AMERICAN UNIVERSITY OF BEIRUT

DERIVING A PLANTING MEDIUM FROM SOLID WASTE COMPOST AND EXCAVATION AND DEMOLITION RUBBLE FOR USE IN THE REHABILITATION OF QUARRIES

by
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AN ABSTRACT OF THE THESIS OF

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Title: Deriving a Planting Medium from Solid Waste Compost and Construction and Excavation Rubble for Use in the Rehabilitation of Quarries

The combination of construction, demolition and excavation (CDE) waste along with the increase in solid waste generation has put a major stress on the country and on the management of its solid waste. Compounding this problem are the issues of quarries closure and rehabilitation and a decrease in forest and vegetative cover. This research aims to provide an integrated solution to the stated problem by developing a “soil mix” derived from a mélange of the organic matter of the solid waste (compost), the CDE waste, and soil. Excavation and construction debris were ground to several sizes and mixed with compost and soil at different ratios. Replicates of these mixes and a set of control (regular soil) were used. In this mix, native and indicator plants are planted (in pots). The plant species used are *Mathiolla crassifolia* and *Zea mays* (Corn).

Results have shown successful growth of both corn and *Mathiolla* seedlings in the mixes with higher amounts of construction rubble and compost i.e. Rubble: Soil: Compost Ratio of 2:1:1 and 1:0:1. However treatments with no compost and with less quantities of rubble demonstrated the inability of the soil used to sustain plant growth alone (1:1:1 and 1:1:0). Last but not least, the control consisting of soil only ended up being the weakest mix with yellow corn leaves and small *Mathiolla* seedlings fifty days after planting and fertilizing. Additionally, soil analysis, rubble and compost analysis were conducted. The samples were tested for heavy metals, nutrient availability and values of pH and EC. No contamination has been reported and an abundance of macronutrients and micronutrients was documented for the soil and compost. High alkalinity is due to the presence of concrete and the high percentage of Calcium Carbonate in Lebanese soils. Accordingly, the most adequate mixes for planting are treatments A (2:1:1) and B (1:0:1) and they should be pursued for a pilot scale study.

CONTENTS

ILLUSTRATIONS

Figure Page

TABLES

Table Page

CHAPTER 1

INTRODUCTION

1.1. Rationale for Study

Lebanon’s rapid urban expansion and high urban population density (1% annual growth rate according to the *World Bank, 2012)*, is one of the main factors contributing to environmental degradation by converting more agricultural lands into buildings and houses. Additionally, the absence of national policy enforcement leads to uncontrolled real estate development, quarries, haphazard dumping of municipal solid waste etc... However, Ministries and Stakeholders are not passive about the subject and many initiatives have been taken in order to reduce the environmental impact of a growing population that often disregards the influence that human activity has on the ecosystems surrounding it. Out of the many environmental problems that Lebanon needs to address, two are the target for this thesis: quarries and construction and demolition waste. The latter have major impacts on both environmental and socio-economic levels. Both problems are part of the same cycle: As the population grows, the demand in the construction sector increases, more older buildings are torn down to make room for new larger buildings leading to more construction and demolition waste being generated and more raw materials are required, thus more quarries are active. Accordingly, measures need to be taken to control both the quarrying sector in Lebanon and the construction and demolition waste management practices. Treatment and management practices of construction and demolition waste need to be optimized to reduce the impact on the environment as well as society.

1.2. Objectives

In this research, a pot experiment is conducted in order to test the ability of ground construction and demolition waste (CDW) in various combinations with solid waste compost and soil to support plant growth. The ultimate main aim of the experiment is to develop a growing medium derived from CDW and compost to rehabilitate and recover abandoned quarries.

CHAPTER 2

LITERATURE REVIEW

2.1. Overview of Solid Waste in Lebanon

Lebanon is a middle income country, with a population of 4.5 million in 2009 and a per capita waste generation rate of 1.1kg/capita/day in urban areas (65% of the total generation rate) and 0.7kg/capita/day in rural areas, summed up to 1.57 million tons of municipal solid waste generated per year *(MoE, 2010)*. The issue of municipal solid waste (MSW) in Lebanon is of paramount importance since municipal solid waste generation is expected to grow more than 60% by 2030 however until now, there is no national municipal solid waste management policy or any implementation plan for the near future (*MoE, 2010*). This means that the management and disposal practices currently in use will not be sufficient to handle the growth and increase in solid waste generation in the coming twenty years. Since MSW is generated from different sources, the materials generated are also variable. The major constituents of MSW are: organic waste, paper, glass, metals, plastic and textiles (see **Error! Reference source not found.**). Furthermore, MSW omposition varies with seasonal changes, lifestyles, income, social classes, education and even areas (MSW composition in urban areas differs from suburban areas of the same country).

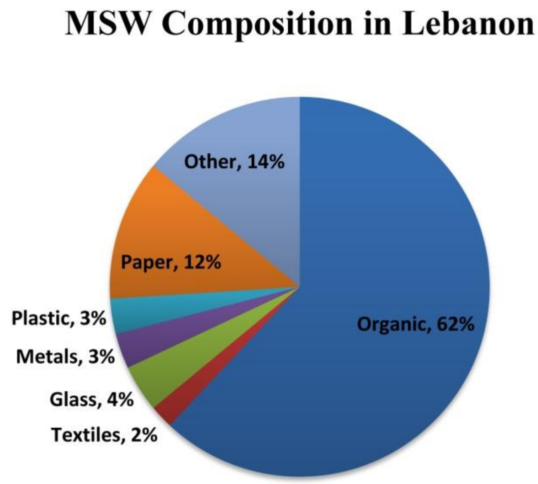

Figure 1. Municipal Solid Waste Composition in Lebanon (MoE State of the Environment Report 2010)

2.1.1. The Construction Sector

From the early to mid-1990s Lebanon went through an extended period of reconstruction and this has picked up again in the past few years making most of the country resemble a large construction site (MoE, 2010). The wastes generated by the construction sector were and still are substantial. In 1996, in the midst of post-war reconstruction, around 10,000 tons of wastes were generated by the quarrying and construction sector (*MoE*, 2010). A recent figure suggests that 5,376 buildings were under construction in 2011, compared to 2,931 buildings in 2007 (*Lynch*, 2010; *Qiblawi*, 2010). More recently, when it comes to upcoming construction, permits displayed a 10.7% year on year increase during the first eight months of 2014 reflecting a 9482 thousand square meters compared to 8562 thousand square meters in 2013 (*Bank Audi, 2014)*. The construction sector is an important sector within the Lebanese economy and through its many activities (buildings, infrastructure development, etc.) may be able to play a major role in promoting sustainable development in Lebanon. The main challenge that it has to face is reducing or minimizing the negative impact that the construction activities have on the environment as well as on the local communities.

2.1.2. Construction and Demolition Waste

Lebanon has a major problem in handling its construction and demolition waste (CDW) waste as well as its municipal solid waste (MSW). The main reason behind this challenge is the ever-expanding construction industry that was first boosted in the early 90s after the war, and the “emergency demolition waste” (*Tamraz et al., 2011)* generated during the war of July 2006 and the Nahr El Bared conflict in summer of 2007. The volumes generated were estimated at 3 million m^3 in 2006 and 0.6 million m^3 in 2007 (*Tamraz et al., 2011)*. The rubble was disposed of in temporary reclaimed sites; however, until today the waste is still there with no apparent plans to remove it. Unfortunately, Lebanon has no official management plan for CDW, not enough landfill space for disposal of the waste and very little knowledge on the environmental and economic benefits of CDW recycling (*Tamraz et al., 2011)*. In fact, only one landfill accepts CDW and it is located in the Matn region in Bsalim (*Tamraz et al., 2011)*. The remaining quantities of CDW are usually disposed of in private lands or used for land reclamation and backfilling. Additionally Lebanon lacks data on the exact quantity of CDW generated and its composition, which makes it more difficult to work on a solution for this problem. Unfortunately, there is no understanding of proper landfilling or of the environmental as well as economic benefits of recycling of CDW among the construction and demolition contractors in Lebanon (*Tamraz et al., 2011)*.

It is important to mention that there is a legal framework dealing particularly with construction and demolition waste treatment although it is often overlooked. **Decree 8735/1974** bans the disposal of bulky and CDW on street sides, in public areas, water streams, on the public maritime domain or in residential areas. It also recommends the disposal of CDW in construction sites or in depressions (*MoE, 2010)*.

2.1.3. Common Management Practices in Lebanon

The most common CDW management practices in Lebanon include landfilling and backfilling for land reclamation purposes. Nationally, there is only one landfill that officially accepts CDW in Bsalim in Mount Lebanon. It receives around 130-150 tons of inert waste per day (*Tamraz et al., 2011).* The rest of the waste is usually either dumped at private dumpsites for an average price of US$ 20 per 20 m^3 truck (*Tamraz et al., 2011)* or it is subject to what is called "Fly Tipping". The latter refers to "illegally dumping waste beside a road, in open land or in valleys" (*Tamraz et al., 2011).* The *Chouaifat* dumpsite for instance is an example of fly tipping site, along with the valleys of *Beit-Meri*, the coastal areas.

However, recycling of construction and demolition waste is not a common practice in Lebanon, although the benefits of recycling are many. One recycling approach to C&DW is *Concrete Recycling.* The latter is already used in several countries around the world. In the Middle East however, Kuwait is a pioneer in building demolition waste recycling.

2.2. Recycling of Construction and Demolition Waste

Construction and demolition waste has typically been recycled into pavement material in several parts of the world, see (CSI, 2009), (Lennon, 2005), (Al Jassar, 2005).

An experiment conducted in Hampshire, UK by the TRL Center for Sustainability is the closest to the work conducted for this thesis. The main aim of the project is to divert 11 500 tons of CDW and 4 500 tons of biodegradable waste from landfills in Hampshire (*Lamb, 2006)* to create a planting medium (or a manufactured soil).

The three main input materials are: construction demolition and excavation wastes, gulley wastes and green wastes compost. CDEW is in fact one of the largest waste streams in the UK, typically generated from debris of construction sites, demolition processes and excavation activities (*Lamb, 2006)*. Crushing and screening of the CDEW was carried out as a first step in the experiment. Successively, two sets of soil mixes were carried out, one at a small scale and one at a large scale in an industrial plant. Ratios of the mixes are the same in both sets i.e. 2:1 trommel fines to compost, 2:1 screened soil to compost and 1:1:1 of all three materials *(Lamb, 2006)*. The performance of the tomato seedlings turned out to be similar among the different soils mixes and the two sets, exhibiting outperformance of the control specimens (peat based potting compost) over the soil mixes. Nevertheless, the tomato seedlings did flower and started to fruit six weeks following growth but not enough to outgrow the control specimens (*Lamb, 2006)*. In parallel, samples were taken of each of the input materials and measuring potentially toxic elements, weeds and phytotoxicity in each of them. The potentially toxic elements that determine the suitability of the materials in a manufactured soil include *(Lamb, 2006)*:

- Arsenic
- Cadmium
- Chromium
- Lead
- Mercury
- Copper
- Nickel
- Zinc
- Selenium
- Boron

2.3. Soil Fertility

Soil fertility by definition is “the ability of the soil to supply essential plant nutrients and soil water in adequate amounts and proportions for plant growth and reproduction in the absence of toxic substances which may inhibit plant growth” *(FAO, 2013).*Therefore, any planting medium used needs to be able to supply the necessary nutrients and hold the amount of water needed by the plant to grow

Seventeen elements are usually recognized as being essential and indispensable for plant growth, three of which are supplied by water and air (*Carbon, Hydrogen* and *Oxygen*). The remaining elements are divided into two categories: Macronutrients and Micronutrients. Macronutrients are needed in large amounts and are in turn divided in two groups: Primary Nutrients and Secondary Nutrients. Micronutrients on the other hand are only needed in trace amounts *(Troeh and Thompson, 1993)*. Primary macronutrients include: *Nitrogen* (N), *Phosphorous* (P) and *Potassium* (K) whereas secondary macronutrients are *Calcium* (Ca), *Magnesium* (Mg) and *Sulfur* (S).

Nitrogen

The primary source of all nitrogen used by plants is N_2 which accounts for 78% of earth’s atmosphere. A good supply of nitrogen is associated with high photosynthetic activity, vigorous vegetative growth and a dark green color (*Havlin, 2013).* Deficiency in nitrogen causes yellowing of leaves, or chlorosis This commonly appears on the lower leaves first with the upper leaves remaining green. However, under severe nitrogen deficiency the lower leaves turn brown and die (*Havlin, 2013).*

Phosphorous

Phosphorous' essential function in plants lies in energy storage and transfer. Additionally, it is a component of every living cell as a part of nucleoproteins that carry the genetic code of plants. It is mainly concentrated in the growing parts of plants hence adequate P supply is often associated with increased root growth. Phosphorous deficiency is mainly manifested in the overall stunting of the plant and a darker green coloration of leaves. As deficiency increases, the dark green turns into a grayish-green to a bluish-green metallic shine. Phosphorous is mobile in plants, it travels from the older to the newly developed tissues hence deficiency in phosphorous late in the growing season affects seed development and plant maturity (*Havlin, 2013)*.

Potassium

Potassium is important for several plant quality characteristics since it is involved in synthesis and transport of photosynthates to the reproductive and storage organs of the plant. It is also involved in the conversion of the photosynthates into carbohydrates, proteins, oils, etc… Deficiency in potassium affects metabolic processes mainly related to photosynthesis, synthesis and translocation of enzymes. Visual symptoms of K deficiency include white spots on leaf edges, chlorosis and necrosis of leaf edges and weakening of stems (*Havlin, 2013)*.

Sulfur, Calcium and Magnesium

Sulfur (S), Calcium (Ca) and Magnesium (Mg) are secondary macronutrients required in relatively large amounts by the plant. Sulfur and magnesium are needed in plants by almost the same amount as phosphorous whereas most plants require more calcium than phosphorous *(Troeh and Thompson, 1993)*.

Sulfur is required in plants for the synthesis of S-containing amino acids which are essential constituents of plant protein that contain almost 90% of sulfur in the plant. Reduced plant growth is characteristic of sulfur deficiency in plants where they become stunted, thin-stemmed and chlorotic *(Troeh and Thompson, 1993)*.

Plants absorb the ionic form of calcium, Ca^{2+}, from the soil solution. Ca^{2+} is essential for the translocation of carbohydrates and nutrients in plants. Accumulation of carbohydrates in leaves under Ca^{2+} deficiency decreases the quantity of carbohydrates in stems and roots, which disrupts normal root function due to the low supply in energy. Therefore Ca^{2+} deficiency mainly causes malformation of storage tissues *(Troeh and Thompson, 1993)*.

Mg^{2+} is a primary constituent of chlorophyll therefore it is associated with good photosynthetic activity. Additionally, magnesium is necessary for optimal activity of almost every phosphorylating enzyme involved in carbohydrate breakdown. Deficiency in magnesium usually causes interveinal chlorosis in leaves where leaf veins remain green *(Troeh and Thompson, 1993)*.

Micronutrients are elements that plants need to complete their life cycles but only in small amounts. They are also called trace elements or minor elements. Micronutrients include: *Iron* (Fe), *Boron* (B), *Chlorine* (Cl), *Copper* (Cu), *Manganese* (Mn), *Molybdenum* (Mo), *Zinc* (Zn), Nickel (Ni). Some of the micronutrients are involved in the production of chlorophyll therefore symptoms of deficiency in these elements can be similar to the chlorosis caused by nitrogen deficiency. However, some micronutrient deficiencies develop distinct symptoms such as interveinal chlorosis *(Troeh and Thompson, 1993)*. Additionally, these symptoms are more prominent on younger leaves because some of the micronutrients do not translocate once they are built up into the plant tissue. Moreover, deficits of micronutrients can decrease yield as well as crop quality without being severe enough to exhibit deficiency symptoms *(Troeh and Thompson, 1993).*

Additionally, “Indicators are physical, chemical and biological properties, processes and characteristics that can be measured to monitor changes in the soil or plant” (*USDA, 1996)*. Plant analysis provides more plant-based information than soil analysis however it is more costly and requires more effort in sampling and analyzing (*FAO, 2008)*. Also, in plant analysis, the overall content of nutrients is important rather than the amount of available nutrients (*FAO, 2008).*

Traditional plant growth analysis uses simple plant characteristics to generate more complex indices related to growth or productivity *(Jolliffe et. al, 1982).*

Plant characteristics include *(Jolliffe et. al, 1982)*:

- Land area (plot size sampled)
- Number of branches per plant
- Number of flowers per plant
- Leaf area per plant
- Leaf dry weight per plant
- Number of plants

- Number of pods per plant
- Total stem length per plant
- Total dry weight per plant
- Time

A more complex analysis of plant growth includes growth rate and leaf area parameters (*Jolliffe et. al, 1982)*:

- Crop Growth Rate
- Leaf Area Index
- Specific Leaf Area
- Relative Growth Rate

General recommendations following the completion of the Hampshire project included (*Lamb, 2006)*:

- Encourage the use of manufactured topsoil as a means of developing markets for compost and in order to maximize recycling of CDEW
- Develop regional markets for manufactured soil to minimize transport costs.
- Encourage the use of recycled products at a national level
- Promote the potential financial benefits of composting and recycling compared to landfilling.

2.4. Overview of the Quarrying Sector in Lebanon

Between the years 1996 and 2005 the number of quarries, in Lebanon, increased from 711 to 1278 quarry and the quarried land area increased from 2875 ha to 5283 ha during that period (*Darwish et.al, 2008).* Furthermore, remote sensing data generated from the study conducted by *Darwish et. al,* (2008) showed that 21.5% of quarries are located in forested land and arable land; 32.4% in grassland and scrubland and 3.2% are actually inside urban zones. Weak national policies and institutional frameworks for the quarrying sector contribute to development of quarries without any environmental consideration (*Darwish et.al, 2008)*. Quarries develop without a post-operation reclamation plan leading to considerable impact on natural resources. Nevertheless, in February 2009, **Decree 2366/2009** which may be considered as a National Master Plan assigned 16 quarrying locations throughout Lebanon. Unfortunately up to date, only 75 quarries are licensed and the rest remain illegal (*Tamraz et al., 2011)*. To make matters worse, the quarrying industry's annual production is estimated at 3.0 million m^3, which is not enough to accommodate for the annual demand for construction that is of 3.77 million m^3 (*Tamraz et al., 2011).* An impact assessment of the quarries showing the degree of impact that the different quarrying sites in Lebanon have on natural resources was conducted by *Darwish et. al* in 2011. The findings of the study state that nearly a quarter of all quarries (929) have moderate to high impact on natural resources in Lebanon, while only 349 have a low impact. The study attributed this fact to the haphazard distribution of quarrying sites that are in turn a result of failed national policy.

2.4.1. Impact of Quarries on Natural Resources

2.4.1.1. On Soil and Land

The absence of structures that divert water in abandoned quarries and the absence of sedimentation ponds, coupled with heavy rainfall increase the risk of erosion of the topmost soil layer on steep slopes where the vegetation cover has been removed or degraded (*Darwish et.al*, 2011). Thus, when no rehabilitation measures are taken prior to the development of the quarrying activity, the susceptibility of the land to runoff and soil erosion increases, and the risk of sedimentation on arable lands also increases. Moreover, erosion from quarries also contributes to metal loading of receiving watercourses.

2.4.1.2.On Water Resources

The karstic nature of fractured limestone rocks increases the susceptibility of groundwater to contamination. According to *Darwish et al.* 70% of current quarries are located on medium rock infiltration classes and 17% on high rock infiltration classes. r. After water infiltrates in mountainous areas, it penetrates hydrographic networks, recharges the groundwater and then it reappears as surface water (*Darwish et. al, 2011*). Hence, risk of groundwater contamination must be directly addressed in order to reduce environmental damage both during the quarrying activity and in the post-exploitation phase.

2.4.2. Plant Succession in Disturbed Habitats - Abandoned Quarries

When a particular area is successively occupied by different communities, the process is called *Succession (Brewer, 1993).* When successional changes occur in areas that have never supported plant communities before, the process is termed *Primary Succession (Randerson, 2006)*. Glacier deposits or bare rock are examples of novel areas where primary succession occurs. Furthermore, *Secondary Succession* is initiated by disturbance such as fires, so it occurs on sites that have previously supported communities (*Randerson, 2006)*. The rate of secondary succession is usually faster than that of the primary succession because the soil is more developed and some organisms already exist on site *(Brewer, 1993)*. Abandoned quarries are also an example of disturbed habitat where secondary plant succession typically takes place.

The earliest plants to grow, also termed *Pioneer Communities* are made up of a limited number of species only. They may either be those with windblown seeds or those carried long distances in or on animals. They may even be plants whose seeds live for many years in the seed bank of the soil. Pioneer species usually have high ecological tolerance in order to survive in harsh environments (*Randerson, 2006)*. The first one or two years, annual herbs are dominant but they are soon replaced by perennial herbs that are in turn replaced by a shrub community followed by a forest (*Brewer, 1993)*. The complete sequence from annual herbs to the climax community is called a successional series or *Sere.* Seral stages typically include *(Brewer, 1993)*:

1. Annual herbs

2. Perennial Herbs
3. Shrubs
4. Early Forest
5. Climax Forest

The climax community is characterized by stability. It is at a steady state of species competition, structures and energy flow. Unlike earlier successional communities, climax communities can tolerate their own reactions and are more highly organized and more complex which makes them more resistant to species invasions *(Brewer, 1993)*.

Many landscapes (Old-fields, shrublands or woodlands) in regions of the Mediterranean witnessed dramatic changes since the beginning of rural migration *(Debussche e. al. 1996)*. Rural migration has led to the abandonment of agricultural lands which affects the composition and structures of vegetation communities *(De Luis et al., 2001)*. Additionally, wildfires and erosion processes are two major disturbances affecting Mediterranean ecosystems, both closely related to climate *(De Luis et al., 2001)*.

In his paper on old-field plant succession in the Mediterranean, *Debussche (1996)* describes five successional stages:

1. Dominance of annuals
2. Dominance of *Labiatae* (*Thymus vulgaris, lavandula latifolia, etc…)*
3. Dominance of *Gramineae* (*Bromus erectus, Poa pratensis, etc…)*
4. Colonization by trees
5. Closing of the forest canopy

On the other hand, in a paper on post-fire succession, *R. Capitanio* (2007) distinguishes three successional stages:

1. Initial Stage: high seedling density, high competition for resources and land cover.
2. Transitional Stage: dominance of shrub species occurring 25-30 years after fire. Species present at high densities at the beginning of the post-fir succession gradually become less important (*Quercus coccifera, Rosmarinus officinalis, Cistus albidus, etc…)*
3. Advanced Stage: dominance of species with low growth rates and long-life cycles (*Buxus sempervirens, Quercus ilex, Juniperus oxycedrus, Hedera hilex etc…)*

CHAPTER 3

MATERIALS AND METHODS

3.1. Materials

Materials used in this experiment consist of construction demolition concrete blocks, organic compost and soil. In addition the plant material used in are Mathiolla crassifolia… and Zea mays…

Mathiolla crassifolia is a native Lebanese species that is classified as a pioneer species occurring during the first stages of succession. It is a coastal wild flower that grows on rocks in proximity to other plant communities. *Mathiolla crassifolia* was thought to be extinct nowadays, until it was found growing between rocks in coastal Beirut (Moustapha Itani) .

Zea mays, commonly known as corn used as a major study plant for many academic disciplines such as physiology, soil fertility and biochemistry *(FAO, 2013)*.

3.2. Experimental Design

In this research, five different soil mixes are assessed in which two different plants are grown. The experimental design is a Randomized Complete Block Design (RCBD) of five treatments and one control treatment applied to both *Mathiolla crassifolia* and *Zea mays* (corn).Five replicates of each treatment were prepared, thus the experiment consists of 50 pots in total. The five treatments were designed as follows:

- Treatment A: 2:1:1 Rubble: Soil: Compost
- Treatment B: 1:0:1 Rubble: Soil: Compost
- Treatment C: 0:1:0 Rubble: Soil: Compost
- Treatment D: 1:1:1 Rubble: Soil: Compost
- Treatment E: 1:1:0 Rubble: Soil: Compost

The pots for the various treatments and control were placed in the “Greenhouse” area at AUB’s Beirut Campus in an area that was exposed to sun. The experiment began in February 2014 and ended in September 2014. Figure 2 illustrates the layout of the pots in the experimental design as adapted in the greenhouse.

Figure 2. Experiment Layout

The weight capacity of each pot was determined to be 8 kg. The mixture quantities for each treatment were determined by a weight ratio of each constituent. Table 1 shows the weight allocation for each treatment.

Table 1. Updated Experimental Design (by Weight of Input Material)

Treatment Number	Treatment Type	Required Ratio (Rubble:Soil:Compost)	Required Quantity of Rubble (kg)	Required Quantity of Soil (kg)	Required Quantity of Compost (kg)	Total Weight of Material (kg)
Treatment A		**2:1:1**	4	2	2	**8**
Treatment B		**1:0:1**	3	0	3	**6**
Treatment C	Control	**0:1:0**	0	6	0	**6**
Treatment D		**1:1:1**	2	2	2	**6**
Treatment E		**1:1:0**	3	3	0	**6**

3.3. Experiment Procedure

3.3.1. Preparation of the Mixes

The materials needed to constitute the mixes were brought in over a period of one month. The compost was first acquired and three bags of 25 kg of organic compost from the local solid waste management company, *Sukomi* were delivered on February 10, 2014: They were opened up and aired out to dry. Next blocks of concrete from a building renovation site were collected (see Figure **3**).The collected concrete was ground (Figure **4**) at an industrial grinder in the Abou Mizen region in Keserwan and crushed (see Figure **5**).Soil from a nursery in Sarba, Keserwan was brought in to the greenhouse area and the mixes were according to the ratios mentioned in the experimental design.

Figure 3. Concrete Blocks to be Ground

Figure 4. Ground Concrete

Figure 5. Industrial Crusher

Figures 6 through 10 show the different mixes on day one of the experiment. The different colors of the mixes are distinctly apparent. Texture of the mix is an important factor to assess its water holding capacity.

Figure 6. Treatment A (2:1:1)

Figure 7. Treatment B (1:0:1)

Figure 8. Treatment C (Control 0:1:0)

Figure 9.Treatment D (1:1:1)

Figure 10. Treatment E (1:1:0)

3.3.2. Planting and Monitoring Plant Growth

Seedlings of *Mathiolla crassifolia* were planted in 25 pots (Three seedlings per pot) and *Zea mays* seeds (corn) were planted in the remaining 25 (five seeds per pot) on April 4, 2014.

A week later all treatments were fertilized with

N: P: K 20:20:20 over seven days in irrigation water. Each treatment was irrigated on average with *8 Liters* of water every day, in which *2g* of the stated fertilizer were added. By the end of the seven days each pot had received *1.75g* of fertilizer.

The experiment was conducted for a period of 40 days and growth patterns of the plants were documented throughout that period.

Traditional plant growth analysis is adopted in this study since the primary aim is simply to test the ability of the different treatments to sustain plant growth therefore, in this experiment, the indicators used to assess successful plant growth were:

- Number of plants in pot
- Average Height of the plant or Stem Length
- Number of leaves
- Average Length of leaves
- Fruit/Flower

The number of plants, number of flowers per plant and the number of leaves per plant were all counted manually. The height of the plants and the length of the leaves were measured using a regular ruler.

3.4. Laboratory Analysis

In addition to the physical attributes, chemical attributes of the input materials were also analyzed. Samples of all three input materials (Soil, Rubble, and Compost) were analyzed for the presence of some heavy metals and for available nutrients. A sample of each material was taken before mixing and prepared for analysis. They were prepared in triplicates and sent out to the Lebanese Agricultural Research Institute (Lari) for analysis. tested for in each sample.

Table **2** lists the elements that were tested for in each sample.

Table 2.Elements for Testing

Soil	Concrete	Compost
Texture	pH	pH
pH	EC	EC
EC	Na	C:N Ratio
%OM	Cl	%OM
%CaCO3	Cd	P
P	Pb	K
K		Fe
Fe		Zn
Zn		Cu
Cu		Mn
Mn		Cd
		Pb

In order to analyze the samples using Atomic Absorption Spectroscopy (Appendix 3) for the presence of heavy metals and available trace elements in the input materials, the samples first needed to be digested or extracted. For the determination of heavy metals, ground concrete was digested using 1M HNO3 and boiled for 10 minutes (see Appendix 4). The analysis of the compost was also done using Atomic Absorption Spectroscopy but the samples were prepared using dry digestion. As for the available trace elements in the soil, samples were digested using DTPA (see Appendix 5). The samples were then taken to Lebanese Agricultural Research Institute in Kleiaat, Mount Lebanon for analysis.

The laboratory analysis included testing of available macronutrients, micronutrients as well as Cadmium and Lead which are classified as heavy metals. Macronutrients and micronutrients are essential to plant growth however the presence of cadmium and nickel in the soil highlights a contamination. The main sources of Cadmium are phosphate fertilizers, coating of metals, fireworks and rubber as well as nickel-cadmium batteries (Alloway, 1990). Nickel on the other hand comes from magnetic tapes and nickel-cadmium batteries (WHO, 1991).

CHAPTER 4

RESULTS AND DISCUSSION

Different growth patterns were observed during the experiment which means the plants interacted differently with each of the mixes.

Measurements were collected the first four weeks of the experiment and the last four weeks of the experiment. The first four weeks of the experiment data on the emergence and initial rate of growth were collected particularly for corn. *Mathiolla* served more as an indicator of plant survival and establishment in the different mixes. Thus, emergence and establishment of the plants were mainly assessed in this phase of the experiment.

4.1. Physical Attributes

4.1.1. Corn

The physical attributes that were measured in order to evaluate growth of the corn crops during the twelve weeks of experiment include: number of plants in pot, average height, number of leaves, average length of leaves and the presence/absence of flower. Results of the measurements are reported in Table 3.

Table 3. Corn Detailed Results

CORN	No. of Plants in Pot	Average Height (in cm)	No. of Leaves	Average Length of Leaves	Flower
Pot No.					
A-1	4	120	8,9,11,9	60	X
A-2	4		9,10,9,9		X
A-3	4		9,10,9,10		X
A-4	4		9,9,10,9		X
A-5	2		9,8		X
B-1	1	120	11	50	X
B-2	2		11,11		X
B-3	2		10,10		X
B-4	4	110	10,10,10,10		X
B-5	5		11,10,9,10		X
C-1	3	30	9,10,9	25	-
C-2	3		10,9,11		-
C-3	3		10,10,10		-
C-4	5		10,10,9,8,9		-
C-5	3		9,9,11		-
D-1	5	50	10,9,10,9,10	50	X
D-2	3		9,11,9		X
D-3	5		11,11,10,10,10		X
D-4	4		10,11,11,11		X
D-5	4		10,9,9,10		X
E-1	5	30	8,9,8,8,8	25	-
E-2	4		6,3,7,8		-
E-3	5		7,6,6,8,8		-
E-4	5		7,7,7,5,8		-
E-5	5		7,8,8,6,8		-

The first two weeks of the experiment, all treatments were found to be growing at the same rate (see Figure 14). This is probably due to the fact that the seed was still the main source of nutrients. By the end of week 3 in the control treatment, treatment C, plants were growing a little faster than all the others. Treatment B started off as the weakest among the five treatments in terms of germination and survival, with most of the *Mathiollas* wilting and germination of fewer corn seeds.

By the end of the first month (Figure 11), difference in growth was still not very significant among the five treatments. As shown in Figure 14, crops were growing at approximately the same rate in all treatments: all were at about the same height, same average number of leaves, length and color of leaves (Table 3). In treatment C however, leaves of plants started becoming chlorotic, this remained throughout the rest of experiment.

Additionally, by the end of the first month could the germination rate of the corn seeds could be measured. Table 4 summarizes the germination rates of all five treatments.

Table 4. Corn Germination Rates

Corn Germination Rate per Treatment	
Treatment	**Germination Rate**
A	72%
B	56%
C	68%
D	84%
E	96%

Figure 11. Pot Experiment Week Four

Twelve weeks after planting, significant difference in growth was observed among the five treatments. In terms of stem height, treatment A (2:1:1, Rubble:Soil:Compost) was the most successful, followed by treatment B (1:0:1, Rubble:Soil:Compost). Although these two treatments did not have the highest germination rates (72% and 56% as shown in Table 4), the seeds that did germinate reached an average height of 110-120 cm (Table 3) by the end of week 12, which is the highest among all five treatments (see Figure 14). The number of leaves in treatments A and B is also the highest as is the length of leaves and their color was the greenest (see Figure 12 and Figure 13). Also, by the end of the experiment, corn in treatments A and B had reached Silk stage of the flowering phase in corn crops which is the last stage before Yield Formation.

Treatment D also reached Silk stage where flowering occurs even though the plants did not grow as healthy and big as in treatments A and B. Treatments C (Control) and E remained the smallest and weakest among treatments exhibiting the shortest average stem height (up to 30 cm), the least number of leaves, length of leaves and the leaves in both treatments were chlorotic (see Table 3). Both treatments did not reach flowering stage. Furthermore, Figure 12 and Figure 13 show the difference in leaf color among the treatments -treatments C (0:1:0, Rubble:Soil:Compost) and E (1:1:0. Rubble:Soil:Compost) exhibit an obvious chlorotic leaf color that began to appear on the fourth week as previously mentioned and which remained all throughout the experiment.

Figure 12. Pot Experiment Week Eleven

Figure 13. Pot Experiment Week Twelve

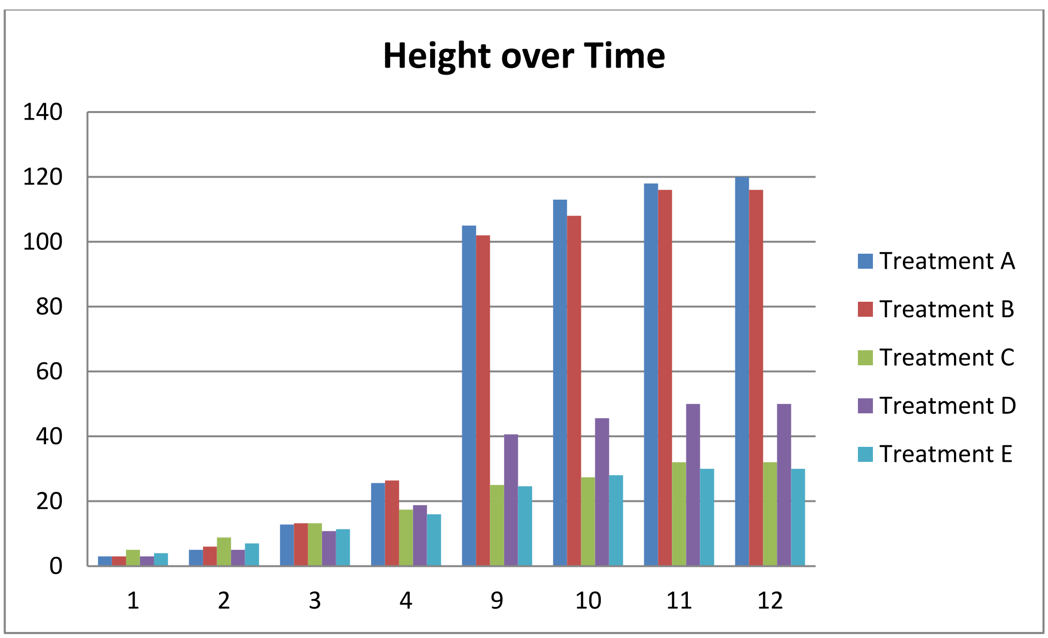

Figure 14. Corn Growth over Time

The treatments containing compost were more successful than the ones containing no compost. The probable reason behind that is the gradual decline in the initially high pH of the compost with time. So starting with a relatively high pH the first three weeks of the experiment, the plants in all treatments performed similarly. With the passage of time, anaerobic bacterial activity is replaced by aerobic bacterial activity in the compost which lowers the pH level making micro nutrients more available to the plants – metals (most of the micronutrients) are more soluble – thus more available for plant uptake - at lower pH.

Thus, the treatments containing compost grew better than the others. Moreover, comparing treatments A (2:1:1) and D (1:1:1), treatment A was more successful than treatment D although both contain compost in the mix. However treatment A having more ground concrete in the mix, must have had better drainage whereas treatment D had poorer drainage thus poorer root zone aeration. Therefore the ground concrete also contributed to the success of treatments A and B by providing a better texture for drainage. Additionally, the chlorosis in treatments C and E, containing no compost highlights an environment that was not suitable for the growth of corn crops.

4.1.2. Mathiolla crassifolia

Similar to corn, physical attributes in *Mathiolla* were measured in order to assess the ability of the mixes to sustain plant growth. The indicators that were evaluated include: number of plants in pot, average diameter and the presence/absence of flower.

Table 5. *Mathiolla* Detailed Results

Mathiolla	No. of Plants in Pot	Height (in cm)	No. of Leaves	Average Diameter (cm)	Fruit/Flower
Pot No.					
A-1	3			23	-
A-2	0				-
A-3	1				-
A-4	1				-
A-5	1				-
B-1	1			25	-
B-2	1				-
B-3	3				-
B-4	3				-
B-5	1				-
C-1	0			10	-
C-2	3				-
C-3	1				-
C-4	1				-
C-5	2				-
D-1	1			15	-
D-2	0				-
D-3	0				-
D-4	0				-
D-5	1				-
E-1	2			15	-
E-2	2				-
E-3	2				-
E-4	3				-
E-5	2				-

Unlike corn that started off as a seed, *Mathiolla* seedlings were used in the experiment in order to test the ability of the treatments to support plant establishment. Three seedlings of approximately 3 cm each were planted). Four weeks after planting, survival rate of the seedlings was documented. The highest survival rate was calculated at 73.3% for treatment E (1:1:0, Rubble:Soil:Compost) and the lowest was treatment D (1:1:1, Rubble:Soil:Compost), 13.3% (see Table 6). Nevertheless, treatment E was not the most successful in terms of plant growth. Similar to corn crops, *Mathiolla*s in treatments A and B were the most successful but with treatment B doing slightly better as observed in Figure 15 and Figure 16. The plants reached an average diameter of 24cm on average in treatments A and B (see Table 5) by the end of week 12 of the experiment.

Table 6. *Mathiolla* Survival Rate

***Mathiolla* Seedling Survival Rate**	
Treatment	**Survival Rate**
A	40%
B	60%
C	46%
D	13.30%
E	73.30%

Figure 15. Mathiolla in Treatment A on Week Twelve

Figure 16. Mathiolla in Treatment B on Week Twelve

Treatment C (Control) as shown in Table 5 and in Figure 17 was the weakest among the five treatments. The average diameter reached did not go over 10 cm in 12 weeks with a 46% seedling survival rate (see Table 6). Drainage in treatment C was not good as irrigation water was accumulating and draining very slowly from the pots. The absence of compost also plays a role in the weakness of the plants as discussed in the previous section.

Figure 17. Treatments C and D on Week Twelve

Treatment D (1:1:1 Rubble:Soil:Compost) and treatment E (1:1:0 Rubble:Soil:Compost) had the same growth pattern and reached approximately the same diameter by week 12 (14.8 and 15 cm respectively as shown in **Error! Reference source ot found.**). However as previously mentioned, treatment D had the lowest survival rate (13.3%) and treatment E the highest (73.3%). Figure **17** shows the two *Mathiollas* that survived in treatment D and Table **6** displays the high survival rate of the plant in Treatment E.

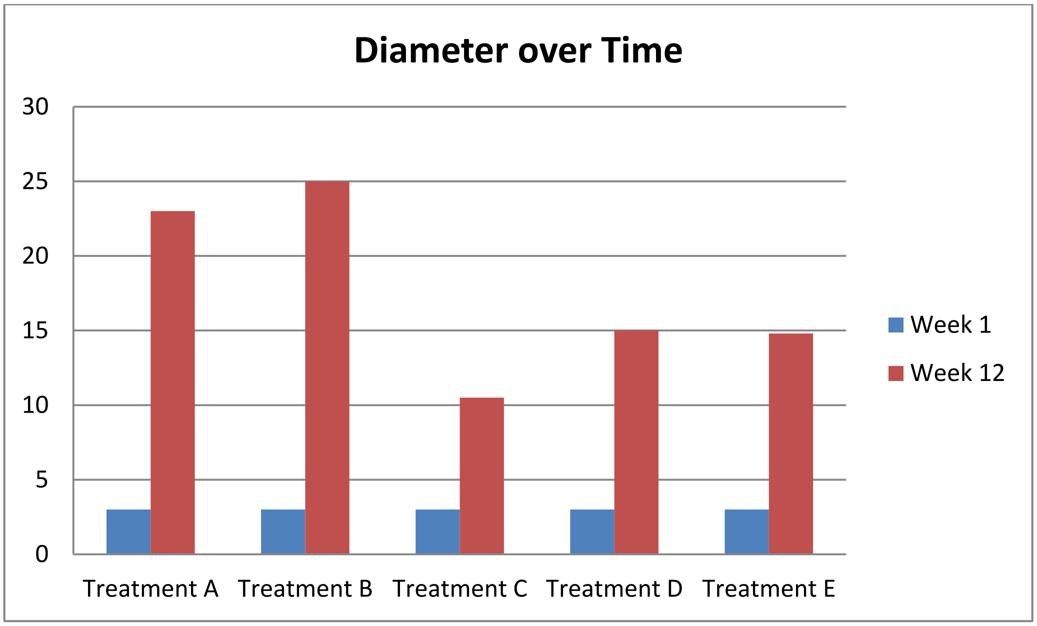

Figure 18. *Mathiolla* growth over time

Figure 19. Treatment E on week twelve

Similar to corn, the *Mathiolla* seedlings planted in treatments A and B were the most successful (up to 25 cm diameter) -. Growth of *Mathiolla* is measured in terms of diameter as it does not grow upwards too much. It was also noticeable that the treatments containing no compost did not perform well (Treatments E and C). Treatment D with a ratio of 1:1:1 Rubble:Soil:Compost also did not perform well. Survival rate of treatment D was documented as the lowest among the five treatments and the two seedlings that did survive did not grow more than 15 cm in diameter in contrast to a 30 cm diameter in treatment B by week twelve. .

Additionally, in all four treatments (A, B, C and D) except treatment E, both corn and *Mathiolla* were either successful or grew poorly, similarly. In treatment E corn crops were not successful and ended up small and wilted by week twelve although it had the highest germination rate (96%), whereas the *Mathiolla* seedlings managed to grow (even if not as big as A and B) 12 cm wider than they were when first planted with the highest survival rate among all treatments (73.3%). *Mathiolla* is a hardy plant that tolerates alkaline soils since Lebanese soil is characterized by a high percentage of $CaCO_3$. It is considered a hardy plant since it grows between rocks on the coast. Thus the fact that it grew in mixes containing concrete and in treatment E which does not contain any compost, highlights the fact that it is tolerant to high pH levels and it is resilient.

4.1.3. Statistical Analysis

A two way analysis of variance (ANOVA) with repeated measures (Time) was used to analyze the results using a common statistical software, STATA, developed by StataCorp. The objective is to test plant response to a planting medium containing excavation and demolition material, therefore the experimental unit is the plant. Statistical analysis was conducted in order to support the visual results of the experiment (See Appendix 1 and 2).

The two-way ANOVA conducted on the results of the corn crops suggested that the mixes did have an effect on plant growth and time as well. An R-squared of 0.9899 suggests that 99% of the variation is explained by the factors (mix and time) thus it is not random (See Appendix 1). In addition P value of all the factors turned out as 0 (mix, time and mix # time) (See Table **7**). Also, P value for Model also resulted in a null value which suggests that at least one factor is significant however in this case all factors were significant which means that the factor "mix" had an effect, "time" had an effect and the different mixes responded to time differently (factor "mix # time").

Table 7. STATA Output for Corn

Stata Outputs for Corn			
Number of Observations	175	**R-Squared**	0.9899

	P-Value
Model	0
Mix	0
Time	0
Mix#Time	0

Additionally, a pair-wise comparison (comparison between the mixes) was done based on the final reading on week twelve following Tuckey's method. The latter is a method for computing P-values that account for multiple comparisons within a factor-variable term. Results of the two-way comparison are reported in Appendix 1 and suggest that Treatments A and B show no significant difference since the P-value is greater than 0.5 and Treatments C and E as well.

As for the Mathiolla, R-Squared is equal to 0.5685 which suggests that 57% of total variation is explained by the factor and is not random. The P-value for "Model" is close to 0 (0.0015) according to Table **8** which means at least one factor is significant and since the only factor is "Mix" with a P-value similar to Model, then the mix has an effect on plant growth.

Table 8. STATA Output for Mathiolla

Stata Outputs for Mathiolla			
Number of Observations	25	**R-Squared**	0.5685

	P-Value
Model	0.0015
Mix	0.0015

A pair-wise comparison between mixes based on the final reading using Tuckey's method (previously explained) was done for the results of Mathiolla also. Results of the two-way comparison are reported in Appendix 2 and suggest that there is no significant difference between treatments A and B, C and D, C and E and eventually A and E given the P-values which are greater than 0.5.

4.2. Chemical Attributes

The chemical attributes of each of the input materials were also investigated and tests for the presence heavy metals and the availability of trace elements were conducted.

Results of the analysis of the soil, concrete and compost are presented in Table **9** :

Table 9. Results of Chemical Analysis

	Soil	Concrete	Compost
Texture	Sandy Loam	-	-
EC	192 µS	1759 µS	13.51 mS
pH	7.19	10.96	7.91
%CaCO3	28	-	-
%OM	2	-	88
C:N Ratio	-	-	16:1
Na	-	185 ppm	-
Cl	-	67.5 ppm	-
P	56 ppm	-	8000 ppm
K	53.07 ppm	-	10980 ppm
Fe	52.25 ppm	-	5600 ppm
Zn	1.908 ppm	-	220 ppm
Cu	3.645 ppm	-	250 ppm
Mn	16.42 ppm	-	120 ppm
Cd	-	0	0
Pb	-	0	100 ppm

4.2.1. Soil Analysis

4.2.1.1. Texture, Electrical Conductivity, pH, %CacO3, %Organic Matter

The soil used in the experiment is a sandy loam with a pH of 7.19 - this is considered neutral to slightly alkaline but optimal for plant growth *(Miller and Gardiner, 2008* - , and electrical conductivity of 192 µS which means the soil is non-saline (*Miller and Gardiner, 2008)*. In addition, the soil has 28% Calcium Carbonate ($CaCO_3$) and 2%

4.2.1.2. Phosphorous (P) and Potassium (K)

. The total amount of phosphorus in the soil used in the experiment was in 56 ppm (see Table 9) which, according to Bashour 2001, is considered a high value (see Table 10).

The amount of potassium in the form of K_2O is 53.07 ppm (see Table 9) which is a relatively low value according to Bashour (2001) - see Table 10 . Potassium deficiency is generally expected in soils low in clay (*Miller and Gardiner, 2008)*. The tested soil contains 16% clay.

Table 10. Nutrient Range in Soils (ppm)- *Bashour, 2001*

Nutrient	**Very Low**	**Low**	**Medium**	**High**	**Very High**
Phosphorus (ppm)	0 to 3	3 to 8	8 to 14	4 to 20	> 20
Potassium (ppm)	0 to 85	85 to 150	150 to 250	250 to 450	> 450

4.2.1.3. Trace Elements: Iron (Fe), Copper (Cu), Zinc (Zn), Manganese (Mn)- DTPA Extraction

Analysis of the soil for availability of micronutrients was conducted using Atomic Absorption Spectroscopy with extraction using DTPA (See Appendix 3).

The soil used in the experiment is rich in micronutrients. It has a very high Iron content of 52.25 ppm (see Table **9**) which is reflected in its red color typical of the Red Mediterranean soil that is rich in iron and associated with hard Limestone, the Terra Rossa found across Lebanon (*Darwish and Zurayk, 1997*).

Copper (Cu) was found to be abundant in the analyzed soil - 3.546 ppm.

Zn was found at concentrations of around 1.908 ppm.

Manganese (Mn) concentration of 16.42 ppm was found in the tested soil used in the mix- this is considered relatively high (Lindsay and Norvell, 1978).

The results reported in Table **9** reflect a soil rich in micronutrients with low potassium content. Therefore the reason behind the failure of treatments C and E could not have been a deficiency in nutrients since the availability of macronutrients (except for potassium) as well as micronutrients is high in the soil. The compost in the other treatments certainly made the nutrients more available to plants by lowering pH levels in the mixes. The poor performance of treatment C could be due to a combination of lack of availability of micronutrients due to relatively high pH levels, and poor drainage (this was improved in the other treatments by the ground concrete pieces). In treatment E, the high alkalinity and salinity (Na and Cl) of the concrete which constitutes 50% of the mix would have inhibited nutrient availability for plant uptake, thus the small size and poor condition of the corn crops and the somewhat acceptable condition of *Mathiolla*. The latter is a coastal plant tolerant to salt and hardy which makes it easier for it to grow in harsh conditions.

Table 11. Levels of Availability of Micronutrients- Lindsay and Norvell 1978

Micronutrients (ppm)				
Availability	**Zinc (Zn)**	**Manganese (Mn)**	**Iron (Fe)**	**Copper (Cu)**
Very Low	0-0.5	0-0.5	0-2.0	0-0.1
Low	0.6-1.0	0.5-1.2	2.0-4.0	0.1-0.3
Medium	1.0-3.0	1.2-3.5	4.0-6.0	0.3-0.8
High	3.0-6.0	3.5-6.0	6.0-10.0	0.8-3.0
Very High	>6.0	>6.0	>10	>3.0

4.2.2. Concrete Analysis

Concrete is basically made from three raw materials: cement, water and aggregates. Cement however, is a combination of compounds made by burning Limestone and Clay together at high temperature (*University of Illinois, 1995)*.

Results of the tests conducted on concrete are shown in Table 9. The concrete that was ground and used in the mixes does not contain any Cadmium (Cd) or Lead (Pb). Sodium content and chlorine were high (185 ppm and 67.5 ppm respectively) as was pH (10.96) reflecting the typical alkalinity of concrete. The high electrical conductivity (EC) of 1759 µS is no surprise given the high concentrations of Na and CL. The alkalinity and the high concentration of Sodium in the concrete would have had an adverse impact on the growth of plants. This is where the benefit of compost may be felt, especially in the lowering of pH. .

4.2.3. Compost Analysis

The compost (Grade A) used in the experiment was brought in from Sukomi, a composting plant in Beirut. Typically, many elements are essential for microbial decomposition however Carbon and Nitrogen are the most vital (*Chen et al., 2011*). The ideal C:N ratio at the beginning of the composting process is 25-30:1 but as composting proceeds, this ratio decreases to reach 15:1 ideally (*Chen et al., 2011)* sometimes ranging from 15 to 20:1 (*UMass Extension, 2014).* As seen in Table 9, the compost used in the experiment has a C:N ratio of 16:1 and a pH of 7.91 along with an EC of 13.51mS. Typical pH levels for composts range from 6.5-8 (*Chen et al., 2011*). EC in compost exceeds the 1-10 mS range typical of compost (*UMass Extension, 2014).* Additionally, the compost contains 88% organic matter. Macronutrients including phosphorous and potassium are found in abundance: 8000 ppm and 10980 ppm respectively. Similarly for the micronutrients, high levels are found in the compost (see Table **9**). Iron was reported at 5600 ppm, Zinc at 220 ppm, Copper at 250 ppm and Manganese at 120 ppm (See Table **9**). In addition, no Cadmium was detected but 100 ppm of Lead was reported. Given that the normal range of Nickel content is between 3 and 100 ppm (Abou Mosleh, 2005), the concentration reported is within range. In summary, the results of the chemical analysis of the compost explain the better performance of the treatments containing compost.

CHAPTER 5

CONCLUSIONS AND FUTURE RECOMMENDATIONS

The experiment conducted aimed at creating a planting medium out of organic waste and construction and demolition waste to ultimately provide a potential solution to a dual problem faced in: management of construction and demolition waste on one hand and the rehabilitation of abandoned quarries on the other. The planting medium created could be used to backfill abandoned quarries where the topsoil has been removed.

The experiment started by gathering all the input material needed for creating mixes of different ratios of soil, rubble and compost.. The mixes created have different ratios of each of the materials:

- Treatment A: 2:1:1, Rubble: Soil: Compost
- Treatment B: 1:0:1, Rubble: Soil: Compost
- Treatment C (Control): 0:1:0, Rubble: Soil: Compost
- Treatment D: 1:1:1, Rubble: Soil: Compost
- Treatment E: 1:1:0, Rubble: Soil: Compost

Treatments A and B turned out to be most successful mixes where treatment A had the best growth of corn and treatment B the best growth of *Mathiolla.* Corn in treatments A and B reached a 110-120 cm height respectively whereas the *Mathiolla* seedlings grew 25-30 cm in diameter respectively (). Treatment D displayed the lowest survival rate of *Mathiolla* seedlings (13.3%) although in general both corn and Mathiolla seedlings grew to a height of 50 cm in corn) and a diameter of 15 cm in *Mathiolla* . Thus Treatment D did sustain plant growth but not as well as A and B and would need further improvement in terms of nutrient availability and drainage for better results. Treatments C (control) and E resulted in the weakest plant growth. Corn did not grow more than 30 cm in height and was chlorotic which reflects a nutrient deficiency. *Mathiolla,* it did not grow larger than 12 cm in diameter in treatment C but reached 15 cm in treatment E, which was made up of concrete and soil only. The explanation behind the different growth patterns of the *Mathiolla* is the fact that it is a coastal hardy plant that grows in environments such as between rocks and anywhere on the coast in addition to being a native plant thus it is tolerant to alkaline soils.

The statistical analysis conducted on STATA served as a support of the visual results and reported positive results. R-squared for both Corn and Mathiolla tests resulted in 0.9 and 0.57 respectively which means that the total variation is explained by the factors and is not random. The reported results of the analysis also suggested that the mixes did have an effect on plant growth and time as well. In addition, the results showed that the different mixes responded to time differently.

In terms of chemical attributes, all three input materials were analyzed in order to understand their composition and justify the results of the physical attributes. In terms of nutrients the soil is adequate for planting however the compost is the material containing the most nutrients and that was reflected in the results. Additionally, it is important to note that neither the concrete nor the compost contains any Cadmium or Lead in amounts considered contaminating which makes it possible to use the planting mix for agriculture as well. In summary, treatments A and B are the best and should be pursued for further study such as a pilot project scale project.

Finally, several future recommendations are proposed for a better understanding of the results. These recommendations include:

- Analysis of each of the mixes on the first week of planting and then on the last week of the experiment.
- Two or three cycles can be repeated using the same mix but different plants to test whether the mix degrades or it gets better with time.
- Analysis of the leachate from irrigation.
- A test of vegetative growth through dry weight analysis.
- The use of more fruiting plants to test the ability of the mix to sustain growth to that stage of growth. And the potential use of the mix in urban agriculture.
- Test the water holding capacity of each mix because the different input materials exhibited different water holding capacities throughout the experiment.
- Conduct a pilot project in an actual quarry

APPENDIX 1

STATISTICAL ANALYSIS: STATA OUTPUT FOR CORN

```
                Number of obs =      175     R-squared     =  0.9899
                Root MSE      = 3.84803     Adj R-squared =  0.9890

     Source |  Partial SS    df       MS           F     Prob > F
  -----------+----------------------------------------------------
      Model |  232723.261    14  16623.0901     1122.63     0.0000
            |
        mix |  5996.31745     4  1499.07936      101.24     0.0000
       time |  4114.69213     6  685.782021       46.31     0.0000
   mix#time |  59416.2325     4  14854.0581     1003.16     0.0000
            |
   Residual |  2369.17319   160  14.8073324
  -----------+----------------------------------------------------
      Total |  235092.434   174  1351.10594

Margins      : asbalanced

---------------------------
             |    Number of
             |  Comparisons
-------------+-------------
    mix#time |           10
---------------------------

------------------------------------------------------------
                  |                                Tukey
                  |   Contrast   Std. Err.        t    P>|t|
------------------+-----------------------------------------
         mix#time |
(2 12) vs (1 12)  |   1.778821   1.598156      1.11    0.799
(3 12) vs (1 12)  |   23.93734   1.598156     14.98    0.000
(4 12) vs (1 12)  |   16.49476   1.598156     10.32    0.000
(5 12) vs (1 12)  |   22.50852   1.598156     14.08    0.000
(3 12) vs (2 12)  |   22.15852   1.598156     13.87    0.000
(4 12) vs (2 12)  |   14.71594   1.598156      9.21    0.000
(5 12) vs (2 12)  |   20.72969   1.598156     12.97    0.000
(4 12) vs (3 12)  |  -7.442576   1.598156     -4.66    0.000
(5 12) vs (3 12)  |  -1.428821   1.598156     -0.89    0.899
(5 12) vs (4 12)  |   6.013755   1.598156      3.76    0.002
------------------------------------------------------------
```

APPENDIX 2

STATISTICAL ANALYSIS: STATA OUTPUTS FOR *MATHIOLLA*

```
                     Number of obs =      25     R-squared     =  0.5685
                     Root MSE      = 6.38436     Adj R-squared =  0.4823

          Source |  Partial SS    df       MS           F     Prob > F
      -----------+----------------------------------------------------
           Model |     1074.24     4      268.56       6.59     0.0015
                 |
             mix |     1074.24     4      268.56       6.59     0.0015
                 |
        Residual |       815.2    20       40.76
      -----------+----------------------------------------------------
           Total |     1889.44    24  78.7266667
```

```
Margins      : asbalanced

---------------------------
             |    Number of
             |  Comparisons
-------------+-------------
         mix |           10
---------------------------
```

```
-----------------------------------------------------
             |                               Tukey
             |   Contrast   Std. Err.        t    P>|t|
-------------+---------------------------------------
         mix |
     2 vs 1  |        5.6    4.037821     1.39    0.643
     3 vs 1  |        -10    4.037821    -2.48    0.136
     4 vs 1  |      -12.4    4.037821    -3.07    0.043
     5 vs 1  |       -3.6    4.037821    -0.89    0.897
     3 vs 2  |      -15.6    4.037821    -3.86    0.008
     4 vs 2  |        -18    4.037821    -4.46    0.002
     5 vs 2  |       -9.2    4.037821    -2.28    0.193
     4 vs 3  |       -2.4    4.037821    -0.59    0.974
     5 vs 3  |        6.4    4.037821     1.59    0.523
     5 vs 4  |        8.8    4.037821     2.18    0.228
-----------------------------------------------------
```

APPENDIX 3

ATOMIC ABSORPTION SPECTROSCOPY

(Bashour and Sayegh, 2001) P.88

Atomic Absorption Spectroscopy (AAS) uses absorption of light to measure the concentration of analyte atoms in a flame or graphite furnace. The light source is usually a hollow-cathode lamp of the element that is being measured. Lamps convert electrical energy levels. Light absorption is proportional to the amount of analyte atoms in the path of light. Concentration measurements are determined from a working curve after calibrating the instrument with standards of known concentration.

Atomic absorption spectroscopy requires that the analyte atoms be in the gas phase. Ions or atoms in a sample must undergo vaporization or atomization in a high-temperature source such as a flame or graphite furnace.

A calibration curve is a plot of the analytical signal as a function of analyte concentration. These calibration curves are obtained by measuring the signal from a series of standards of known concentration. The calibration curves are then used to determine the concentration of an unknown sample, or to calibrate the linearity of an analytical instrument.

APPENDIX 4

PROCEDURE OF SAMPLE DIGESTION USING HNO_3

(Bashour and Sayegh, 2001) P.100

1. Add 100 ml of 1:1 HNO_3 to 2g of air-dried soil (<1mm) in a 150 ml beaker.
2. Place the sample on a hot plate, cover with a watch glass, and heat at 95 Degrees Celsius for 15 minutes.
3. Cool the digest and add 5 ml of concentrated HNO_3. Reflux for an additional 30 minutes at 95 Degrees Celsius.
4. Repeat the last step and reduce the solution to about 5ml without boiling.
5. Cool the digest again and add 2ml of deionized water and 3ml of 30% H_2O_2.
6. With the beaker covered, heat the sample gently to start the peroxide reaction. If effervescence becomes excessively vigorous, remove the sample from hot plate. Continue to add 30% H_2O_2 in 1ml increments followed by gentle heating until effervescence subsides.
7. Add 5ml of concentrated HCL and 10 ml of de-ionized water and reflux the sample for an additional 15 minutes without boiling.
8. Cool and filter through a Whatman No.42 filter paper. Dilute to 50 ml with de-ionized water. Analyze for Cd, Pb, Cr, and Ni by AAS.

APPENDIX 5

PROCEDURE OF SAMPLE DIGESTION USING DTPA

(Bashour and Sayegh, 2001) P.87

1. Weigh 5g of air-dried soil (<2mm) in a 100 ml polyethethylene centrifuge tube, add 20 ml DTPA solution, and shake for 30 minutes on a mechanical shaker.
2. Centrifuge, and decant into sample bottle fitted with funnel and filter paper.
3. If needed, dilute the extract so that the reading is in the linear working range of the atomic absorption spectrophotometer.

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