- Root growth also proved to be a indicator of plant compatibility of recycled construction materials but should treated with caution because roots structures can be very differing within one classification.
- The pH-value also proved to be a good indicator, which was shown in the coherence with the Fresh weight plant yield.

Numerous coherences were examined during the analysis of the test results.

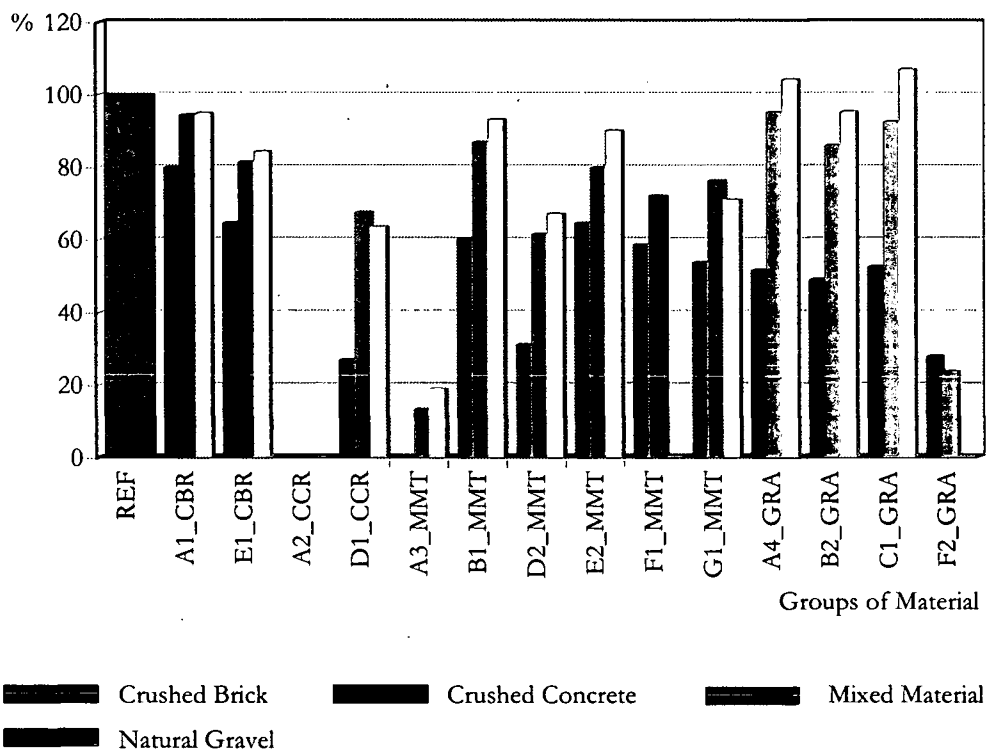
What can be said at first sight from the obtained results is that reference and compost materials have a positive influence on all results.

There were comparisons between material characteristics such as conductivity or pH-value and the results from the plant compatibility test such as sprout length and fresh weight yield. The different results of the plant compatibility test were also compared to evaluate there correlation and importance.

The only comparisons which produced reasonable results for this test of plant compatibility were: fresh weight yield with sprout length, fresh weight yield with germination rate, fresh weight yield with root growth and fresh weight yield with pH-value. These comparisons will be discussed in chapters 0 to 5.1.5.

Each description will begin with a Figure of coherence and be followed by stating the most important characteristics.

5.1.1 Fresh weight yield of all tested substrates



The dark shade represents the 100 % recycled material substrate
The normal shade represents the 75 % recycled material substrate/ 25 % reference substrate
The light shade represents the 75 % recycled material substrate/ 25 % compost

Figure 5-1: Average Fresh weight yield of all tested substrates as a percentage in relation to the reference substrate*

Source: Alexander Leitner, 2007

The results in Figure 5-1 show the influence of the reference substrate and the compost on the results of the Fresh weight yield. It is clear that these added substrates have better influence on some materials than others. Crushed brick materials are only influenced lightly whereas the natural gravel almost doubles.

*F1 and F2 in the mixtures with compost (75/25C) where not tested due to lack of substrate

5.1.2 Fresh weight plant yield and sprout length

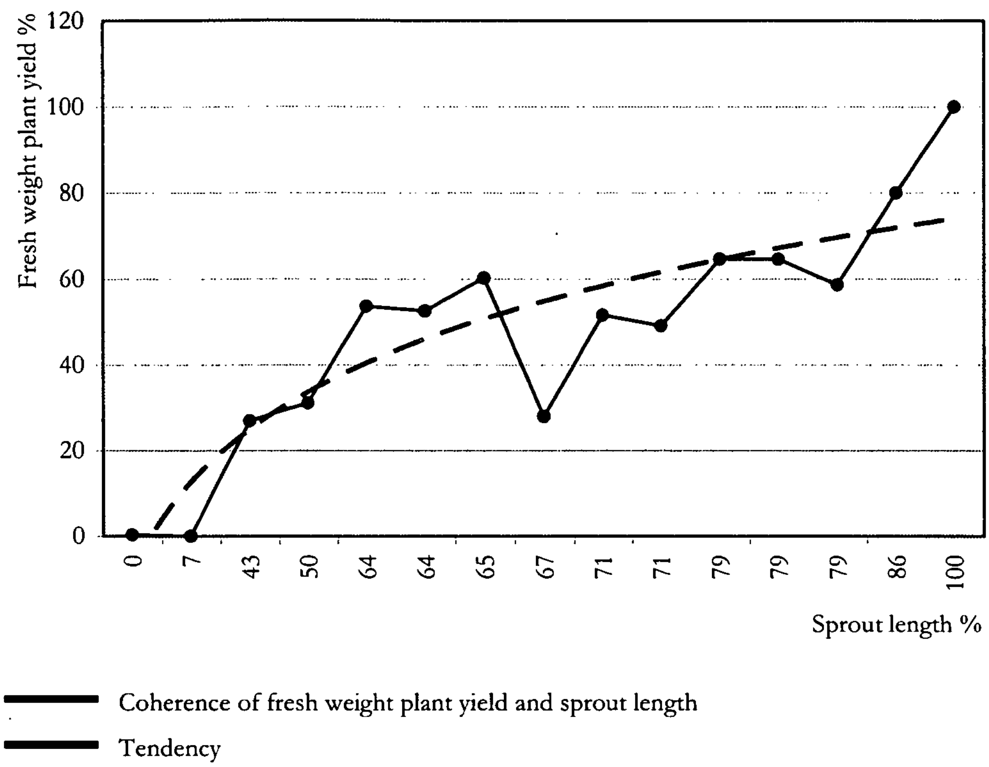


Figure 5-2: Coherence between fresh weight plant yield and sprout length

Source: Alexander Leitner, Vienna 2007

An increasing sprout length was applied on the abscissa (in percentage compared to the reference material) and set in relation to the fresh weight plant yield (in percentage compared to the reference material) on the ordinate. Only results from the 100 % recycled material substrates were used for this figure.

The coherence in Figure 5-2 shows that:

- There was an increasing tendency in the relation of fresh weight yield and sprout length.
- These parameters could be used efficiently to classify the plant compatibility of recycled construction materials
- The largest difference were between the sprout length of 65 % and 67 % (fresh weight yield between 28 % and 60 %

5.1.3 Fresh weight plant yield and germination rate

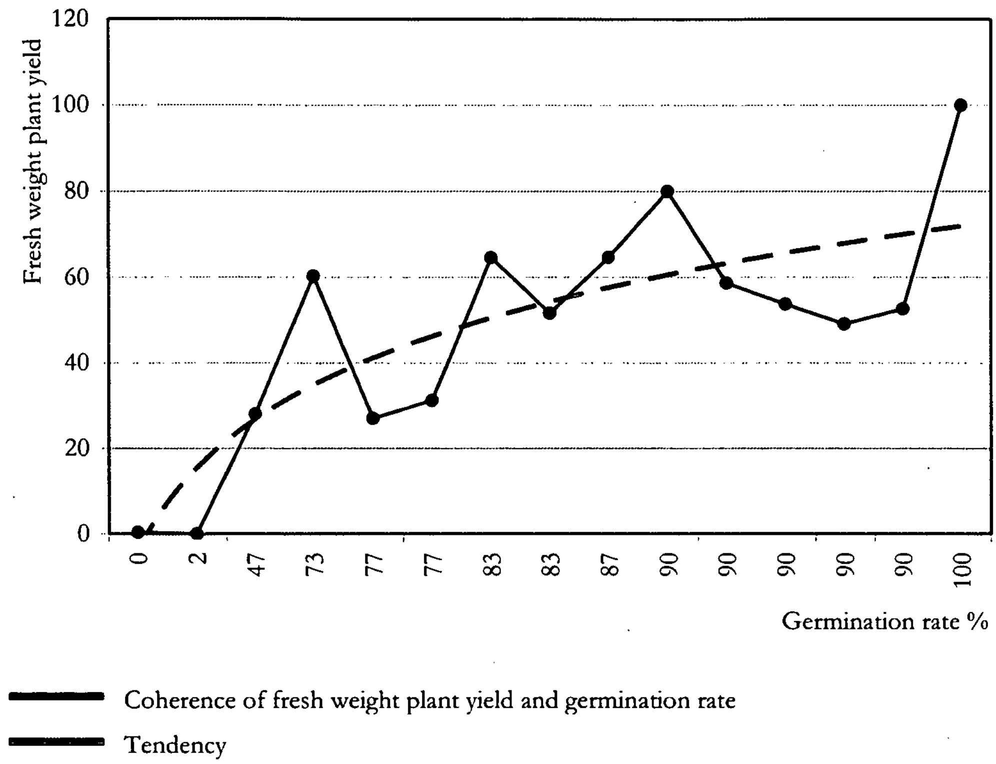


Figure 5-3: Coherence between fresh weight plant yield and germination rate.
Source: Alexander Leitner, Vienna 2007

An increasing germination rate was applied on the abscissa (in percentage compared to the reference material) and set in relation to the fresh weight plant yield (in percentage compared to the reference material) on the ordinate. Only results from the 100 % recycled material substrates were used for this figure

The results in Figure 5-3 show that:

- There was an increasing tendency in the relation of fresh weight yield and germination rate.
- These parameters could be used efficiently to classify the plant compatibility of recycled construction materials.
- The largest differences were at the germination rate of 90 % (fresh weight yield between 49 % and 80 %). This was likely to be caused by an error in estimating the germination rate.

5.1.4 Fresh weight plant yield and root growth

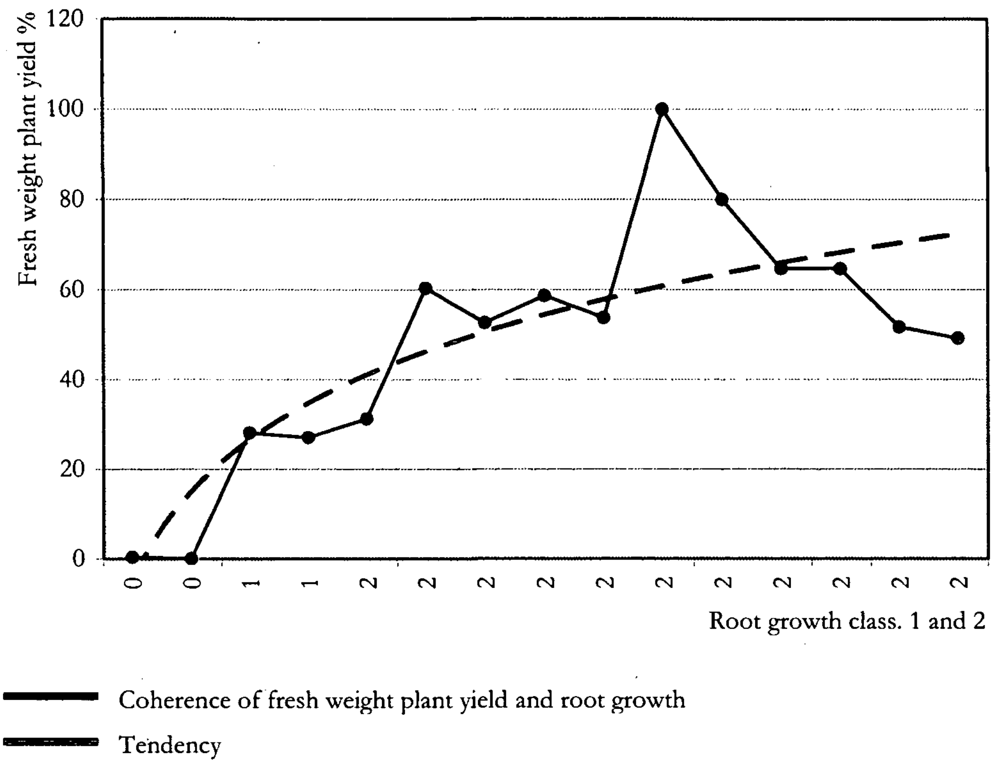


Figure 5-4: **Coherence between fresh weight plant yield and root growth.**

Source: Alexander Leitner, Vienna 2007

An increasing root growth was applied on the abscissa (in classifications 1 and 2) and set in relation to the fresh weight plant yield (in percentage compared to the reference material) on the ordinate. Only results from the 100 % recycled material substrates were used for this figure.

The results in Figure 5-4 show that:

- There was a increasing tendency in the relation of fresh weight yield and root growth
- There were very large differences in the classification 2 (31 %-100 %) and the values between both groups were very close (27 % and 31 %).
- The root growth could only be used to disqualify a material if the was extremely bad growth but not to classify it because the borders were to close.

5.1.5 Fresh weight plant yield and pH-value

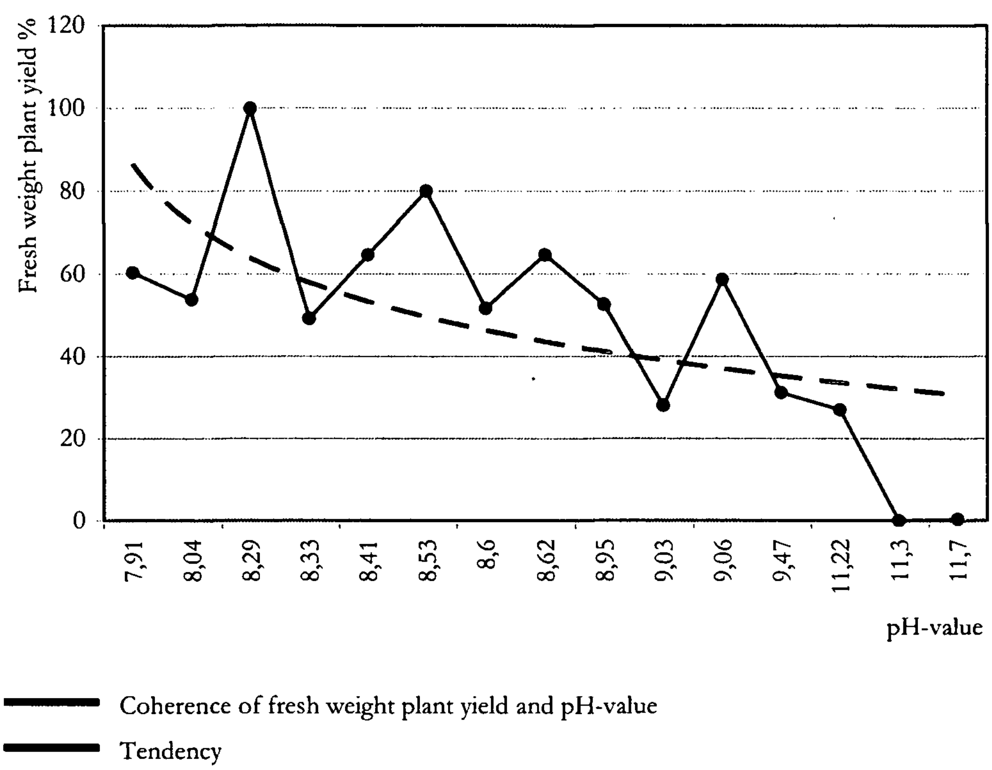


Figure 5-5: Coherence between fresh weight plant yield and pH-value

Source: Alexander Leitner, Vienna 2007

An increasing pH-value was applied on the abscissa and set in relation to the fresh weight plant yield (in percentage compared to the reference material) on the ordinate. Only results from the 100 % recycled material substrates were used for this figure.

The results in Figure 5-5 show that:

- There was a decreasing tendency in the relation of fresh weight yield and increasing pH-value.
- The pH-value was a suitable indicator.

5.2 Classification of Materials

In this chapter every material is discussed and classified on the basis of the researched parameters: fresh weight plant yield, sprout length, germination rate, root growth and pH-value. The plant colour is a good indicator for nutrients and will also be discussed. Material characteristics such as density are also taken in to account. Only results from the 100 % recycled material substrates were used for this classification.

The Classification is not defined by clear borders. This would not be sensible due to very complex coherences. It must be understood as a combination of all researched parameters.

The plant compatibility of the recycled materials was classified as:

1. Satisfactory
2. Semi-Satisfactory
3. Unsatisfactory

Each description will begin by showing an image of the plant development immediately before harvesting and a figure containing the most important parameters: fresh weight plant yield, sprout length and germination rate. It will be followed by a discussion stating the most important points, and a classification of the material concerning plant compatibility.

For all results please refer to Appendix 8.1-Table of results.

5.2.1 Material A1_CBR crushed brick

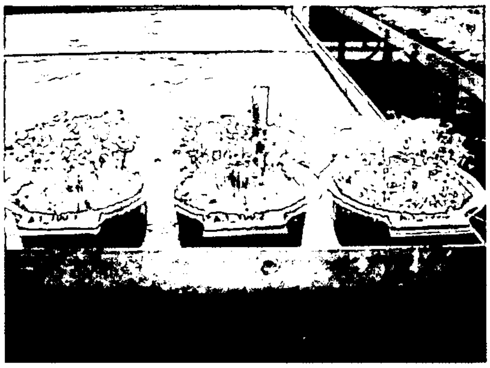


Figure 5-6: A1_CBR crushed brick after 9 days

Source: Alexander Leitner, Vienna 2007

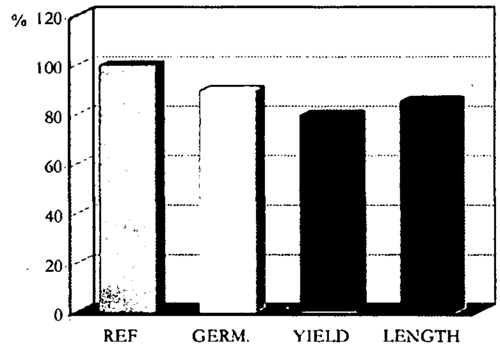


Figure 5-7: A1_CBR crushed brick; germ., yield, length

Source: Alexander Leitner, Vienna 2007

The crushed brick substrate A1 had the best results in most researched parameters.

With a fresh weight plant yield of 80% it was in first place. It is likely that this was caused by the good water storage capacity of clay and nutrients which were missing in other substrates. A1 also had a good pH-value of 8.53. The material was loosely layered due to the large fraction of coarse material. The sprout length was at 86% of the reference substrate which was also the best result of the materials. The root structure which was rated with the highest grade matched those of the reference material and the natural gravel. The germination rate of 90% also contributed to the good picture of this material. The plant was light green, like the reference substrate.

After taking all these results under consideration the plant compatibility of A1_CBR was classified as satisfactory.

5.2.2 Material E1_CBR crushed brick

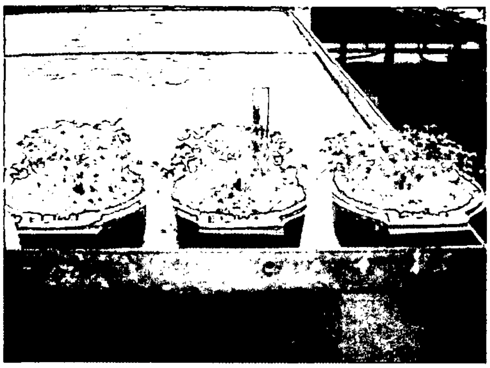


Figure 5-8: E1_CBR crushed brick after 9 days

Source: Alexander Leitner, Vienna 2007

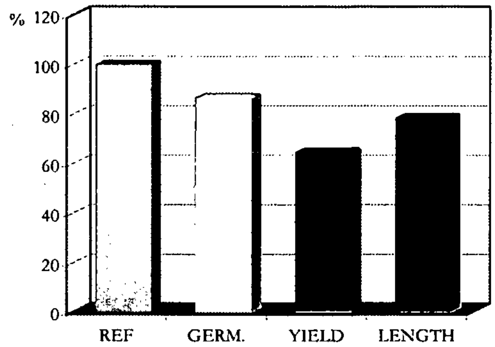


Figure 5-9: E1_CBR crushed brick ; germ., yield, length

Source: Alexander Leitner, Vienna 2007

E1_CBR, the second crushed brick tested, had very similar results to the first A1_CBR.

Although the fresh weight plant yield was lower at 65% it was still in second place together with the mixed material E2. With a germination of 87% it was good as A1_CCR. The leaves had a light green colour like the reference substrate. The pH-Value was good at 8.62. The sprout length of 79% was also the second best result. E1 had a highly rated root growth very similar to the reference substrate.

After taking all these results into consideration the plant compatibility of E1_CBR was classified as satisfactory.

5.2.3 Material A2_CCR crushed concrete

Figure 5-10: A2_CCR crushed concrete after 9 days

Source: Alexander Leitner, Vienna 2007

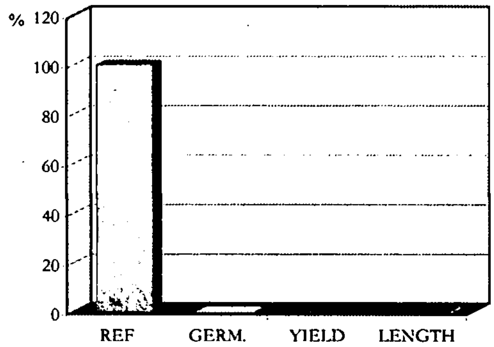


Figure 5-11: A2_CCR crushed concrete; germ., yield, length

Source: Alexander Leitner, Vienna 2007

A2, a crushed concrete substrate, was the material with the worst results.

There was no fresh weight plant yield, subsequently no germination nor sprout length. The only roots that could develop were on a small piece of compost in the 75% recycling material/ 25% reference substrate mixture, close to the surface (Figure 5-11)

These results were likely to be due to a very high pH-value of 11.66 and a possible reaction of the cement in this material.

After taking all these results into consideration the plant compatibility of A2_CCR was classified as unsatisfactory.

5.2.4 Material D1_CCR crushed concrete

Figure 5-12: D1_CCR crushed concrete after 9 days

Source: Alexander Leitner, Vienna 2007

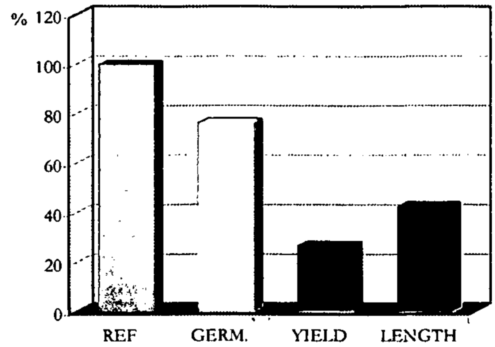


Figure 5-13: D1_CCR crushed concrete; germ., yield, length

Source: Alexander Leitner, Vienna 2007

D1_CCR, the second crushed concrete tested, had slightly better results than the first one A1_CCR

The fresh weight plant yield was one of the worst at only 27%, but the germination rate relatively good at 77% (far better than the other concrete). Also the sprout length was low at 43%. The leaves were clearly dark green. From the root growth it was also seen that this cress had not developed well.

The pH-value (11.22) was slightly lower than D1, but still very high.

After taking all these results into consideration the plant compatibility of D1_CCR was classified as semi-satisfactory.

5.2.5 Material A3_MMT mixed material

Figure 5-14: A3_MMT mixed material after 9 days

Source: Alexander Leitner, Vienna 2007

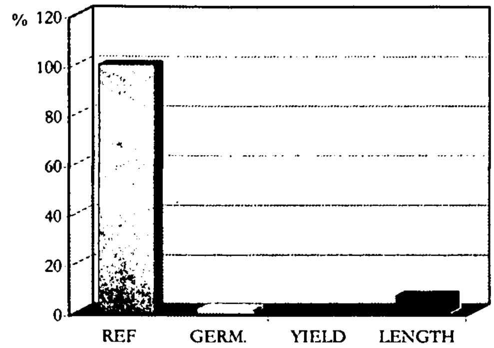


Figure 5-15: A3_MMT mixed material; germ., yield, length

Source: Alexander Leitner, Vienna 2007

The A3 mixed material had the second to worst results.

All results were almost at 0% apart from a few sprouts that lifted the result of the fresh weight yield to 2 % and the sprout length to 7%.

As you can read under the material descriptions in chapter 3.3 this material was basically a pure crushed concrete material which explains the second highest pH-value of 11.27, which is likely to be the cause for this bad result.

After taking all these results into consideration the plant compatibility of A3_MMT was classified as unsatisfactory.

5.2.6 Material B1_MMT mixed material

Figure 5-16: B1_MMT mixed material; after 9 days

Source: Alexander Leitner, Vienna 2007

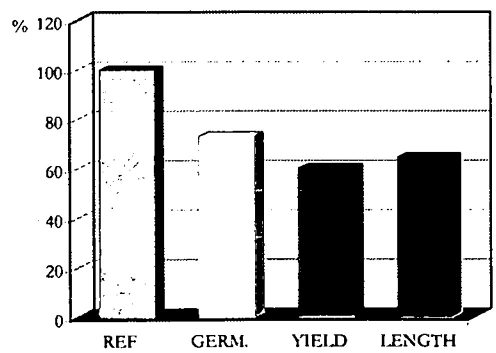


Figure 5-17: B1_MMT mixed material; germ., yield, length

Source: Alexander Leitner, Vienna 2007

B1 had the second best results in the mixed material group.

The fresh weight yield of 60% was the third best result of all. A germination rate of 73% was not especially high but acceptable. The leaves were clearly dark green. The sprouts reached 65% compared to the reference substrate. The development of the roots was rated as good.

This was a material with a high content of brick and a good pH-value at 7.91. There were no impurities found in this material.

After taking all these results into consideration the plant compatibility of B1_MMT was classified as satisfactory.

5.2.7 Material D2_MMT mixed material

Figure 5-18: D2_MMT mixed material; after 9 days

Source: Alexander Leitner, Vienna 2007

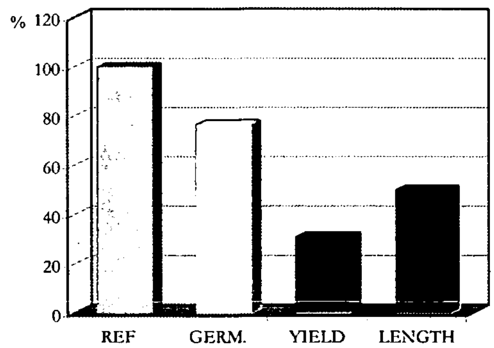


Figure 5-19: D2_MMT mixed material; germ., yield, length

Source: Alexander Leitner, Vienna 2007

This substrate had the worst results in the mixed material fraction.

The fresh weight yield was relatively low at 31%, as was the germination rate at 77%. The colour was dark green. The sprout length was also relatively low at 50%. The roots proved to have a healthy development.

This material had a high content of brick, but a high pH-value at 9.47. There were also a lot of impurities found in this material. All these factors could have been the reason for the bad result.

After taking all these results into consideration the plant compatibility of D2_MMT was classified semi-satisfactory.

5.2.8 Material E2_MMT mixed material

Figure 5-20: E2_MMT mixed material; after 9 days

Source: Alexander Leitner, Vienna 2007

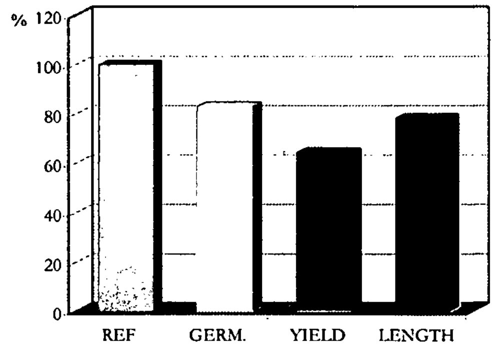


Figure 5-21: E2_MMT mixed material; germ., yield, length

Source: Alexander Leitner, Vienna 2007

Material E2 had the best results in the mixed materials group.

All results were almost identical to E1_CCR. The fresh weight yield was at 65% and a germination rate at 83 %. The cress was dark green. The sprout length was at 79% which also a positive result. The roots were very similar to those in the reference material.

E2 was mixed material with a very high content of crushed concrete, with a pH-value of 8.41 which could explain the good results considering the crushed brick substrates had the best results.

After taking all these results into consideration the plant compatibility of E2_MMT was classified satisfactory.

5.2.9 Material F1_MMT mixed material

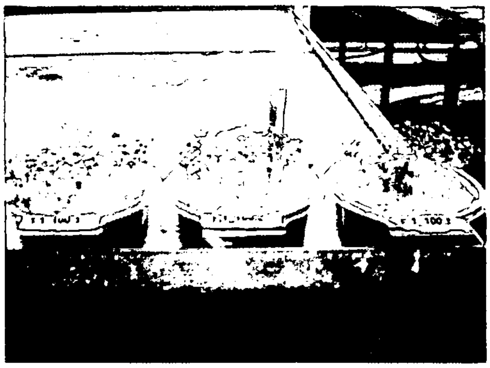


Figure 5-22: F1_MMT mixed material; after 9 days

Source: Alexander Leitner, Vienna 2007

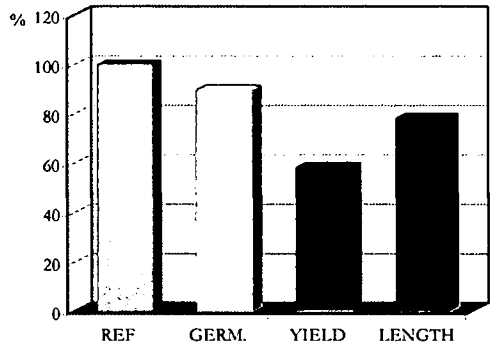


Figure 5-23: F1_MMT mixed material; germ., yield, length

Source: Alexander Leitner, Vienna 2007

F1 was in the centre span of the mixed materials.

The fresh weight yield was 59 %, the germination rate 90 %. The plant colour was dark green. The sprout length was one of the highest at 79%. The roots also had a healthy development.

F1 had a relatively high content of natural stone and a pH-value of 9.06. No impurities were found in this material.

After taking all these results into consideration the plant compatibility of F1_MMT was classified as satisfactory.

5.2.10 Material G1_MMT mixed material

Figure 5-24: G1_MMT mixed material; after 9 days

Source: Alexander Leitner, Vienna 2007

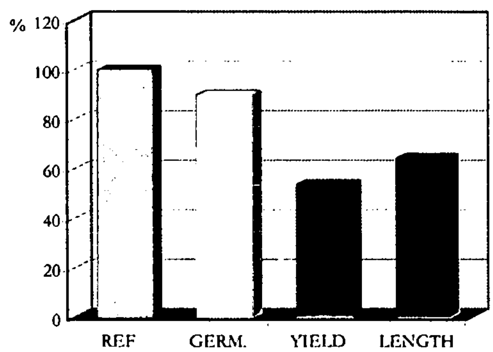


Figure 5-25: G1_MMT mixed material; germ., yield, length

Source: Alexander Leitner, Vienna 2007

G1 was another material in the centre span of the mixed materials.

Apart from the root growth which was not very good, the results were satisfactory. The fresh weight yield was at 54%, the germination rate at 90%. The cress grown on G1 was dark green and the sprout length at 65% of the reference material.

This material had a pH-value of 8.04 and a relatively high content of natural stone.

After taking all these results into consideration the plant compatibility of G1_MMT was classified as satisfactory.

5.2.11 Material A4_GRA natural gravel

Figure 5-26: A4_GRA natural gravel; after 9 days

Source: Alexander Leitner, Vienna 2007

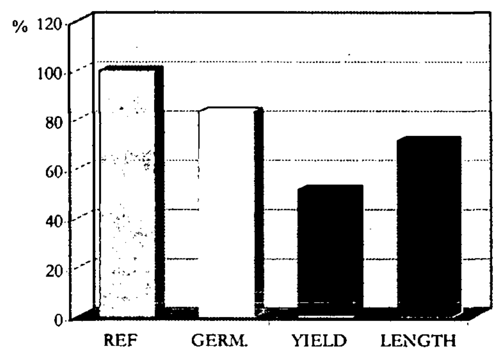


Figure 5-27: A4_GRA natural gravel; germ., yield, length

Source: Alexander Leitner, Vienna 2007

All natural materials had very similar results which correlate to the centre span of the mixed materials.

The fresh weight plant yield was at 52%, the germination rate at 83%. All plants were dark green and the sprouts were 71 % of the reference substrate. The pH-value was 8.6.

A4 was a natural gravel with typical characteristics. The moderate results were likely to be due to a lack of nutrients and not to a negative influence from the substrate.

After taking all these results into consideration the plant compatibility of G1_MMT was classified as satisfactory.

5.2.12 Material B2_GRA natural gravel

Figure 5-28: B2_GRA natural gravel; after 9 days

Source: Alexander Leitner, Vienna 2007

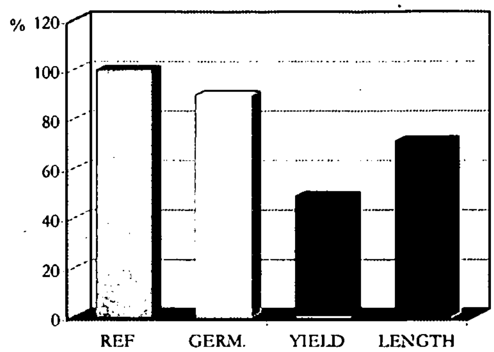


Figure 5-29: B2_GRA natural gravel; germ., yield, length

Source: Alexander Leitner, Vienna 2007

All natural materials had very similar results which correlate to the centre span of the mixed materials.

The fresh weight plant yield was at 49%, the germination rate at 90%. All plants were dark green and the sprouts were 71 % of the reference substrate. The pH-value was 8.33. A4 was natural gravel with typical characteristics. The moderate results were likely to be due to a lack of nutrients and not to a negative influence from the substrate.

After taking all these results into consideration the plant compatibility of B2_GRA was classified as satisfactory.

5.2.13 Material C1_GRA natural gravel

Figure 5-30: C1_GRA natural gravel; after 9 days

Source: Alexander Leitner, Vienna 2007

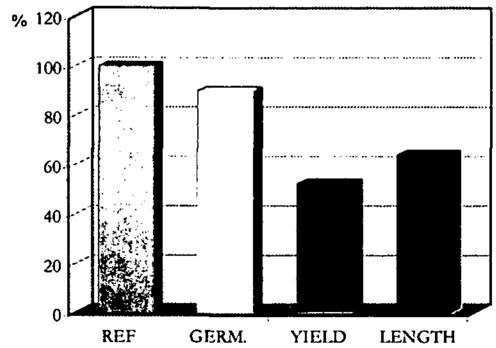


Figure 5-31: C1_GRA natural gravel; germ., yield, length

Source: Alexander Leitner, Vienna 2007

All natural materials had very similar results which correlate to the centre span of the mixed materials.

The fresh weight plant yield was at 53 %, the germination rate at 90 %. All plants were dark green and the sprouts were 64 % of the reference substrate. The pH-value was 8.95. C1 was natural gravel with typical characteristics. The moderate results were likely to be due to a lack of nutrients and not to a negative influence from the substrate.

After taking all these results into consideration the plant compatibility of C1_GRA was classified as satisfactory.

5.2.14 Material F2_GRA natural gravel

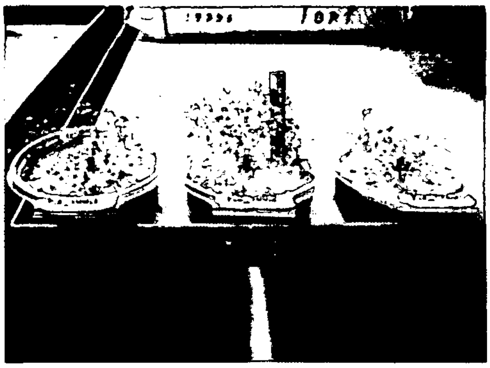


Figure 5-32: F2_GRA natural gravel; after 9 days

Source: Alexander Leitner, Vienna 2007

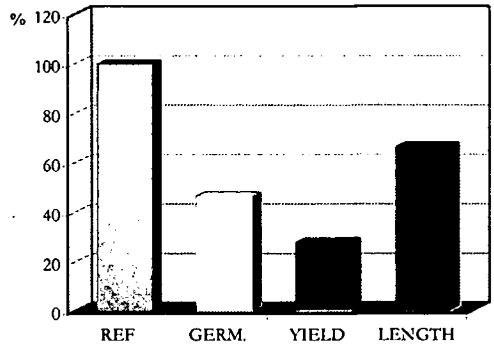


Figure 5-33: F2_GRA natural gravel; germ., yield, length

Source: Alexander Leitner, Vienna 2007

F2 was an exception in the group of natural gravel substrates. All results were significantly worse.

The fresh weight plant yield was at 28 %, the germination rate at 47 %. All plants were dark green and the sprouts were 67% of the reference substrate. The pH-value was 9.03.

F2 was natural gravel with typical characteristics, apart from a very high content of fine material. One possible explanation for the bad results could be over watering during the planting phase.

After taking all these results into consideration the plant compatibility of F2_GRA was classified as semi-satisfactory.

5.3 Conclusion

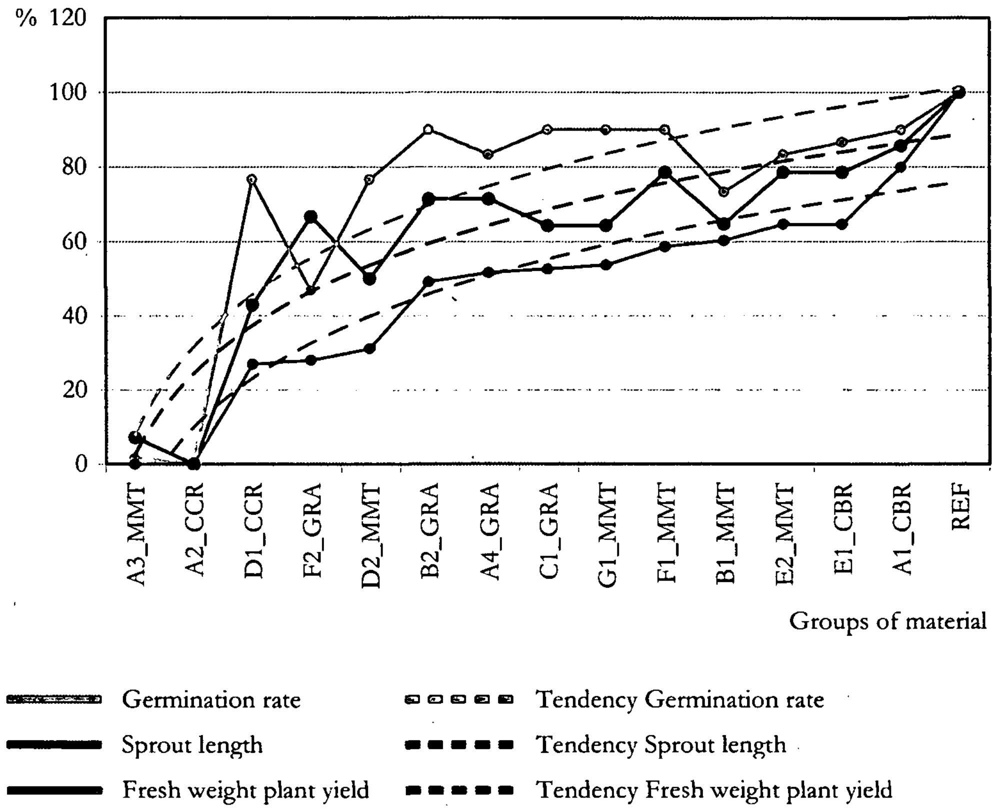


Figure 5-34: **Germination rate, Sprout length and Fresh weight plant yield in percentage compared to the reference substrate.**

Source: Alexander Leitner, Vienna 2007

Figure 5-34 illustrates the combined results of germination rate, sprout length and fresh weight yield. On the abscissa there is a sequence of materials which is the result of the Fresh weight yield.

Figure 5-35 shows that:

- The crushed brick materials (CBR) achieved the best results.
- The crushed concrete materials (CCR) achieved the worst results.
- The mixed materials (MMT) and the natural gravel (GRA) are within the centre span.

	Fresh weight plant yield	Germination rate	Sprout length	Plant colour	Root growth	Classification
	[%]	[%]	[%]	[light green; dark green]	[2=good; 1=bad]	satisfactory semi-satisfactory unsatisfactory
REFERENCE	100	100	100	light green	2	satisfactory
A1_CBR	80	90	86	light green	2	satisfactory
E1_CBR	65	87	79	light green	2	satisfactory
A2_CCR	0	0	0	0	0	unsatisfactory
D1_CCR	27	77	43	dark green	1	semi-satisfactor.
A3_MMT	0	2	7	dark green	1	unsatisfactory
B1_MMT	60	73	65	dark green	2	satisfactory
D2_MMT	31	77	50	dark green	2	semi-satisfactor.
E2_MMT	65	83	79	dark green	2	satisfactory
F1_MMT	59	90	79	dark green	2	satisfactory
G1_MMT	54	90	64	dark green	2	satisfactory
A4_GRA	52	83	71	dark green	2	satisfactory
B2_GRA	49	90	71	dark green	2	satisfactory
C1_GRA	53	90	64	dark green	2	satisfactory
F2_GRA	28	47	67	dark green	1	semi-satisfactor.

Figure 5-35: **Table with all relevant results of the plant compatibility test**

Alexander Leitner, Vienna 2007

Summarizing all relevant results of the plant compatibility test for recycled construction materials it can be concluded that:

- It is not possible to define the plant compatibility of construction materials solely by characteristics of the material (Apart from the pH-value which was a good indicator)
- The modified plant compatibility test carried out in this thesis is suitable to define the plant compatibility of recycled construction materials.
- The crushed brick materials tested can be seen as plant compatible
- The mixed materials tested can be seen as plant compatible (Apart from materials with a high crushed concrete content).
- The natural gravel tested is plant compatible.
- The tested crushed concrete has a tendency to be not compatible with plants.
- Compost had a positive effect on all tested recycled materials

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7 List of Figures

8 Appendix

Substrate	Mixture	Germination rate	Plant colour	Fresh weight plant yield	Root growth	Sprout length
		[%]	[light green; dark green]	[%]	[2=good; 1=bad]	[%]
REFERENCE	100% REF	100	light green	100	2	100
					2	
A1_CBR	100% RCL	90	light green	80	2	86
	75% RCL/ 25% REF	100	light green	94	2	100
	75% RCL/ 25% COMP	90	light green	95	2	93
E1_CBR	100% RCL	87	light green	65	2	79
	75% RCL/ 25% REF	97	light green	81	2	79
	75% RCL/ 25% COMP	90	light green	84	2	93
A2_CCR	100% RCL	0	0	0	2	0
	75% RCL/ 25% REF	3	dark green	0	2	43
	75% RCL/ 25% COMP	2	dark green	0	2	0
D1_CCR	100% RCL	77	dark green	27	1	43
	75% RCL/ 25% REF	97	dark green	68	1	93
	75% RCL/ 25% COMP	90	dark green	64	1	79
A3_MMT	100% RCL	2	dark green	0	1	7
	75% RCL/ 25% REF	47	dark green	13	1	43
	75% RCL/ 25% COMP	47	dark green	19	1	43
B1_MMT	100% RCL	73	dark green	60	2	65
	75% RCL/ 25% REF	73	light green	87	2	82
	75% RCL/ 25% COMP	100	light green	93	2	76
D2_MMT	100% RCL	77	dark green	31	2	50
	75% RCL/ 25% REF	97	dark green	61	2	64
	75% RCL/ 25% COMP	90	dark green	67	2	71
E2_MMT	100% RCL	83	dark green	65	2	79
	75% RCL/ 25% REF	93	dark green	80	2	86
	75% RCL/ 25% COMP	97	dark green	90	2	93
F1_MMT	100% RCL	90	dark green	59	2	79
	75% RCL/ 25% REF	83	dark green	72	2	79
	75% RCL/ 25% COMP	not tested				
G1_MMT	100% RCL	90	dark green	54	2	64
	75% RCL/ 25% REF	97	dark green	76	2	79
	75% RCL/ 25% COMP	97	dark green	71	2	86
A4_GRA	100% RCL	83	dark green	52	2	71
	75% RCL/ 25% REF	80	light green	95	2	93
	75% RCL/ 25% COMP	100	light green	104	2	100
B2_GRA	100% RCL	90	dark green	49	2	71
	75% RCL/ 25% REF	90	light green	86	2	93
	75% RCL/ 25% COMP	100	light green	95	2	93
C1_GRA	100% RCL	90	dark green	53	2	64
	75% RCL/ 25% REF	100	light green	93	2	93
	75% RCL/ 25% COMP	100	light green	107	2	93
F2_GRA	100% RCL	47	dark green	28	1	67
	75% RCL/ 25% REF	60	dark green	24	1	67
	75% RCL/ 25% COMP	not tested				

CBR = crushed brick

CCR = crushed concrete

MMT = mixed materials

GRA = natural gravel

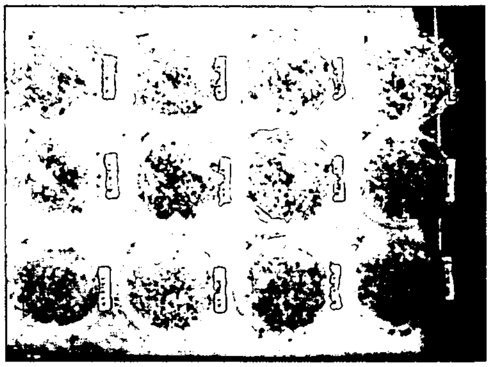
100% RCL = 100 % recycled material

75% RCL/25% REF = 75 % recycled material/25 % reference material

75% RCL/25% COMP = 75 % recycled material/ 25 % compost

8.2-Germination rate and plant colour after 9 days

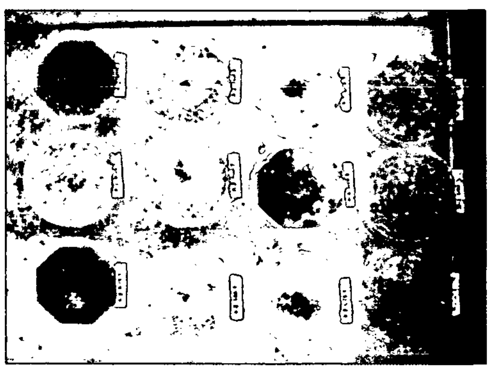
Crushed Brick CBR



A1

E1

Crushed Concrete CCR



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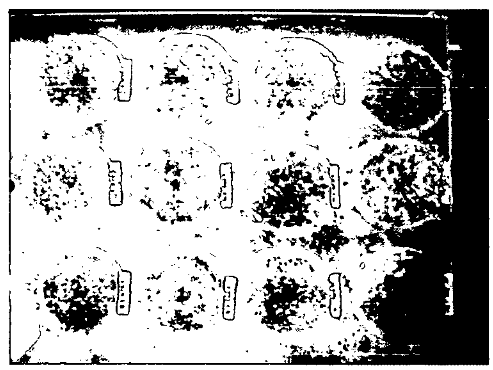
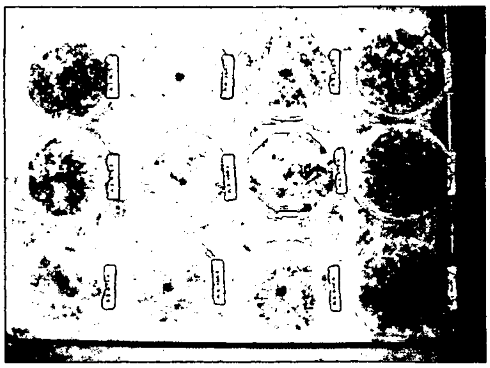


D1

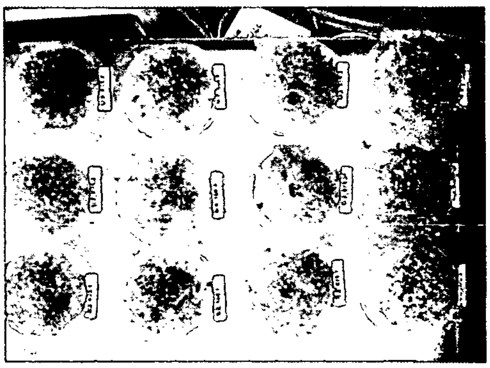
8.2-Germination rate and plant colour after 9 days

Mixed Material MMT



A3

B1



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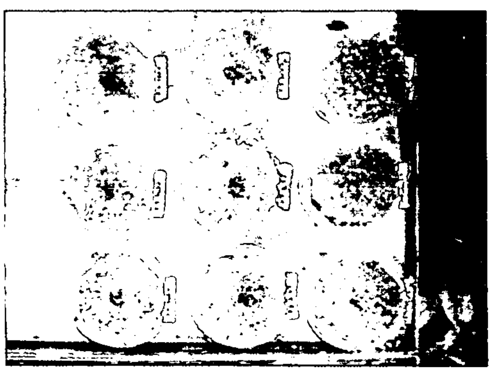
E2



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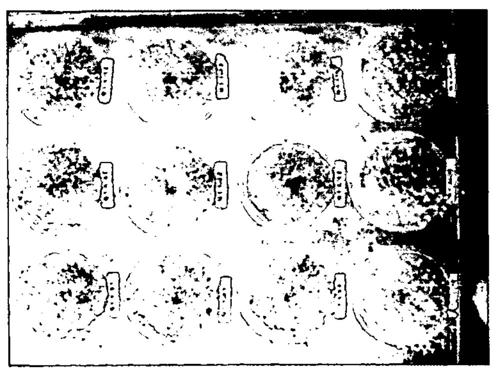
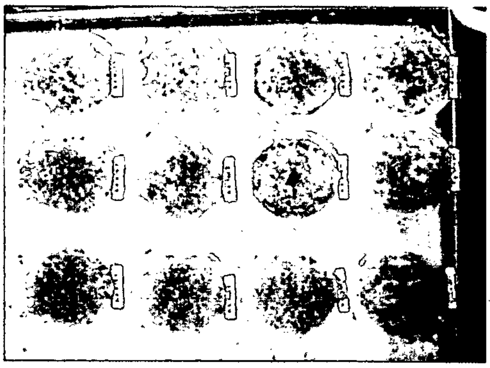


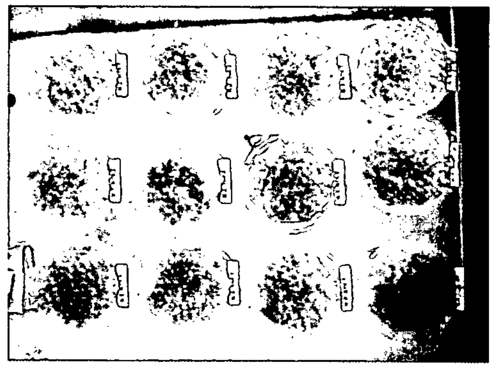
G1

8.2-Germination rate and plant colour after 9 days

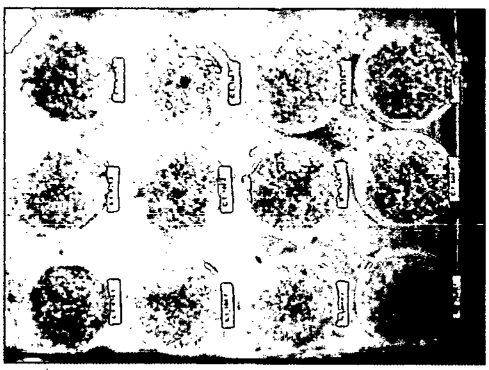
Natural gravel GRA



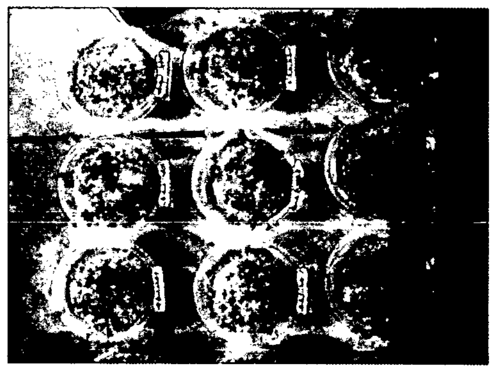
A4



B2



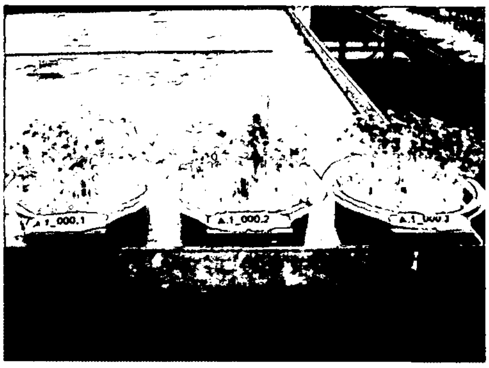
C1

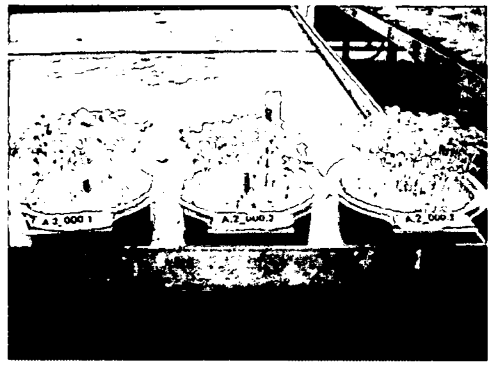


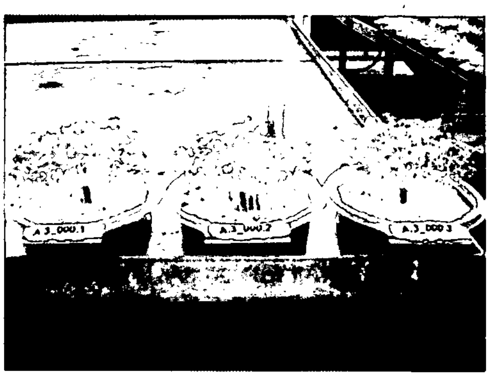
F2

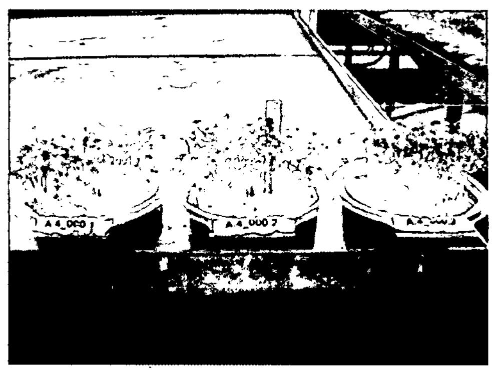
8.3-Sprout length after 9 days

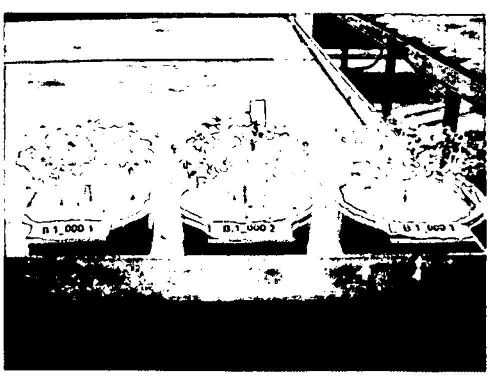
Reference material





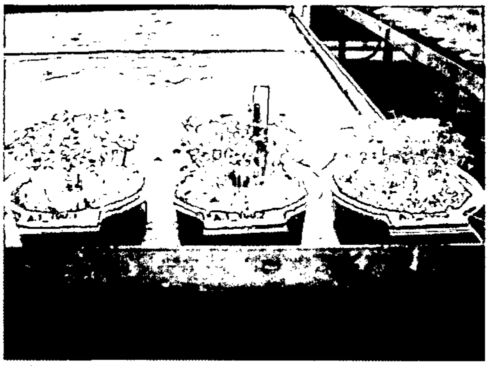
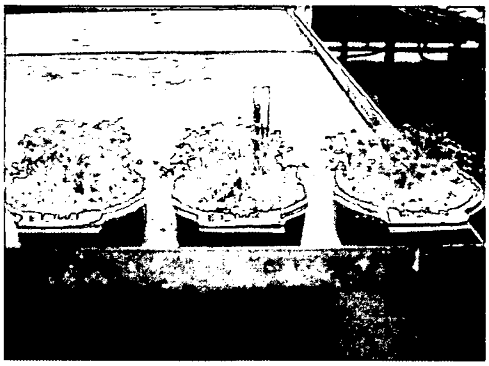






8.3-Sprout length after 9 days

Crushed Brick CBR

A1	E1
	
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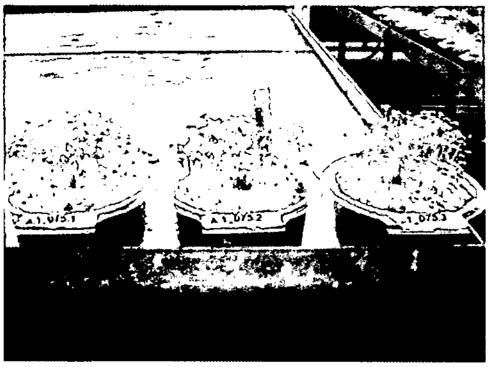	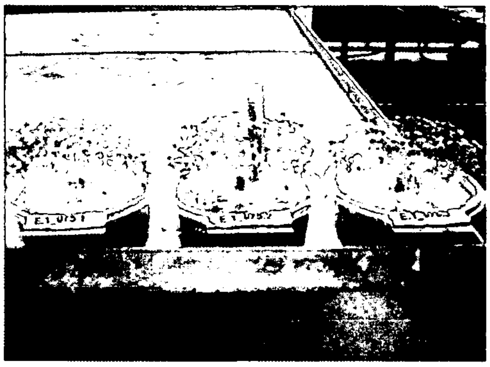
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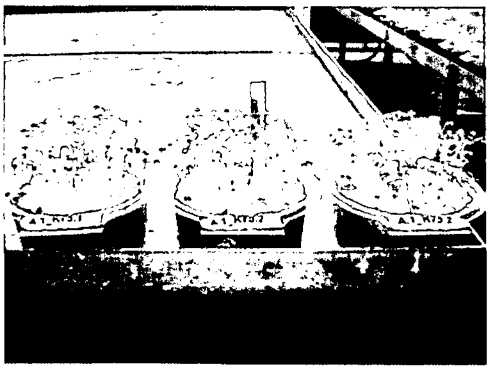	
75 % Recycled Sub./25 % Compost	**75 % Recycled Sub./25 % Compost**

8.3-Sprout length after 9 days

Crushed Concrete CCR

A2	D1
	
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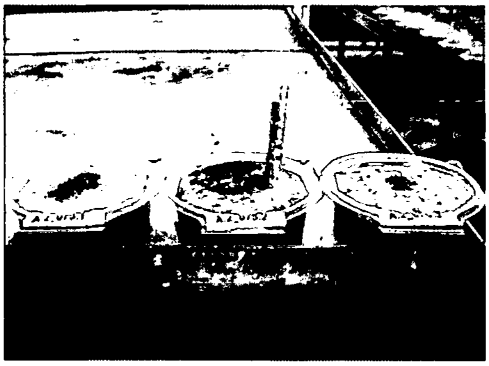	
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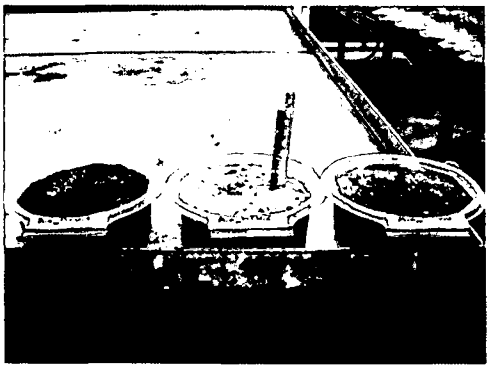	
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8.3-Sprout length after 9 days

Mixed Material MMT

A3	B1
	
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	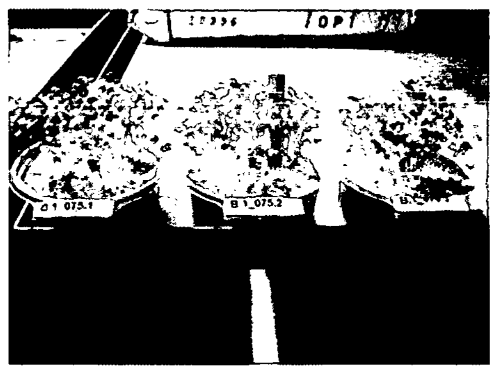
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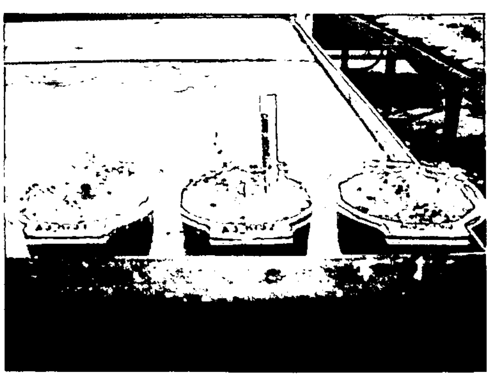	
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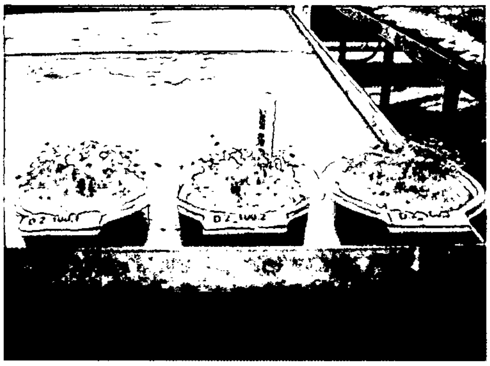
8.3-Sprout length after 9 days

Mixed Material MMT

D2 | **E2**



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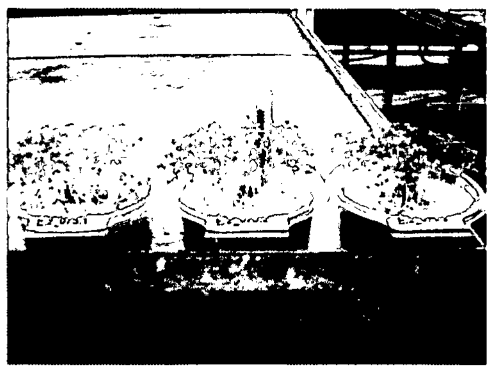

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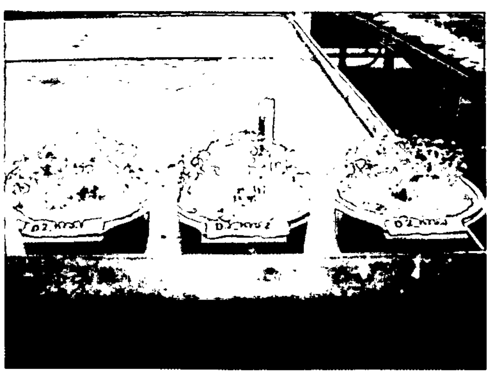


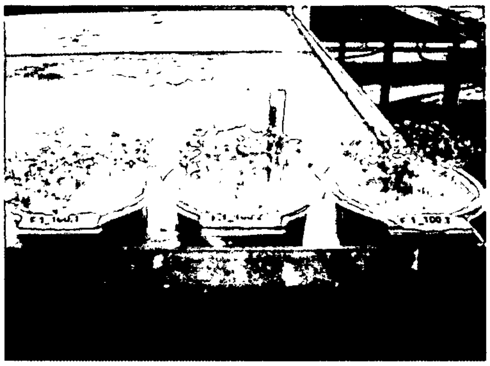
75 % Recycled Sub./25 % Compost

75 % Recycled Sub./25 % Compost

8.3-Sprout length after 9 days

Mixed Material MMT

F1 | **G1**



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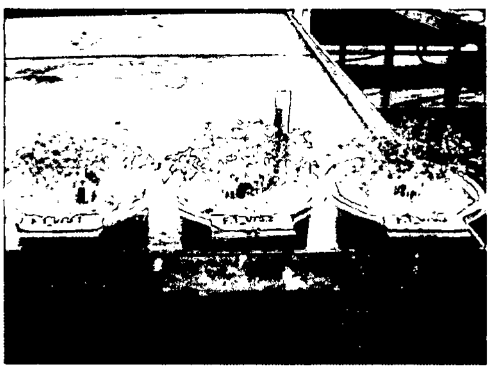
100 % Recycled Substrate



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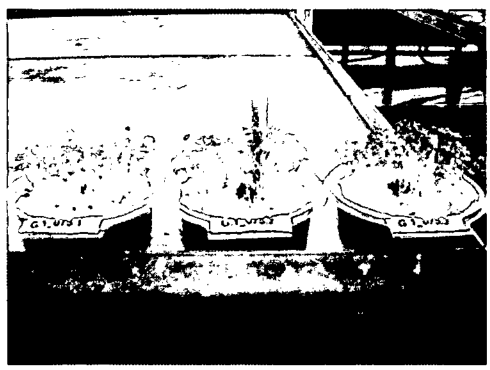


75 % Recycled Sub./25 % Reference Sub.

Not enough substrate for this sample!

75 % Recycled Sub./25 % Compost

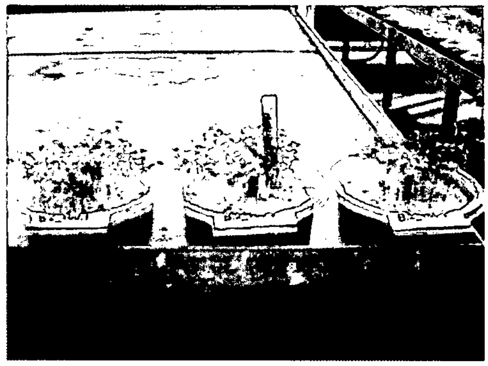
75 % Recycled Sub./25 % Compost

8.3-Sprout length after 9 days

Natural Gravel GRA

A4 | **B2**

100 % Recycled Substrate



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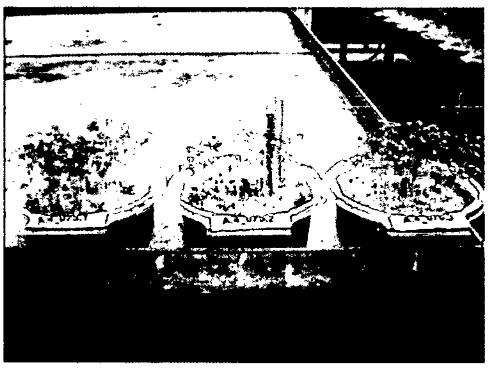

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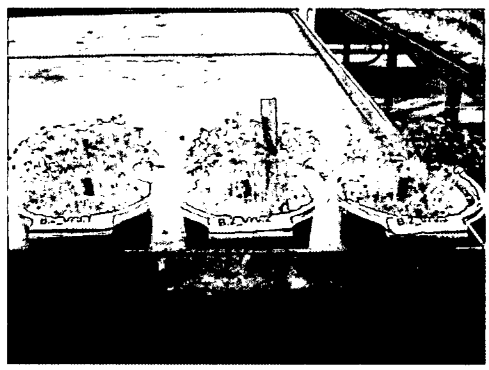

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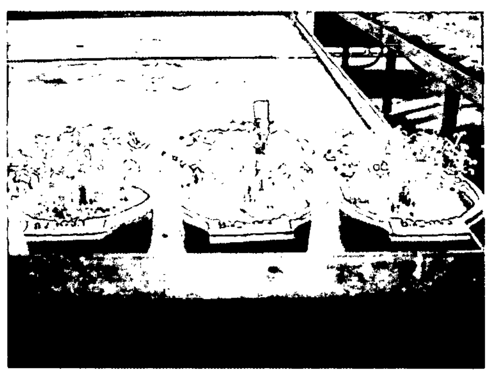
75 % Recycled Sub./25 % Compost



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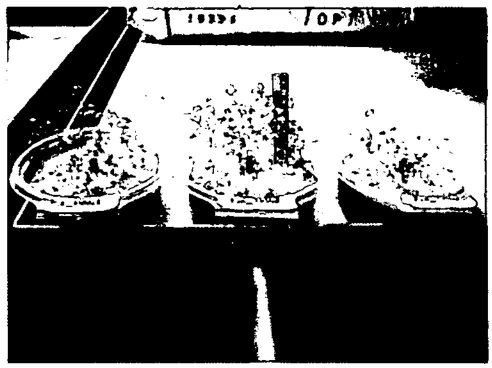
8.3-Sprout length after 9 days

Natural Gravel GRA

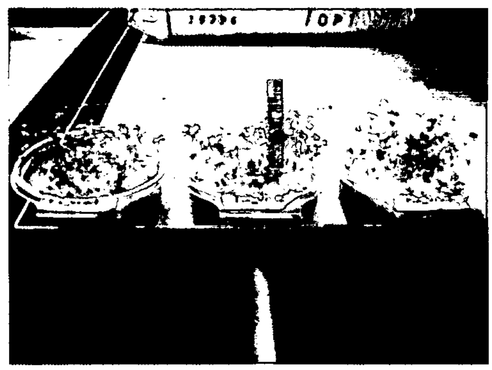
C1 | **F2**

100 % Recycled Substrate



100 % Recycled Substrate

75 % Recycled Sub./25 % Reference Sub.



75 % Recycled Sub./25 % Reference Sub.

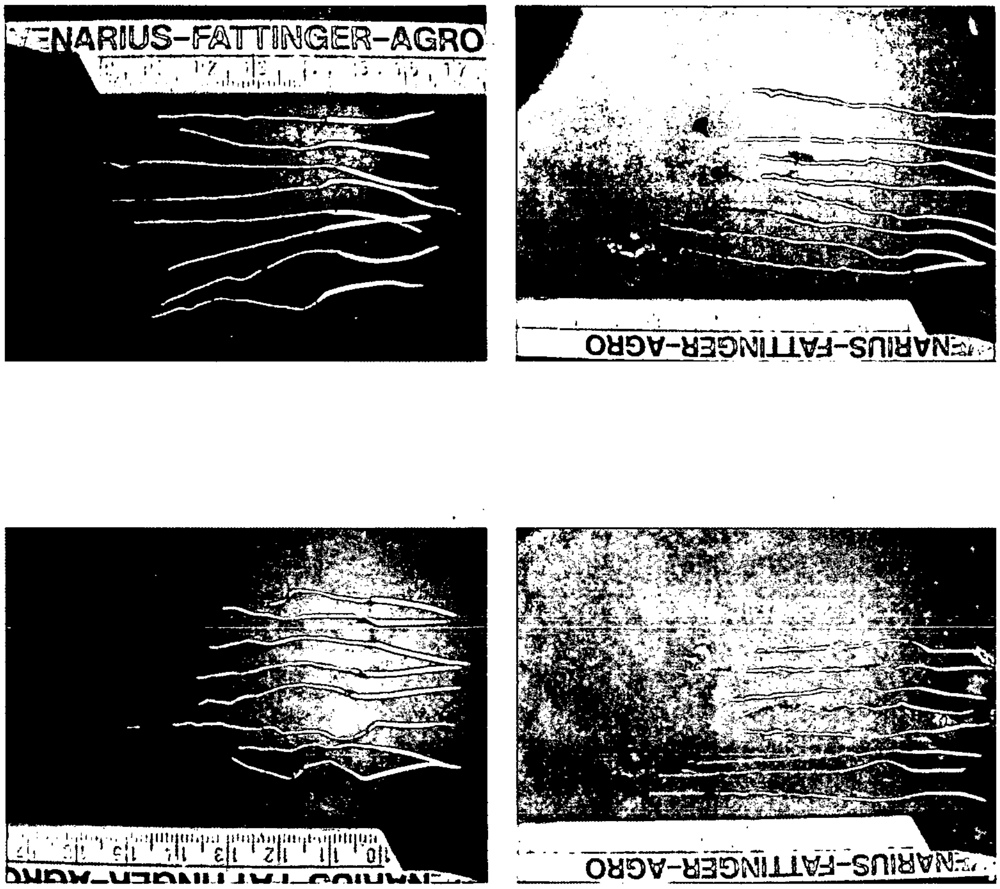
75 % Recycled Sub./25 % Compost

Not enough substrate for this sample!

75 % Recycled Sub./25 % Compost

8.4-Root growth after 9 days

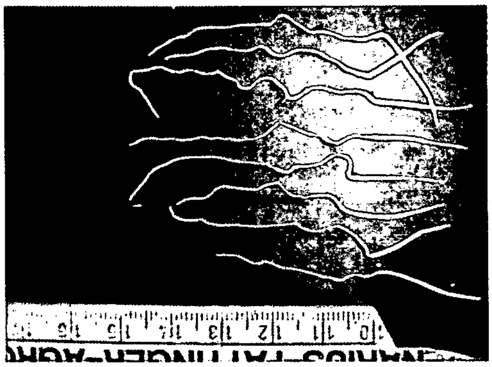
Reference material



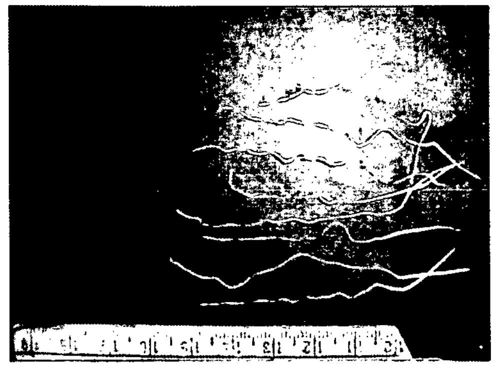
8.4-Root Growth after 9 days

Crushed Brick CBR

A1 **E1**

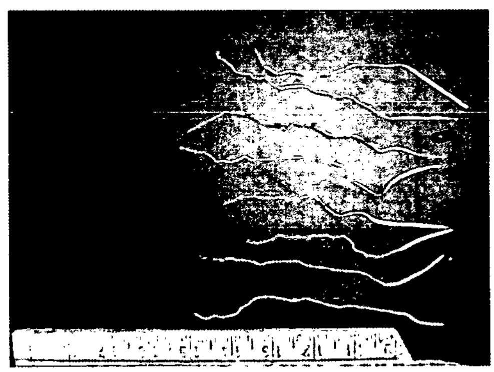


100 % Recycled Substrate



100 % Recycled Substrate

75 % Recycled Sub./25 % Reference Sub.



75 % Recycled Sub./25 % Reference Sub.

75 % Recycled Sub./25 % Compost

75 % Recycled Sub./25 % Compost

8.4-Root growth after 9 days

Crushed Concrete CCR

A2

No root growth!

100 % Recycled Substrate

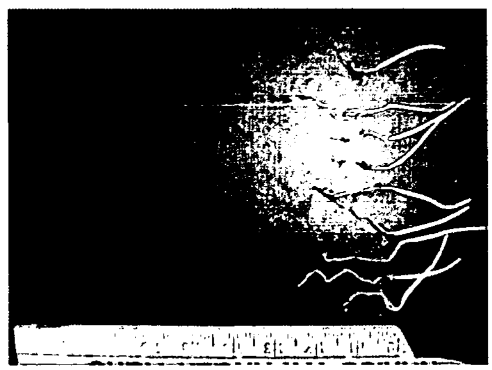
D1

100 % Recycled Substrate

A2

75 % Recycled Sub./25 % Reference Sub.

D1



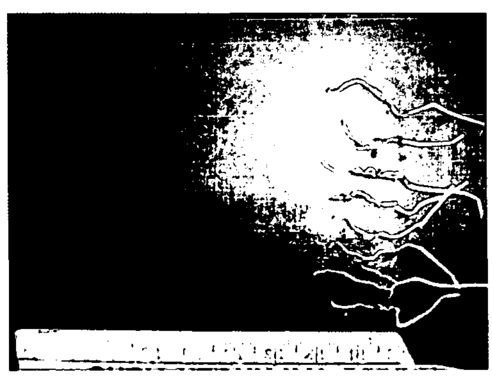
75 % Recycled Sub./25 % Reference Sub.

A2

No root growth!

75 % Recycled Sub./25 % Compost

D1



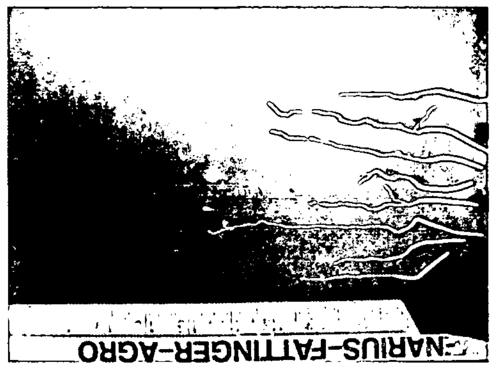
75 % Recycled Sub./25 % Compost

8.4-Root growth after 9 days

Mixed Material MMT

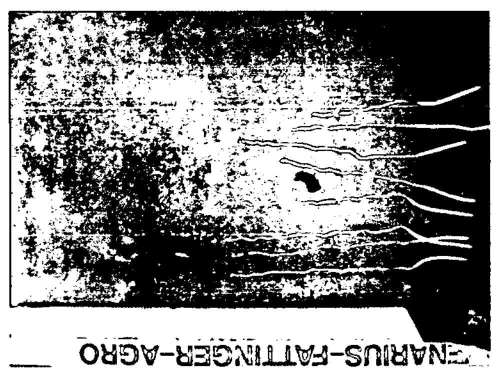
A3 | **B1**

100 % Recycled Substrate

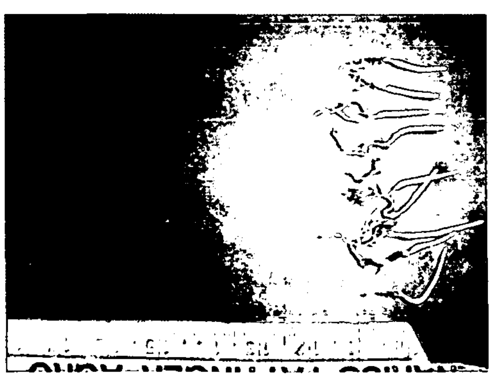


100 % Recycled Substrate

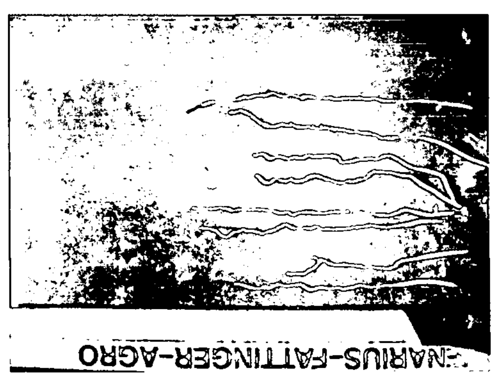
75 % Recycled Sub./25 % Reference Sub.



75 % Recycled Sub./25 % Reference Sub.



75 % Recycled Sub./25 % Compost

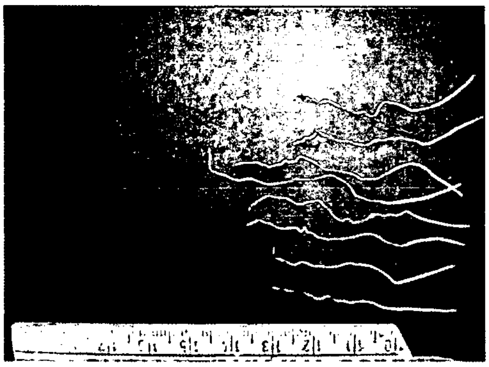


75 % Recycled Sub./25 % Compost

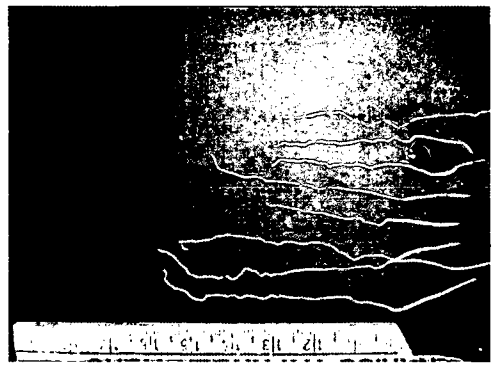
8.4-Root growth after 9 days

Mixed Material MMT

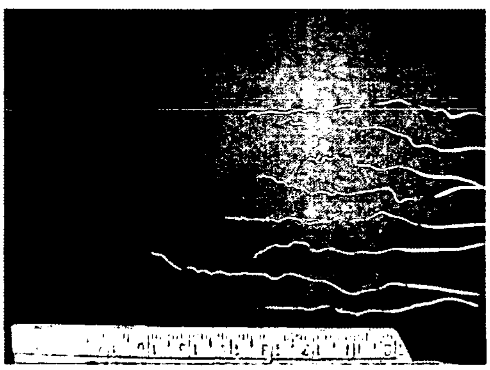
D2 **E2**



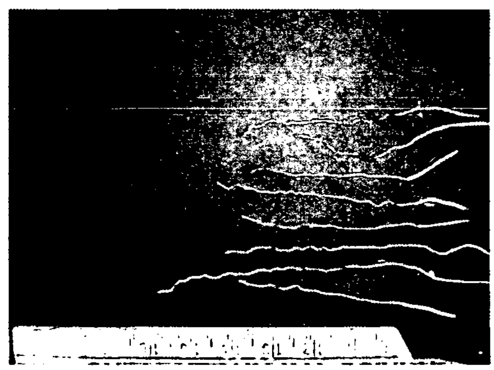
100 % Recycled Substrate



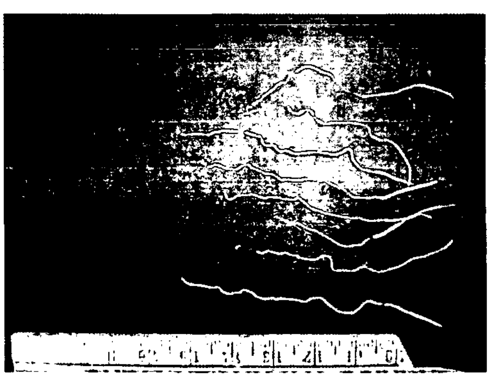
100 % Recycled Substrate



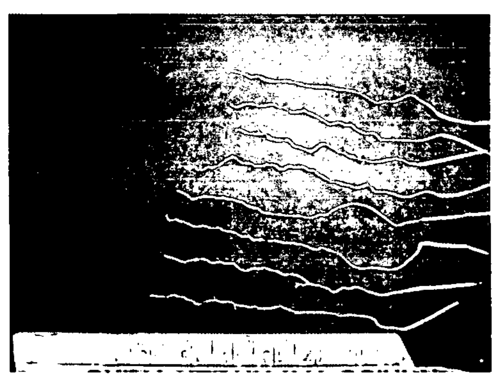
75 % Recycled Sub./25 % Reference Sub.



75 % Recycled Sub./25 % Reference Sub.



75 % Recycled Sub./25 % Compost

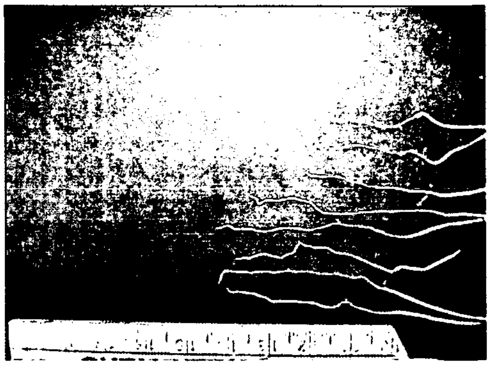


75 % Recycled Sub./25 % Compost

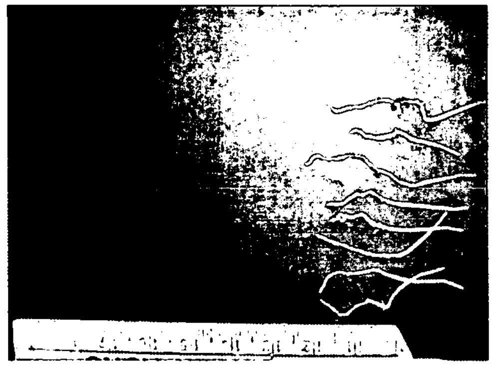
8.4-Root growth after 9 days

Mixed Material MMT

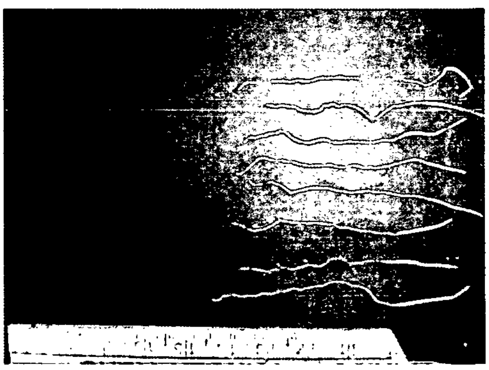
F1 **G1**



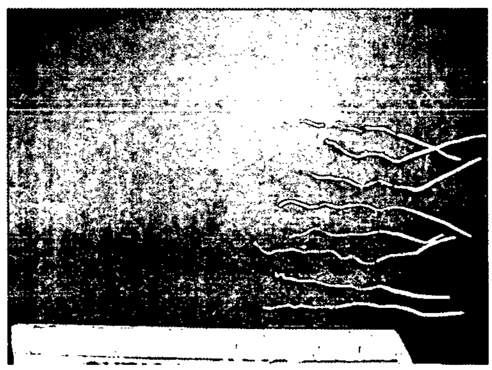
100 % Recycled Substrate



100 % Recycled Substrate



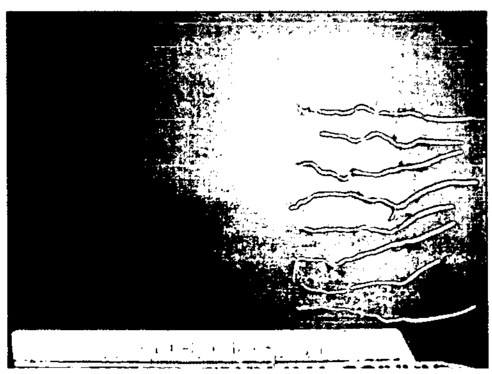
75 % Recycled Sub./25 % Reference Sub.



75 % Recycled Sub./25 % Reference Sub.

Not enough substrate for this sample!

75 % Recycled Sub./25 % Compost

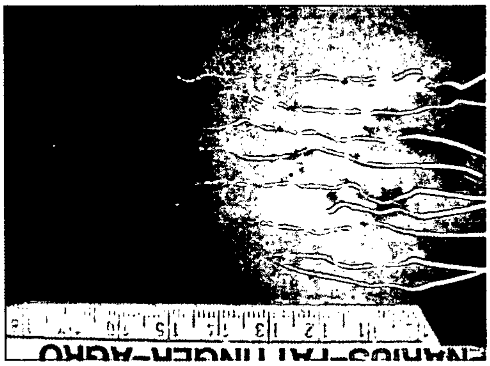


75 % Recycled Sub./25 % Compost

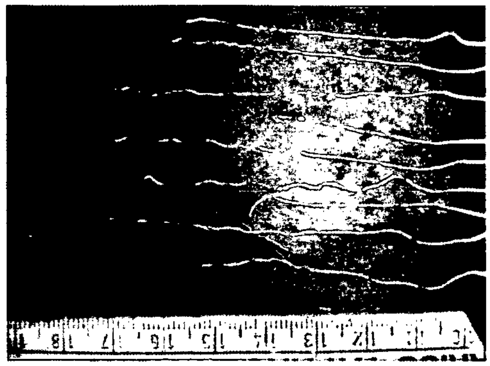
8.4-Root growth after 9 days

Natural Gravel GRA

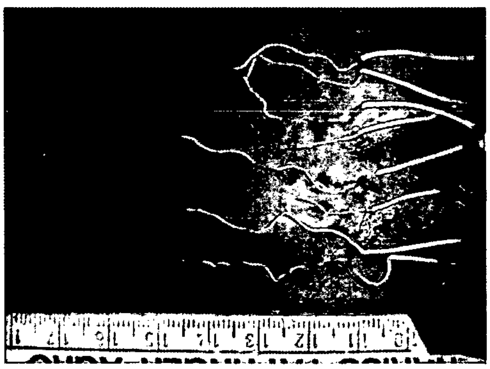
A4 **B2**



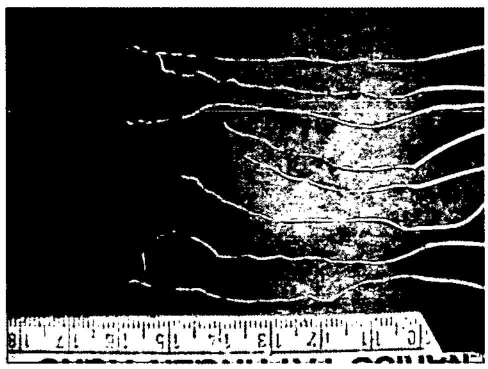
100 % Recycled Substrate



100 % Recycled Substrate

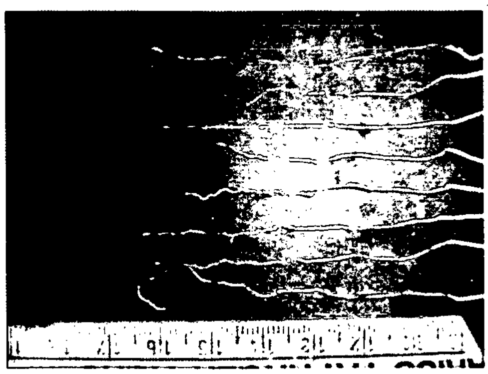


75 % Recycled Sub./25 % Reference Sub.



75 % Recycled Sub./25 % Reference Sub.

75 % Recycled Sub./25 % Compost



75 % Recycled Sub./25 % Compost

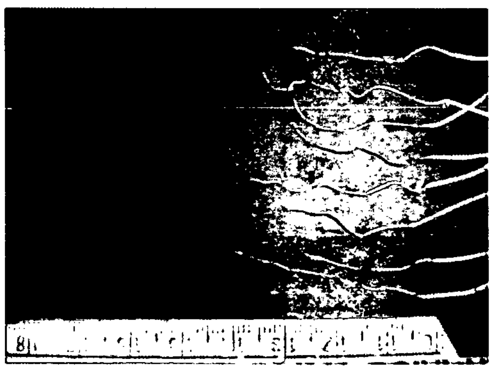
8.4-Root growth after 9 days

Natural Gravel GRA

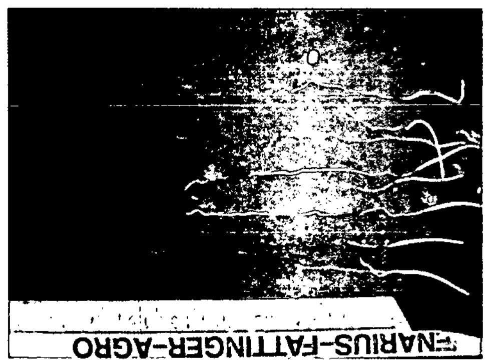
C1	F2

100 % Recycled Substrate

100 % Recycled Substrate



75 % Recycled Sub./25 % Reference Sub.



75 % Recycled Sub./25 % Reference Sub.

75 % Recycled Sub./25 % Compost

Not enough substrate for this sample!

75 % Recycled Sub./25 % Compost