

Potential nutrient release from rock based minerals ameliorants (rock flours) in gold mine rehabilitation

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ABSTRACT

Gold mines produce significant volumes of waste material in the form of tailings and waste rock during their life cycle. A large ecological footprint is therefore created that needs to be rehabilitated. Rehabilitation planning can be extensive and a large volume of topsoil is required to function as a growth medium. To reduce the volume of topsoil required, an alternative is to use the waste material (waste rock) as a resource to minimize rehabilitation expenses. The use of rock-based ameliorants, also known as rock flour, has been successfully tested in both agriculture and environmental applications for rehabilitation and nutrient availability. Previous studies done on this subject indicates that rock powder could provide the essential nutrients to plants during the rehabilitation process to promote plant growth.

In this study, three common igneous rocks, namely granite, gabbro and andesite, were used as a finely ground rock-based ameliorant for rehabilitation. The seed of *Cynodon dactylon* (Couch grass) was sown into pots to provide an incubation cover and test the vitality of the plant after chemical and physical alteration of the material during the experiment.

Three concentrations of granite, gabbro, and andesite were mixed with gold tailings as a growth medium. Due to the low pH value of the gold tailings material, lime was added to half of the samples to test the impact of liming in conjunction with rock flour. Vegetation surveys included the monitoring of the germination potential of the *C. dactylon* seed, the dry weight and nutrient absorption potential of *C. dactylon* in the different mediums and changes in the chemical and physical soil parameters over time.

The results indicated that andesite rock flour was the most effective ameliorant to be used for rehabilitation of gold mine tailings. However, if a growth medium has high saline conditions, a mixture of andesite and granite ameliorants would provide the best chance of success to rehabilitate a gold mine tailings storage facility (TSF). By using these ameliorants, the footprint created by gold mines as well as the rehabilitation costs can be reduced.

Keywords: Gold tailings, gold mines, rock-based ameliorants, *Cynodon dactylon*, rehabilitation, waste rock.

OPSOMMING

Goudmyne produseer aansienlike volumes afvalmateriaal in die vorm van afvalmateriaal en afvalstene gedurende hul lewensiklus. 'n Groot ekologiese voetspoor word dus geskep wat gerehabiliteer moet word. Rehabilitasiebepanning kan omvattend wees en 'n groot volume bogrondmateriaal is nodig om as groeimedium te funksioneer. Om die volume bogrondmateriaal wat benodig word te verminder, is 'n alternatief om die afvalmateriaal (afvalstene) as 'n hulpbron te gebruik om rehabilitasiekoste te verminder. Die gebruik van rotsgebaseerde ameliorante, ook bekend as klipmeel, is suksesvol getoets vir beide landbou- en omgewingstoepassings vir rehabilitasie en voedingstofbeskikbaarheid. Studies wat reeds gedoen is op die onderwerp het bewys dat gesteente poeier verskaf die noodsaaklike voedingstowwe aan plante tydens die rehabilitasie proses en bevorder die groei van plante.

In hierdie studie word drie algemene stollingsgesteentes, naamlik graniet, gabbro en andesiet, gebruik as 'n fyngemaalde rotsgebaseerde ameliorant vir rehabilitasie. Die saad van *Cynodon dactylon* (kweekgras) is gesaai in potte om 'n inkubasiebedekking te gee en die lewenskrachtigheid van die plant na die chemiese en fisiese verandering van die materiaal tydens die eksperiment te toets.

Drie konsentrasies graniet, gabbro, andesiet is gemeng met goudafval as 'n groeimedium. As gevolg van die lae pH-waarde van die goudafvalmateriaal is kalk by sommige monsters bygevoeg. Plantkundige opnames sluit in die monitering van die ontkiemingspotensiaal van *C. dactylon* saad, die drooggewig en die nutriëntabsorpsiepotensiaal van *C. dactylon* in die verskillende mediums. Veranderinge in die chemiese en fisiese grondparameters sal met verloop van tyd gemeet word.

Die resultate het aangedui dat andesietklipmeel die effektiëste ameliorant was wat vir rehabilitasie gebruik kan word. As die groeimedium egter hoë sout kondisies het, sal 'n mengsel van graniet en andesietklipmeel beter resultate toon vir rehabilitasie van goudslikdamme. Deur hierdie ameliorante te gebruik kan die voetspoor wat deur goudmyne geskep word asook die rehabilitasiekoste verminder word.

Sleutelwoorde: Goudafvalmateriaal, goudmyne, rotsgebaseerde ameliorante, *Cynodon dactylon*, rehabilitasie, afvalstene.

ABBREVIATIONS

A 1	:	1 st concentration of Andesite rock powder
A 2	:	2 nd concentration of Andesite rock powder
A 3	:	3 rd concentration of Andesite rock powder
AMD	:	Acid mine drainage
Al	:	Aluminium
Al ₂ O ₃	:	Aluminium oxide
As	:	Arsenic
ATP	:	Adenosine triphosphate
B	:	Boron
BIF	:	Banded Iron Formation
BSi	:	Biogenic silica
C	:	Carbon
C	:	Control
Ca	:	Calcium
<i>C. dactylon</i>	:	<i>Cynodon dactylon</i>
Cd	:	Cadmium
CEC	:	Cation exchangeable capacity
Cl	:	Chlorine
CO ₂	:	Carbon dioxide
CO ₃ ²⁻	:	Carbonate
Cu	:	Copper
DNA	:	Deoxyribonucleic acid

DOC	:	Dissolved organic carbon
EC	:	Electrical conductivity
ECA	:	Environmental Conservation Act
EMP	:	Environmental Management Plan
Fe	:	Iron
Fertasa	:	Fertilizer Association of Southern Africa
Ga 1	:	1 st concentration of gabbro rock powder
Ga 2	:	2 nd concentration of gabbro rock powder
Ga 3	:	3 rd concentration of gabbro rock powder
Gr 1	:	1 st concentration of granite rock powder
Gr 2	:	2 nd concentration of granite rock powder
Gr 3	:	3 rd concentration of granite rock powder
H	:	Hydrogen
HCO ₃ ⁻	:	Bicarbonate
Hg	:	Mercury
HREE	:	Heavy rare earth elements
K	:	Potassium
Mg	:	Magnesium
Mn	:	Manganese
Mo	:	Molybdenum
N	:	Nitrogen
Na	:	Sodium
Ni	:	Nickel

NH ₄	:	Ammonium
NO ₃ ⁻	:	Nitrates
O	:	Oxygen
OH	:	Hydroxyl ion
P	:	Phosphorus
Pb	:	Lead
PGPR	:	Plant Growth-Promoting Rhizobacteria
PI _(abs)	:	Performance Index
RNA	:	Ribonucleic acid
S	:	Sulphur
Sb	:	Antimony
Si	:	Silicon
SiO ₂	:	Silica
Si(OH) ₄	:	Monosilicic acid
Sn	:	Tin
SO ₄ ²⁻	:	Sulphates
SOM	:	Soil organic matter
Th	:	Thorium
Ti	:	Titanium
TSF	:	Tailings storage facility
U	:	Uranium
W	:	Tungsten
Zn	:	Zinc

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CHAPTER 1

INTRODUCTION

1.1 Conceptualization of the project

Mines in South Africa are forced by legislation to rehabilitate the land to a post-closure land use as defined by their environmental management plan (EMP). The post-closure land use should be self-sustainable, which entails the establishment of vegetation cover on the tailings storage facilities (TSFs) without further maintenance (Weiersbye *et al.*, 2006:102; Mains *et al.*, 2006:131; Mendez & Maier, 2008b:278; Mendez & Maier, 2008a:48; Schimmer & van Deventer, 2018:21). When the rehabilitation plan is not properly designed, the site will stay barren due to a combination of factors, which could include the pH concentration of the material, metal toxicity, poor soil structure, deficient nutrient levels and low organic matter, as well as stressed microbial communities. (Cooke & Johnson, 2002:42; Wong, 2003:775; Weiersbye *et al.*, 2006:110; Mains *et al.*, 2006:132; Mendez & Maier, 2008b: 48; Barrutia *et al.*, 2011:256, 257; Asensio *et al.*, 2013:446; Schimmer & van Deventer, 2018:21).

One of the main challenges regarding the rehabilitation of TSFs is the lack of sufficient nutrients to support the establishment and growth of the vegetation. Nutrient availability is specifically critical during the seed development and germination phases (Bradshaw, 1983:4; Cooke & Johnson, 2002:50; Wong, 2003:775; Mendez & Maier, 2008a:48; Mendez & Maier, 2008b:278; Schimmer & van Deventer, 2018:21). To date the rehabilitation point of view is to use a self-restricted method. Therefore, only a selected few plant species are used as vegetation cover. The result is a low density ecosystem, with restricted post-closure land use potential and wildlife conservation value (Bradshaw, 1983:4; Cooke & Johnson, 2002:49; Schimmer & van Deventer, 2018:21-22). To have a successful rehabilitation site, the environmental challenges, ecological processes and the complexity thereof need to be comprehensively understood (Wick *et al.*, 2007:942; Barrutia *et al.*, 2011:266; Schimmer & van Deventer, 2018:22).

An EMP describes the method to be used to monitor the progress of the rehabilitation of a TSF. Furthermore, after the rehabilitation plan is executed, it is evaluated in order to determine the success in terms of ecosystem functions (Wick *et al.*, 2007:942; Schimmer & van Deventer, 2018:22; Barrutia *et al.*, 2011:266). Tailings storage facilities (TSFs) are very complex environments, and a single parameter cannot be used to determine the effectiveness of the environmental conditions of the success of the rehabilitation. Parameters include soil erosion and vegetation properties such as production, cover, density and diversity. Soil parameters such as soil quality, i.e. pH, salinity and nutrient status, are also considered (Sheoran *et al.*, 2002:2; Cooke & Johnson, 2002:49; Wick *et al.*, 2007:942; Schimmer & van Deventer, 2018:22). Therefore, a

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thorough investigation I required to ensure the rehabilitation process could have any chance to succeed.

The focus of the modern rehabilitation viewpoint is more directed towards soil fertility, soil organic matter (SOM) and the selection of plant species. These narrow-focused ideas may lead to mines not obtaining a Mine Closure Certificate from the South African government. Therefore, an alternative viewpoint is necessary to establish a dynamic, healthy ecosystem that can support post-mine land use under extreme environmental conditions (Pascual *et al.*, 1999:255; Cooke & Johnson, 2002:43; Wong, 2003:775; Ros *et al.*, 2003:4443; Schimmer & van Deventer, 2018:23). The viewpoint for rehabilitation needs to be open-minded to ensure the mine can close as by the legislation pieces of South African government.

One way to achieve successful rehabilitation is to include microorganisms as a key component, as microorganisms play a fundamental role in nutrient cycling, geochemical alterations, plant establishment and soil formation (Cooke & Johnson, 2002:49; Sheoran *et al.*, 2002:2; Wick *et al.*, 2007:942; Schimmer & van Deventer, 2018:23). Another aspect that could improve the rehabilitation process is the addition of ameliorants to aid in critical ecosystem processes. The latter was the main objective of this study (Wong 2003:776; Wong, 2003:775; Mains *et al.*, 2006:132; Asensio *et al.*, 2013:446; Schimmer & van Deventer, 2018:23). Amelioration could also have a positive effect on the nutrient status of gold TSF's.

In this study, three common igneous rocks, namely granite, gabbro, and andesite were used as finely ground rock-based ameliorants for rehabilitation. The seed of *Cynodon dactylon* (Couch grass) was sown to provide an incubation cover and test the seed vitality and growth of the plant after the chemical and physical alteration of the material during the experiment. This material was then used to evaluate the rehabilitation potential of the three ameliorants and their effectiveness.

1.2 Hypothesis

Granite, gabbro and andesite rock flours can successfully be used as ameliorants to improve the properties of tailings in storage facilities as a growth medium and base to improve the establishment and cover of the vegetation during the rehabilitation process to make it more sustainable.

1.3 Aims and objectives

1.3.1 Aims of the project

- The primary aim was to determine whether granite, gabbro and andesite can be used as rock flours to improve the establishment and growth potential of the vegetation used in the rehabilitation of gold mine tailings.
- A secondary aim was to determinate the effectiveness of each type of rock flour to serve as an ameliorant for the rehabilitation of gold mine tailings.

1.3.2 Objectives

- To determine the effect of rock ameliorants on the soil nutrient availability prior to, during and after the experimental phase.
- To determine the effect of rock ameliorants on basic soil parameters, which include the monitoring of pH, electrical conductivity (EC), linear shrinkage, particle size distribution and aggregate stability.
- To evaluate the germination potential of *C. dactylon* seed on gold tailings material as a growth medium.

1.4 Layout of this thesis

The use of three common igneous rocks for the rehabilitation of gold mine tailings is the main theme of this study. Chapter 2 reviews the literature regarding various aspects of TSFs and the amelioration thereof. Some of the main discussions include mine rehabilitation and legislation in South Africa, an overview of tailings as a growth medium regarding physical and chemical properties, and the mineralogy of applied rock flours. Chapter 3 gives the materials and methods used in this study. The results obtained are discussed in Chapter 4. Chapter 5 consists of the concluding remarks of this study and recommendations for similar future studies. Thereafter, the bibliography contains the list of references used in this dissertation. Finally, additional documents are included as annexures at the end of the dissertation.

CHAPTER 2

LITERATURE STUDY

The literature discussed in this section focusses on the use of granite, gabbro and andesite rocks as rock flour regarding their mineralogy and weathering potential, respectively. The properties of gold mine tailings will be investigated to identify challenges related to the rehabilitation of gold mine tailings using rock flour.

2.1 Introduction

In South Africa, rehabilitation of degraded mining areas is guided by several legislation pieces. The strict environmental legislation of South Africa states broadly that it is part of the basic human rights to have a healthy environment. This is evident by the numerous acts that speak toward *environmental acts (Weiersbye et al., 2006:102):

- Environment Conservation Act (ECA), 73 of 1989;
- ECA Amendment Act 50 of 2003;
- Conservation of Agricultural Resources Act 43 of 1983;
- National Environmental Management Act 107 of 1998;
- National Nuclear Regulator Act 47 of 1999;
- National Environmental Management: Biodiversity Act 10 of 2004;
- National Environmental Management: Air quality Act 39 of 2004;
- Minerals and Petroleum Resources Development Act 28 of 2002;
- National Environmental Management: Protected Areas Act 57 of 2003;
- National Environmental Management Amendment Act 46 of 2003.
- National Water Act 36 of 1998.

The mining industry in particular need to adhere to these acts. Of these, gold mines need to address acid mine drainage (AMD) if sulphide-bearing minerals are present. Acid mine drainage can reduce the pH of TSFs to such a level that metals can become toxic for the environment (Akcil

& Koldas, 2006:1139; Tutu et al., 2008:3667; Schimmer, 2018:44). Gold mines need also to address the extreme edaphic conditions they exert. They often change the environment to reduce water-holding capacity, have toxic elements, low nutrient availability, highly fluctuating temperatures, high salinity and an acidic pH (Akcil & Koldas, 2006:1139; Rafael et al., 2017:3; Schimmer, 2018:47). As a result, ecosystems can lose their functions if mining degradation of landscapes continues (Broadman et al., 2017:106; Wu et al., 2017:162). Because of the legislation, South African gold mines need to address the effect that they have on the ecosystem by means of rehabilitation.

Rehabilitation of gold mining areas often require specialist interventions. One form of intervention is that of amelioration. Amelioration could be defined as a human intervention to improve the soil, in this case, gold mine tailings properties. Amelioration increases the rate of ecosystem and landscape recovery as the natural recovery rate is often too slow (Brady & Weil, 2008:679; De Souza et al., 2013:56; Rafael et al., 2017:3). Many sources exist from which ameliorants can originate. One such source of ameliorant originates from the waste material of mines and quarries (Silva et al., 2005:994; Burghlea et al., 2015:188; Rafael et al., 2017:3-4). The waste material from the gold mines could possibly be used as amelioration within the rehabilitation process.

Of the tons of waste material generated by mines in South Africa, only a few can be used as amelioration. This is due to the fact, that some of the waste material generated by mines could have properties that have the potential to hinder the rehabilitation process. Therefore, it is important to understand the mineralogy of the rock types that would be used as rock flours.

2.2 Mineralogy of applied rock flours

The mineralogy of the three rock types used in this study will be discussed to investigate what the potential of the rock types could have as ameliorants. The three rock types are granite, gabbro and andesite and will be discussed in this order.

2.3.1 Granite

Granite consist out of primary and secondary minerals. The primary minerals are quartz and potassium feldspar and in some cases sodium-rich potassium (Klein & Dutrow, 2007:507, 540; Monroe, *et al.*, 2007:120; Dippenaar & van Rooy, 2014:14; Kaur, *et al.*, 2019:1895). The secondary minerals of granite that could be present in minor quantities, include muscovite and dark silicates like amphiboles or boitite. (Klein & Dutrow, 2007:507,540; Dou *et al.*, 2019:101; Ferreira *et al.*, 2019:418; Kaur *et al.*, 2019:1895). Minor accessory minerals could also be present in small concentrations. These minerals include zircon, titanite, apatite, magnetite, ilmenite and tourmaline (Klein & Dutrow, 2007:581; Dou *et al.*, 2019:101). Therefore, granite consist of the following minerals in general:

Chapter 2 Literature study

- Quartz (SiO_2)
- Feldspar (KAlSi_3O_8)
- Orthoclase ($(\text{K}, \text{Na})\text{AlSi}_3\text{O}_8$)
- Alkali feldspar ($(\text{K}, \text{Na}, \text{Ca})(\text{Si}, \text{Al})_4\text{O}_8$)
- Biotite ($(\text{K}(\text{Mg}, \text{Fe})_3\text{AlSi}_3\text{O}_{10}(\text{OH})_2$)

As one of the primary minerals, quartz is the dominant primary mineral. Quartz in general, is resistant to chemical and physical weathering (Silva *et al.*, 2005: 994; Sleep & Hessler, 2006:595-596). If granite undergoes weathering, quartz-rich sand particles are the most common by-product along with some feldspar and intermediate and mafic minerals as secondary minerals (Silva *et al.*, 2005: 994; Sleep & Hessler, 2006:597; Garzanti *et al.*, 2019:15-16). Therefore, quartz will not change much when undergoing weathering.

Feldspar is present in high abundance in the mineral composition of granite alongside quartz, however, the type of feldspar depends thereof. The feldspar could either have potassic end members (orthoclase, microcline) or calcic-sodic end members (plagioclase) (Scarciglia *et al.*, 2005:13; Kirschbaum *et al.*, 2005:484; Dippenaar & Van Rooy, 2014:15). When plagioclase weathers into clay-size particles, kaolinite is the most common end-product (Weinert, 1980:56; Kirschbaum *et al.*, 2005:485; Dippenaar & Van Rooy, 2014:17). Therefore, the real change of granite will occur due to the weathering of the feldspar and accessory minerals.

Despite that quartz and feldspar contribute to the main content of granite, the rock's complexity is increased by the many other secondary and accessory minerals that fills up the remaining part of the composition. The end-product due to weathering could be complex and unpredictable (Weinert, 1980:55; Melzer *et al.*, 2012:329). Some of the minerals (primary and secondary) that granite consist of are able to undergo altering while weathering down into smaller particles. This process occurs when a mineral change into a new mineral before weathering into smaller size particles. In the case of granite, biotite could be altered into chlorite, muscovite and/or vermiculite, or plagioclase altered into gibbsite, kaolinite or smectite (Drever, 1994:2326; Compton *et al.*, 2003:247). Granite have a few secondary and accessory minerals that could alter the mineralogy slightly as a result, the nutrients that granite could provide to vegetation as an ameliorant may differ as the end-product of granite that had formed.

2.2.1 Gabbro

The second rock type used in this study is gabbro, which mainly consist of only primary minerals, however, secondary minerals could be present. The primary minerals are plagioclase and pyroxene (ortho- and clinopyroxene) that originated from mafic (basaltic) lava (Hessler & Lowe, 2006:189; Klein & Dutrow, 2007:507, 583; Scoon & Mitchell, 2012:518; Keeditse *et al.*, 2016:608). The secondary minerals could also be present in small concentrations. These minerals include magnetite, apatite and olivine (Scoon & Mitchell, 2012:523; Keeditse *et al.*, 2016:611). Gabbro in general, consist of the following composition of primary minerals:

- Plagioclase ($\text{NaAlSi}_3\text{O}_8$)
- Pyroxene ($(\text{Na, Ca})(\text{Mg, Fe, Al})(\text{Al, Si})_2\text{O}_6$)

Plagioclase and pyroxene, that are the primary minerals of gabbro, are prone to weather more quickly than the primary minerals of granite. According to the Bowen's reaction series, plagioclase and pyroxene are the first two minerals to weather into smaller size particles (Hessler & Lowe, 2006:189; Dannhaus *et al.*, 2018:619, 634). The dominant clay mineral to which gabbro weathers is kaolinite, although illite, smectite and vermiculite may also be present in small quantities, depending on climatic conditions (Scarciglia *et al.*, 2005:23; Kemnitz & Luke, 2019:214). The primary minerals of gabbro weather down rapidly to clay minerals, so to use gabbro as an ameliorant could provide better nutrient early in the experiment but might not have sufficient nutrients for the long run.

2.2.2 Andesite

The third rock type used is andesite, which mainly consist of feldspar as primary mineral while secondary minerals could be present. The type of feldspars that andesite mainly consist of is oligoclase- or andesine feldspar (Klein & Dutrow, 2007:583-584; Monroe *et al.*, 2007:119). Secondary minerals could also be present in small concentration or might be absent entirely. The secondary mineral could include quartz (Couch *et al.*, 2001:1037; Klein & Dutrow, 2007:584; Monroe *et al.*, 2007:119). Furthermore, other minerals can be present as phenocrysts. Finally, the candidates include minerals like hornblende (amphibole), biotite, augite or orthopyroxene (Couch *et al.*, 2001:1037; Klein & Dutrow, 2007:584; Monroe *et al.*, 2007:119). Andesite generally consists of the following minerals:

- Plagioclase ($\text{NaAlSi}_3\text{O}_8$)
- Pyroxene ($(\text{Na}, \text{Ca})(\text{Mg}, \text{Fe}, \text{Al})(\text{Al}, \text{Si})_2\text{O}_6$)
- Amphibole ($(\text{Ca}, \text{Na})_2(\text{Mg}, \text{Fe}, \text{Al})_5(\text{Al}, \text{Si})_8\text{O}_{22}(\text{OH})_2$)

As stated before, the primary minerals of andesite are similar to gabbro, therefore, more prone to weathering. As for andesite, the end-products of andesite of weathering is mainly kaolinite as the dominant clay (Tan *et al.*, 2017:33; Vierra *et al.*, 2018:306; Bondje *et al.*, 2019:243; Figure 2-1). Secondary clay minerals can also be formed from plagioclase. The secondary clay minerals that might be formed in small concentrations are goethite and halloysite (Tan *et al.*, 2017:33; Vierra *et al.*, 2018:306; Bondje *et al.*, 2019:243). Furthermore, different clay minerals can be formed as end-products from plagioclase, if the necessary minor accessory minerals are present. Of these minor accessory minerals are aluminium (Al) resulting in gibbsite (Harley & Gilkes, 2000:28; Sak *et al.*, 2018:23). When amphibole and biotite are present it can weather into chlorite. Further weathering of chlorite produces manganese- (Mn) and iron (Fe) oxides, or even oxyhydroxides (Vierra *et al.*, 2018:303; Kemnitz & Luke, 2019:214). Biotite is, however, also able to weather into vermiculite (Harley & Gikes, 2000:27; Vierra *et al.*, 2018:307-308). As a result, andesite could weather into a vast amount of different clay minerals at a rapid pace, depending on the climate conditions.

The mineralogy of granite, gabbro and andesite consist of as discussed above indicated that the three rock types could have a sufficient nutrient status for plants in a rehabilitation process as ameliorants. The following nutrients are formed as weathering products for plant uptake, i.e. potassium (K), Al, Si, Sodium (Na), Calcium (Ca), Magnesium (Mg) and Fe. These nutrients may have positive or negative effects on plant growth, which will be discussed in depth in section 2.5.2.3. The nutrient status of the mine tailings material is controlled by the pH as each element has its own range to be available to plant for uptake. The mine tailings material generally has a low nutrient status, which negatively influences vegetation establishment (Cooke & Johnson, 2002:49; Mendez & Maier, 2008a:48; Schimmer & Van Deventer, 2018:3). Welch (1995) (cited by Harley & Gilkes, 1999:11) identified 17 essential nutrient elements for the growth and development for plants. These elements can be grouped into nine macro-nutrients (C, H, O, N, K, Ca, Mg, P, S) and eight micro-nutrients (B, Cl, Cu, Fe, Mn, Mo, Ni, Zn) (Table 2-3 and Table 2-4). When used for rehabilitation purposes, the weathering products of granite, gabbro and andesite should have a positive effect on the suitability of gold mine tailings as growth mediums for vegetation.

2.3 Weathering

In order to understand the weathering process of the three rock types discussed above into the nutrients necessary for vegetation uptake, the weathering process will be discussed in more detail. Firstly, the Bowen's reaction series will be discussed thereafter, the weathering rates and the factors that have an influence on it.

2.3.1 Bowen's reaction series

The weathering of the three rock types can be explained by the Bowen's reaction series that illustrates the dominant minerals and the most common process of the weathering of the different minerals, as well the resistance to weathering and type of magma of which the minerals respectively. The Bowen's reaction series explains how different minerals crystallise from the most common magmas at the optimum temperature and pressure within the environment (Bowen, 1922:196; Monroe *et al.*, 2007:111; Winter, 2010:124 and Figure 2-1). As the magma cools down, the respective minerals can crystallise from the magma, ranging from the ultramafic minerals towards the felsic minerals as the pool of elements becomes less diverse. The ultramafic minerals that crystallise first are the least resistant to chemical weathering (Figure 2-1). On the other hand, the felsic minerals are more resistant to chemical weathering. Therefore, the ultramafic minerals will weather more easily into nutrients for plant uptake (Monroe *et al.*, 2007:111; Winter, 2010:124). Besides the resistance against weathering that is in generally determined by the two different magmas from which the different rock types crystallise from. The rate of weathering of the different rocks are mainly controlled by the factors that influence the weathering rate. The latter is influenced by particle size and climate that will be discussed in more detail (Harley & Gilkes, 1999:31; Monroe *et al.*, 2007:180; Zhu *et al.*, 2008:260; Rafael *et al.*, 2017:44; Wu *et al.*, 2017:167; Ramos *et al.*, 2017:2700). Therefore, even though a schematic exist to indicate the most common process of weathering, there exist no guarantee it would be the process that will occur (Figure 2-1).

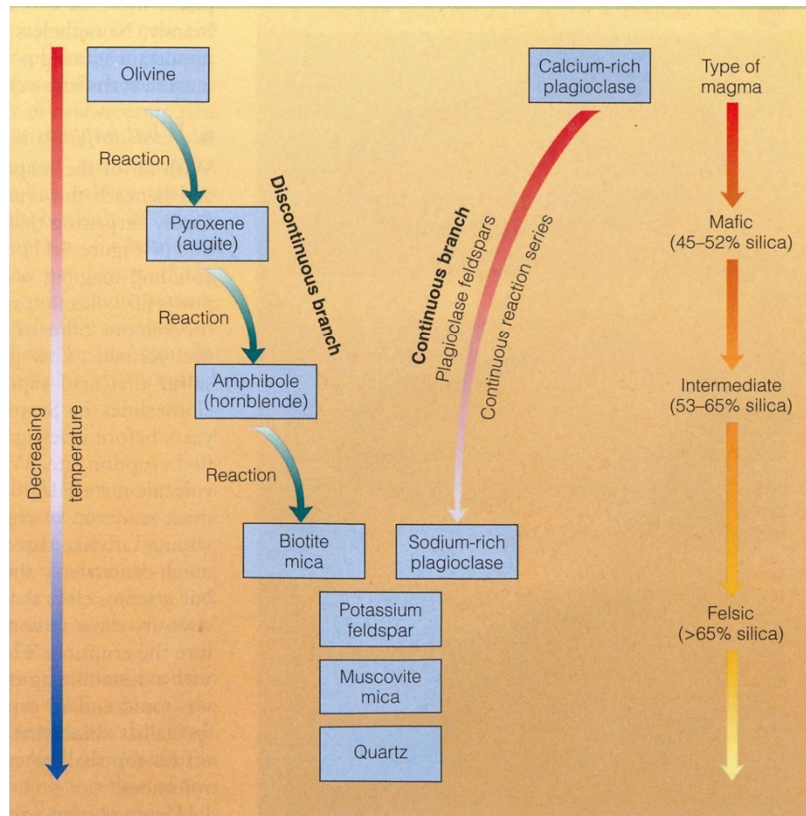


Figure 2-1: Bowen's reaction series indicating the weathering resistance of the common rock types and how the weathering resistance reacts to the temperature (Monroe *et al.*, 2007:111).

2.3.2 Weathering rates

The different rocks that can crystallise out of the two main groups of magma, can weather at different rates. The factors that have an influence on the rate at which the rocks weather could also have an effect on each other. The factors include bulk soil solution composition, temperature, climate, pH, changes in rhizosphere pH and redox, or chelation by organic acids (Harley & Gilkes, 1999:31; Wu *et al.*, 2017:167; Ramos *et al.*, 2017:2700). However, the effect these factors would have is controlled by the size of the particles. The smaller the particles of the ameliorants the bigger the surface area of the particles, thus increasing the rate of weathering (Monroe *et al.*, 2007:180; Zhu *et al.*, 2008:260; Rafael *et al.*, 2017:44). For this the milling of the three ameliorants into fine particles would increase the effectiveness of the ameliorants.

To determine if the chemical or physical type of weathering process would be the dominant in South Africa the Weinert N-value needs to be determined. The Weinert N-value was created by concentrating on the parent material of the rock types that weathered into soil material and not the soil material itself. The process will be discussed in more detail in the next paragraph. The Weinert N-value is an index to determine the dominant type of weathering (Weinert, 1980:51; Breytenbach, 2009:14; Figure 2-2). In short, Weinert (1980:32) stated that, in regions where the

Weinert N-value is below five, the moisture in the soil is high enough to cause the rocks to decompose rather than disintegrate. Where the Weinert N-value is above five, rocks will disintegrate and not decompose (Weinert, 1980:56; Breytenbach, 2009:14). Figure 2-2 illustrates the line for the N value. The line itself is where the N-value is equal to five, with the smaller values to the east and the larger values to the west. It is evident that South Africa can be divided into regions according to the two main weathering processes, decomposition ($N < 5$) and disintegration ($N > 5$) (Weinert, 1980:56; Breytenbach, 2009:14; Figure 2-2). Table 2-1 illustrates the decomposition of the primary rock-forming minerals with the Weinert N-value and their weathering products (Weinert, 1980:56). Therefore, by knowing the Weinert N-value, one could potentially know what to expect as weathering end-products.

Weinert had created the Weinert N-value by focussing on the parent material of the rock types that weathered into soil material and not the soil material itself. The parent material was divided into two main groups of rock types namely, decomposing and disintegrating rock types (Weinert, 1980:19; Breytenbach, 2009:14). To determine to which category the different rock types belong to, certain factors that influence weathering was considered. These factors were the origin and the climate conditions under which the rock weathers (Weinert, 1980:24, 25; Breytenbach, 2009:14). The reason why climate was a deciding factor to which group the rocks belong to will be discussed in more detail.

Climate could have the greater influence on weathering rates than particle size as it influences the dominant weathering directly. The rainfall that is influenced by climate determines if the environment in question will have chemical or physical weathering as the dominant weathering process (Weinert, 1980:26; Harley & Gilkes, 1999:31; Monroe *et al.*, 2007:180; Breytenbach, 2009:14; Wu *et al.*, 2017:167; Ramos *et al.*, 2017:2700). When rainfall occurs in significantly quantities and high temperatures are present in an environment, the dominant weathering process will be chemical. On the other hand, when rainfall is scarce, the physical weathering will be dominant (Weinert, 1980:26; Breytenbach, 2009:14). Rainfall or irrigation could have a side effect. The side effect is that leaching of the nutrients and elements could occur (Compton, *et al.*, 2003:243; Khomo, *et al.*, 2013:193; Chadwick, *et al.*, 2013:1172). Therefore, climate conditions of an environment influence greatly the end-products of weathering of the different rock types.

Table 2-1: The decomposition of the primary minerals according to the N-value (adapted from Weinert 1980:57). N-value is used in South Africa to determine the dominant type of weathering (Breytenbach, 2009:14; Weinert, 1980:51)

Decomposition products of primary minerals			
N-value	Minerals		
	Quartz	Feldspar	
		Orthoclase	Plagioclase
		Muscovite	Biotite Amphibole Pyroxene Olivine
	↓	↓	↓
N>10	Quartz	No change	No change
N 5-10	Quartz	Hydromica	Hydromica
N 2-5	Quartz	Kaolinite	Montmorillonite
N<2	Quartz	Kaolinite	Kaolinite Montmorillonite

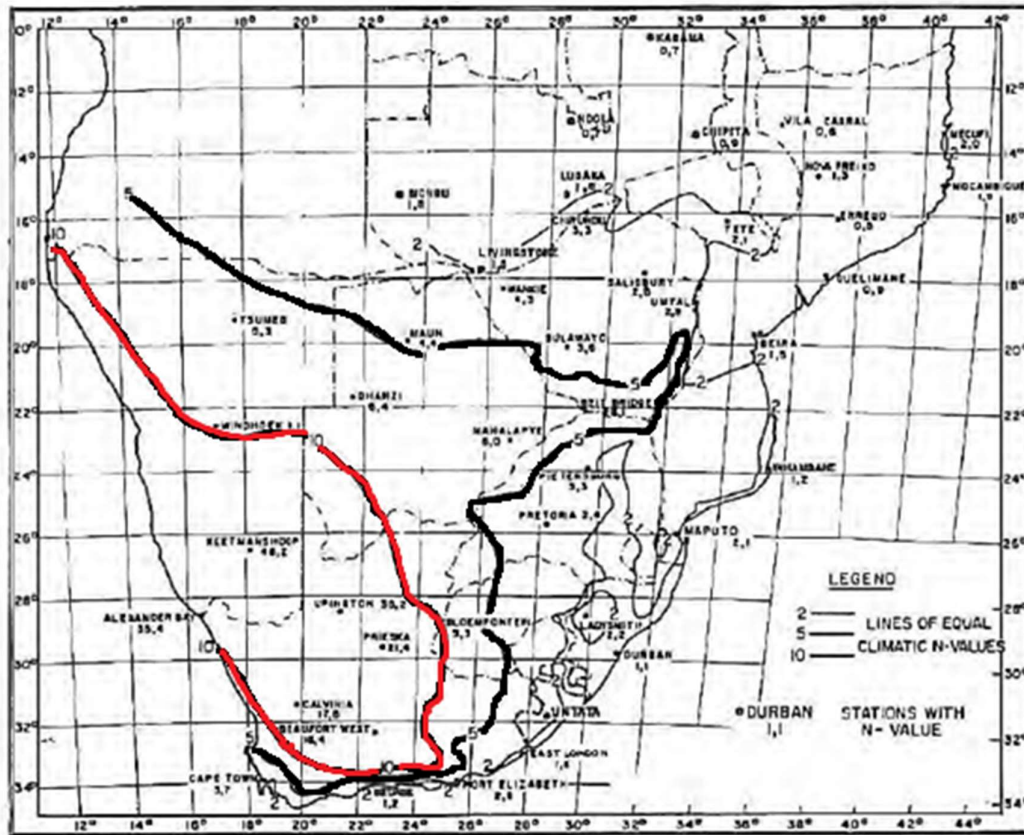


Figure 2-2: The Weinert N-value lines (5 (black) and 10 (red)) in Southern Africa that illustrate the dominant type of weathering (Weinert, 1980:32).

2.4 An overview of gold tailings material

Gold tailings material commonly has a fine texture, contains no organic matter, no to little clay mineral, and in most cases has a low pH value (more acidic conditions). This makes the rehabilitation process more difficult, as this material has high bulk densities and is characterised by extreme compaction with low water infiltration rates often resulting in surface waterlogging (Cooke & Johnson, 2002:49; Weiersbye *et al.*, 2006:103). With a low pH of 2 to 5, the metals present in the tailings storage facility (TSF) can become toxic. These metals could include zinc, lead, aluminium, uranium, cadmium and the semimetal arsenic (Cooke & Johnson, 2002:49; Weiersbye *et al.*, 2006:101; Tutu *et al.*, 2008:3672; Jamieson *et al.*, 2015:86). Furthermore, as gold tailings material has no organic matter and little clay material, a low nutrient status is expected, especially, of macro-nutrients such as nitrogen (N), potassium (K) and phosphorus (P) (Cooke & Johnson, 2002:49; Wong, 2003:775; Mains *et al.*, 2006:132; Asensio *et al.*, 2013:446; Schimmer & Van Deventer, 2018:3). To understand the difficulty of the rehabilitation of gold mine tailings material, the physical and chemical properties, metal mobility and toxicity, nutrient status, salinity, organic matter content, and the presence or absence of micro-organisms will be discussed in more detail.

2.4.1 Physical properties

The mining method to extract gold from the rocks it contains results in a fine texture waste material as gold tailings material. According to Mendez and Maier (2008a:48) and Kossoff *et al.* (2014:231) the grains of tailings mainly consist of sand (625µm – 2 mm), with some silt (3.9 – 625 µm) and clay (<3.9µm) particles. In rare cases, some gravel (>2 mm) particles can be present. As a result of the fine texture, the tailings material causes unfavourable conditions for vegetation establishment (Wjiesekara *et al.*, 2016:127; Schimmer & Van Deventer, 2018:3).

All the unfavourable conditions created due to the fine texture hinders vegetation to establish on the gold tailings material. One of the main factors that hinder vegetation establishment is the low infiltration rate created by the crusting and sealing of the soil surface due to alternating dry and wet weather conditions (Singer *et al.*, 1992:391; Schimmer & Van Deventer, 2018:3). Additionally, the bulk density of the gold tailings materials could differ from gold mine to gold mine. The bulk density may differ because of the parent material from which the gold tailings material consist of (Sarsby as cited by Kossoff *et al.*, 2014:231). However, the bulk density of gold tailings is generally around 1.8 – 1.9 g/cm³, which changes with every 30 m in depth to around 0.09 – 0.17 g/cm³ (Kossoff *et al.*, 2014:231; Young *et al.*, 2015:251). Singer *et al.* (1992:391), as well as Brady and Weil (2008:929), define bulk density as a measurement of the mass of dry soil per unit of bulk volume, which includes the space filled with air. Another factor that affects the establishment is

temperature. The temperature on the surface of the tailings can be so high that it creates a hindering for the vegetation establishment (Kruger, 2017:13; Schimmer & Van Deventer, 2018:3). Surface temperatures of up to 60°C have a negative influence on the germination of the seeds. These high temperatures mainly occur on the north-facing slopes in the Southern Hemisphere (Fitter *et al.*, 1998:29; Bell, 2002:46; Karandish & Shanzari, 2016:872). The temperature is mostly influenced by the radiation absorption or reflection of the material, which is affected by the evaporation rate and the factors that could affect the evaporation rate such as, moisture and air in the soil (Kruger, 2007:43; Bell, 2002:46). Therefore, to have a chance of a successful rehabilitation, the necessary factors that could have a negative effect on the vegetation needs to be investigated prior to the start of rehabilitation.

The temperature of tailings material is controlled by a few factors. Moisture of the tailings material is one such factor, due to that moist reduce the reflection of the material (Bell, 2002:47; Kruger, 2017:89). The colour of the tailings is another factor. The darker-coloured material tend to absorb more light radiation than the lighter-coloured counterparts. Lastly, the chemical properties and reaction rates can also affect the temperature of tailings material Bell, 2002:47; Kruger, 2017:89). There is not much what can be done to the colour of the tailings material to keep the temperature low, however, to keep it moist until the vegetation is well establish could improve the rehabilitation success.

Some of the parent material from which the gold is extracted from have expanding properties that could cause the tailings material to have expanding capabilities. The expanding and shrinking of the tailings material that occurs in changing climate conditions, is mainly controlled by plasticity content. The latter, have an influence on the water-holding capacity, infiltration rate, soil strength and the volume change behaviour (Meimaroglou & Mouzakis, 2019:28; Onyelowe *et al.*, 2019:3531; Puppala *et al.*, 2013:188). The plasticity content of the tailings material is controlled by the main group of clay minerals. The two groups are the smectite and kaolinite clays (Meimaroglou & Mouzakis, 2019:28; Liu *et al.*, 2016:5; Limean & Bayraktutan, 2007:937). Of the two clay groups, the smectite group is in general considered as to be the “problematic soil” due to its extensive plasticity characteristics this group possess. The main difference between the two clay groups are the interlayer bonds that keep the clay layers close to each together. The interlayer bonding is done by forces such as van der Waals forces and hydrogen bonds (Meimaroglou & Mouzakis, 2019:28; Liu *et al.*, 2016:5; Limean & Bayraktutan, 2007:937). Therefore, the type of dominant clay group needs to be identified as it could lead to more problems that could makes the rehabilitation of the tailings more challenging.

The expanding and shrinking potential of the tailing material that occurs under changing climate conditions of wet and dry conditions. This process take place when water molecules that enter

the clay layers and force the clay layers apart (Meimaroglou & Mouzakis, 2019:29; Puppala *et al.*, 2013:188; Sani, 2019:2345). The process is controlled by the cation exchangeable capacity (CEC) and organic matter. The latter the gold tailing does not have abundance of, whereas, CEC is an indication of what type of clay mineral could be present. A high CEC indicates that montmorillonite could be present whereas, a lower CEC indicates that kaolinite could be present (Meimaroglou & Mouzakis, 2019:29; Puppala *et al.*, 2013:188; Sani, 2019:2345). The cations that are present in the soil solution could causes the clay minerals to aggregate, causing flocculation. The swelling potential can increase if the clay aggregates increase in size (Puppala *et al.*, 2013:188; Ghobadi *et al.*, 2014:612; al-Swaidani *et al.*, 2016:715; Liu *et al.*, 2017:6). By knowing the CEC of the tailings material, the potential that the plasticity content, therefore, the expanding and shrinking could pose as a potential problem for the rehabilitation of the tailings material.

Gold TSF is commonly a harsh environment with a factor of conditions that are not ideal for vegetation. With low pH levels the heavy metals that have toxic potential leach out to the surrounding environment (Kiventerä, *et al.*, 2019:1; Thouin, *et al.*, 2019:1; Khoeurn, *et al.*, 2019:1; Wang, *et al.*, 2019:2). Due to the abundance of heavy metals the leaching of these metals could have distractive effects on the surrounding environment. There exists a couple of factors that effects the leaching potential of the heavy metals. The most common factor that affects the leaching of heavy metals is a low pH level that creates acidic conditions (Thouin, *et al.*, 2019:2; Khoeurn, *et al.*, 2019:2; Guo, *et al.*, 2013:3068). AMD is the largest cause that generates acidic conditions. As a result, enhance the mobility of heavy metals which may create severe environmental problems (Saria, *et al.*, 2006:134; Guo, *et al.*, 2013:3071; Ahmari & Zhang, 2013:743). If there are micro-organisms present the production process of AMD can be increased (Schwab, *et al.*, 2007:2936; Saria, *et al.*, 2006:134; Guo, *et al.*, 2013:3069; Cheng, *et al.*, 2009:14). Temperature of the tailings is another factor that could have a slight effect on the leaching potential. The leachability of heavy metals could increase slightly as the temperature increase (Guo, *et al.*, 2013:3072; Wang, *et al.*, 2019:6). The particle sizes from which the tailings material consist of could also have a potential effect. As the leaching potential is positively correlated with the amount of fine-grained particles. This is because, the fine-grained particles have a larger surface area (Guo, *et al.*, 2013:3072; Schwab, *et al.*, 2007:2938; Wang, *et al.*, 2019:6; Sun, *et al.*, 2018:217).

Besides the most common negative effects that AMD cause, there exist side products due to the AMD process. One side product of the production of AMD is Fe³⁺ hydroxides. This cause the release of additional hydrogen ions into the aquatic environment, which in turns could decrease the pH further (Saria, *et al.*, 2006:138). Due to the slow process of oxidation, the leaching of the remaining elements could continue for a long time (Khoeurn, *et al.*, 2019:8; Wang, *et al.*, 2019:6).

Climate is a vital factor, as climate affects many reactions, i.e. weathering intensity, secondary mineral formation and the mobility of the metals present in the TSF (Khoeurn, *et al.*, 2019:2; Harley & Gilkes, 1999:31). When a restricted layer exist the leaching of potential toxic metals could be extensively hindered (Kiventerä, *et al.*, 2019:4; Kumar, *et al.*, 2019:18). The leaching potential of tailings material can therefore, be complex.

One way to reduce the leaching potential of TSF's are by increasing the pH (Thouin, *et al.*, 2019:2; Khoeurn, *et al.*, 2019:2). Drainage quality of TSF is controlled by the waste rocks lithology's from which the TSF consist of, the presence of micro-organisms and local climate conditions (Khoeurn, *et al.*, 2019:2; Wang, *et al.*, 2019:6). Climate is a vital factor, as climate affects many reactions, i.e. weathering intensity, secondary mineral formation and the mobility of the metals present in the TSF (Khoeurn, *et al.*, 2019:2; Harley & Gilkes, 1999:31; Monroe *et al.*, 2007:180). Rain is one of the factors controlled by the climate conditions.

Water is one of the main elements that initiates the leaching of the heavy metals into the environment. In the raining season the dissolution of salt and ions occurs at a rapid pace, especially the initial flushing event. Afterwards, the second phase is the slow oxidation of the remaining elements. Due to the slow process of oxidation, the leaching of the remaining elements could continue for a long time (Khoeurn, *et al.*, 2019:8; Wang, *et al.*, 2019:6). During the oxidation of the remaining elements AMD could form that also play a role in the transportation of the heavy metals into the surrounding environment (Wang, *et al.*, 2019:4; Kiventerä, *et al.*, 2019:1). In addition, some alumino-silicates could have a neutralising effect that could hinder the leaching of heavy elements like Al^{3+} (Khoeurn, *et al.*, 2019:9; Jurjovec, *et al.*, 2002:1511). The effect an irrigation could have on the leaching potential of heavy metals could be significantly. Therefore, it should be considered in the planning phase of the rehabilitation process (Khoeurn, *et al.*, 2019:11; Khan, *et al.*, 2008:686). Therefore, many ways exist to hinder the leaching of toxic heavy metals.

The effect an abandon mine tailings could have on the surrounding environment could be destructive, even on a large scale. The most common effect is that the toxic elements are transported into the agricultural lands, therefore, increasing the concentration of these elements in the soil. Transportation of heavy metals could occur through wind, runoff water (with AMD), and seepage with precipitation (Wang, *et al.*, 2019:2; Huang, *et al.*, 2013:1331). Factors that could control the transportation of the heavy metals, i.e. including pH, infiltrated water, water infiltration rate, physical-chemical properties of the tailings, as well as the transport distance and oxidation (Wang, *et al.*, 2019:8; Khoeurn, *et al.*, 2019:8). Furthermore, the fine grains of which gold TSF consist of can often be transported to the surrounding environment through the wind (Wang, *et*

al., 2019:6; Sun, *et al.*, 2018:217). As a result, the rate of transportation of the heavy metals are unpredictable.

Mine tailings could already have dissolvable salts and metals, before an irrigation system was used to water the vegetation in the rehabilitation process. Therefore, these dissolved metals and salts were already bioavailable and as a result, easily leach out into environment (Wang, *et al.*, 2019:5; Nemati, *et al.*, 2011:408). If micro-organisms are present in sulphide bearing TSF could accelerates the weathering phase of these elements (Wang, *et al.*, 2019:7; Cheng, *et al.*, 2009:14). When a restricted layer exist the leaching of potential toxic metals could be extensively hindered (Kiventerä, *et al.*, 2019:4; Kumar, *et al.*, 2019:18). As a result there exist many factors to consider when trying to determine the leaching potential of mine tailings material and the environmental risk the metals that are present could potentially have when leached out into the environment.

2.4.2 Chemical properties

Gold tailings are usually either extremely acidic [pH(H₂O) two to five], or extremely alkaline [pH(H₂O) eight to nine] dependant on the source of the ore. South African gold tailings material is extremely acidic (Cooke & Johnson, 2002:49; Mendez & Maier, 2008a:48; Mendez & Maier, 2008b:278). The acidic nature of South African gold mines are not the only characteristics that pose as a problem on a chemical scale. Other properties include insufficient nutrient status, no organic matter content, potential toxic elements in high concentrations, and elevated saline concentrations (Cooke & Johnson, 2002:49; Mendez & Maier, 2008a:48; Mendez & Maier, 2008b:278; Anawar, 2015:116, 117; Wang *et al.*, 2017:595). The chemical properties of gold mine tailings material will be further investigated, especially the pH value, metal mobility and toxicity, nutrient status, salinity, organic matter content, and micro-organism content.

2.4.2.1 pH value

The pH of a soil solution is a vital part to understand what happens with the chemistry and therefore, the nutrients of the soil. The pH value is widely considered as the 'master variable' that plays a vital role in soil/substrate chemistry and plant nutrition (Sparks, 2003:267; Brady & Weil, 2008:23; Hodson & Donner, 2013:218). The pH value is a measurement of the hydrogen ion concentration, and is calculated by $\text{pH} = -\log[\text{H}^+]$ (Sparks, 2003:267; Brady & Weil, 2008:23). The pH is such an important instrument to measure to understand the chemistry of the soil/ substrate as it affects some of the critical aspects. Some of the key aspects of the pH value are that it affects plant growth, the availability of mineral elements (Figure 2-3), the toxicity of elements, and microbial activity (Fertasa, 2007:96; Brady & Weil, 2008:654; Hodson & Donner, 2013:218). Therefore, pH could give an indication of the state the soil health is in. Furthermore, the pH value

(H₂O) of soils can be classified into certain pH value range groups (Table 2-2Error! Not a valid bookmark self-reference.).

Table 2-2: Soil pH (H₂O) ranges with explanations (adapted from Hodson and Donner (2013:218; Sparks 2003:268)).

pH range	Explanation
> 9.5	Strongly alkaline
8.5 – 9.5	Moderately alkaline
7.5 – 8.5	Slightly alkaline
6.5 – 7.5	Neutral
5.5 – 6.5	Slightly acidic
4.5 – 5.5	Moderately acidic
< 4.5	Strongly acidic

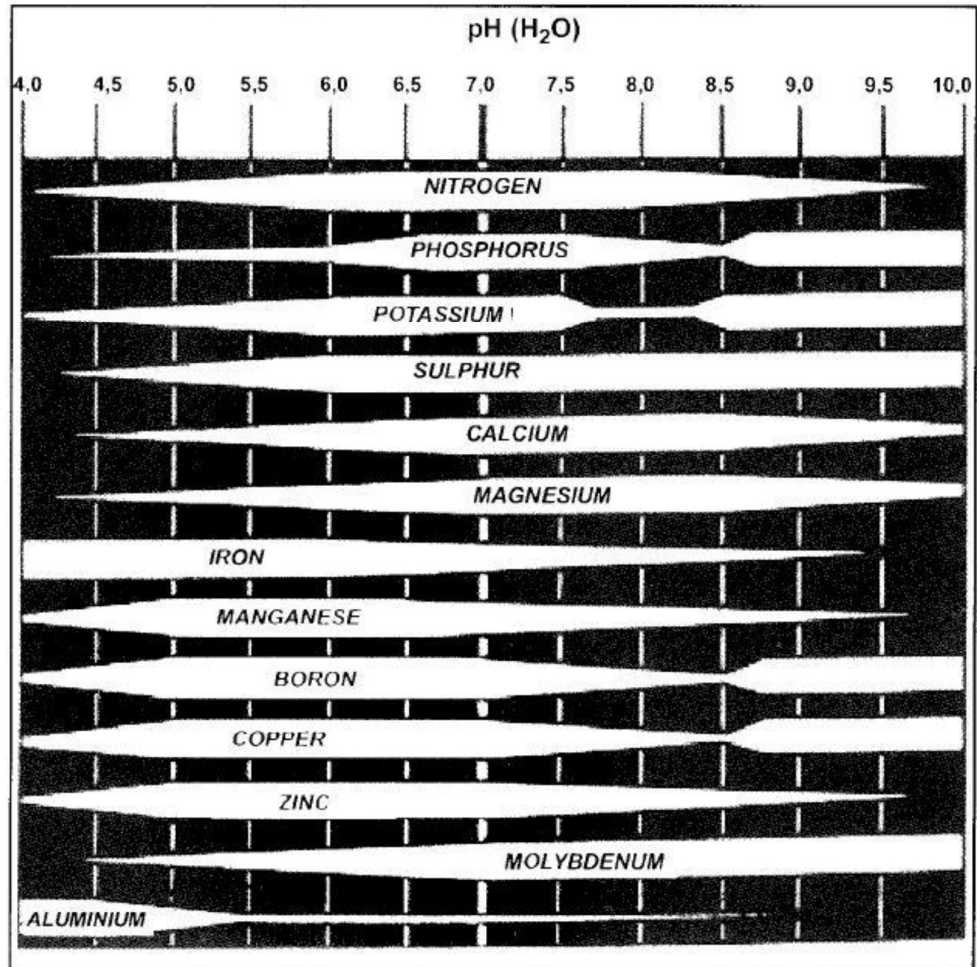


Figure 2-3: The nutrient availability chart as affected by soil pH (H₂O) values (Fertasa, 2007:96)

As pH influence what elements is available for plant uptake. It is an indication what nutrient, therefore, element could be toxic or available for plant uptake as nutrients (Figure 2-3). The macronutrients, nitrogen (N), potassium (K) and phosphorus (P), along with sulphur (S), are highest concentrations available between pH values of 5.5 and 7.5, and calcium (Ca), magnesium (Mg) and the micronutrients are in the highest concentrations available in a pH range of 7 to 8 (Figure 2-3). However, the nutrients could be present in sufficient concentrations under other pH conditions. Therefore, each nutrient has its own unique range in which that element would be in available the soil solution for uptake in sufficient concentrations.

2.4.2.2 Metal mobility and toxicity

Even though that toxic elements could cause a serious problem in an unstable environment, in some cases on a large scale. The same potential toxic elements occurs naturally in the soil but, they are normally well below the critical concentration that may inhibit plant growth mainly affected

by pH (Hodson & Donner, 2013:195; Ashraf *et al.*, 2019:714; Wang *et al.*, 2019:1). This is the case as the pH of natural soil is much higher than those of gold tailings material. The pH value is probably the most important variable that affects the mobility of potential toxic metals and their availability, especially in arid conditions (Cooke & Johnson, 2002:49; Mendez & Maier, 2008a:48; Mendez & Maier, 2008b:278; Hodson & Donner, 2013:196; Anawar, 2015:117; Wang *et al.*, 2017:595). Therefore, by improving the pH of gold tailings material the risk of a problem related to the toxic elements can significant reduced.

Some of the heavy metals that commonly are present in mine tailings material, have the potential to become toxic under low pH conditions and could cause a large scale contamination. The Fertilizer Association of Southern Africa (Fertasa) (2007:96) and Anawar (2015:111) explain that, under low pH conditions, toxic elements such as arsenic (As), antimony (Sb), Cu, lead (Pb), cadmium (Cd), zinc (Zn), mercury (Hg), tin (Sn), Fe, Mn, Al, titanium (Ti), uranium (U), tungsten and (W) thorium (Th) can become bio-available for plants (Figure 2-3). In many cases the amount of heavy metals are present in mine tailings material are limited to small concentrations. Even so, these elements have the potential to become toxic with a low pH value (Jamieson, 2015:86; Young *et al.*, 2015:250; Kruger, 2017:17; Schimmer & Van Deventer, 2018:3). As a result, the studies by Kossoff *et al.* (2014:232) and Anawar *et al.* (2015:660) state that, due to the low nutrient status of the heavy metals and their potential toxicity, it is very difficult to rehabilitate mine tailings facilities, especially if large scale contaminations occur from the surrounding area.

2.4.2.3 Nutrient status

The nutrient status of the mine tailings material is controlled by the pH as each element has its own range to be available to plant for uptake. The mine tailings material is generally has a low nutrient status, which negatively influences vegetation establishment (Cooke & Johnson, 2002:49; Mendez & Maier, 2008a:48; Schimmer & Van Deventer, 2018:3). Welch (1995) (cited by Harley & Gilkes, 1999:11) identified 17 essential nutrient elements for the growth and development for plants. These elements can be grouped into nine macro-nutrients (C, H, O, N, K, Ca, Mg, P, S) and eight micro-nutrients (B, Cl, Cu, Fe, Mn, Mo, Ni, Zn) (Table 2-3 and Table 2-4).

Table 2-3: The most essential macro-nutrients and micro-nutrients required by plants to develop and grow (Fertasa, 2007:90; Kruger, 2017:18-19)

Macro nutrient	Function	Macro-nutrient	Function
Nitrogen	Used in combination with hydrogen, carbon, oxygen and seldom sulphur to produce amino acids, enzymes, chlorophyll, alkaloids, and nucleic acids. Mainly occurs as high molecular weight proteins in plants.	Calcium	Important for the maintenance of membrane permeability and cell integrity. Collaborates in protein production. Critical role in the quality of fruits and vegetables.
Phosphor	Component of adenosine triphosphate (ATP) that supplies energy to various reactions, deoxyribonucleic acids (DNA) and ribonucleic acids (RNA). Associated with cell forming, root- and flower development, and ripening	Magnesium	Component of the chlorophyll molecule. Co-factor in many bridging structures of ATP, enzymes activating phosphorylation processes, or adenosine diphosphate and enzyme molecules.
Potassium	Involved in maintaining water status and cell turgor pressure. Regulates opening and closing of stomata. Required for accumulation and translocation of newly-formed carbohydrates.	Sulphur	Part of protein synthesis. Forms part of the amino acids cysteine, thiamine and biotin. Reduces disease frequency.

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Macro nutrient	Function	Macro-nutrient	Function
Copper	<p>A constituent of the chloroplast protein plastocyanin.</p> <p>Contributes to protein and carbohydrate metabolism.</p> <p>Takes part in desaturation and hydroxylation of fatty acids.</p>	Iron	<p>The key component of many plant enzyme systems like the terminal respiration step and electron transport.</p> <p>Component of the protein ferredoxin and required for NO₃ and SO₄ reduction, energy production and N assimilation.</p> <p>Functions as a catalyst for chlorophyll formation.</p> <p>Required for the oxidation-reduction process.</p>
Molybdenum	<p>Component of two major enzyme systems, namely nitrogenase and nitrate reductase.</p> <p>Collaborates with the production of proteins.</p>	Manganese	<p>Required in the photosynthetic electron transport system for oxidation-reduction reactions.</p> <p>Acts as a bridge for ATP and enzyme complexes and is essential in photosystem II (PSII) for photolysis.</p>
Boron	<p>Involved in cellular activities, division, differentiation and maturation.</p> <p>Essential for the synthesis of RNA.</p> <p>Connected with pollen germination, growth and improvement of pollen tube stability.</p>	Chlorine	<p>Contributes to the oxygen evolution in PSII during photosynthesis.</p> <p>Raises cell osmotic pressure.</p> <p>Affects stomatal regulation.</p> <p>Increases hydration of plant tissue.</p>
Zinc	<p>Similar enzymatic functions to Mn and Mg.</p> <p>Carbonic anhydrase is activated by zinc only.</p> <p>Catalyst for various reactions.</p>		

Table 2-4: The positive and negative symptoms of the nutrients that granite, gabbro and andesite can provide for vegetation growth. The nutrients include potassium, aluminium, silicon, sodium, calcium, magnesium and iron.

Nutrients	Positive symptoms	Negative symptoms	References
<p>Potassium (K)</p>	<p>The plant need potassium in relatively high concentrations.</p> <p>Phosphor is, however, different from nitrogen and phosphor as it is not available in organic structures and compounds, but available in the cell fluid.</p> <p>Potassium also plays a vital role in the transport of nitrogen throughout the plant, starch translocation and improved photosynthesis.</p> <p>Other responsibilities include improving fibre strength and controlling the opening and closing of stomata.</p> <p>Potassium improves the strength of stems, contributes to cold- and drought resistance, as well as fruit quality.</p> <p>Potassium improves the formation of proteins, sugar, and starch and oils.</p>	<p>Potassium deficiencies are first seen on older leaves.</p> <p>The older leaves turn yellowish and necrosis of the leaf edges occurs at a later stage.</p>	<p>Fertasa, 2007:90-94;</p> <p>Tully & Ryals, 2017:763-635.</p>

Nutrients	Positive symptoms	Negative symptoms	References
	Potassium is mobile in plants.		
Aluminium (Al)	<p>Beneficial effects include blocking negative charge sites on the cell wall and thus promoting P uptake.</p> <p>Aluminium can regulate P uptake to prevent P toxicity.</p> <p>Al changes the distribution of growth regulators and prevents Cu and Mg toxicities.</p>	<p>An insufficient concentration of Al causes inhibition of root growth, negatively affecting the uptake of especially P, Ca, and Mg nutrients.</p> <p>Besides root growth, shoot growth is also negatively affected.</p> <p>The result of root growth inhibition is chlorosis, with necrotic spots on the margins of young leaves.</p> <p>Furthermore, marginal chlorosis progresses to the centre of the lamina on older leaves.</p> <p>A high concentration of Al can be toxic to plants.</p> <p>Furthermore, Al can alter the structure of plasma walls, causing a decrease in the permeability for nutrients.</p>	<p>Nursyamsi <i>et al.</i>, 2000:51-52;</p> <p>Fertasa, 2007:90-94;</p> <p>Steiner <i>et al.</i>, 2011:1780-1781,1783.</p>
Silicon (Si)	<p>Silicon is able to improve plant growth with regard to various abiotic and biotic stresses.</p> <p>Silicon gives resistance against pathogens and</p>	<p>Silicon can become toxic for plants at a concentration as low as 50 mg/L.</p> <p>Insufficient concentrations of Si may cause growth inhibition for some plant</p>	<p>Richmond & Sussman, 2003:268;</p> <p>Mitani & Ma, 2004:1255;</p> <p>Massey & Hartley, 2006:2299, 2302;</p>

Nutrients	Positive symptoms	Negative symptoms	References
	<p>enhances the growth of stems.</p> <p>Abiotic stress includes sodium stress, drought stress, metal toxicity, nutrient imbalance, radiation damage, high temperature and freezing.</p> <p>Helps plant species against the damage caused by animals, especially insects.</p> <p>Increases P availability for plants, can improve tolerance against certain heavy metal elements and improves the palatability of grass species.</p>	<p>species, mostly because of declining fertility.</p>	<p>Guntzer <i>et al.</i>, 2012:205-206;</p> <p>Gerami & Rameeh, 2012:93;</p> <p>Ju <i>et al.</i>, 2017:2.</p>
Sodium (Na)	<p>Plants do not require sodium in large quantities. Na can, however, replace K in many functional roles, even though Na mobility is limited under natural conditions.</p> <p>Na is, on the other hand, essential for C4 plants.</p> <p>Na also supports the growth potential of plants.</p>	<p>Without sufficient concentrations of Na, C4 plants develop chlorosis and necrosis, and will be unable to form flowers.</p> <p>In drought conditions, plants with an insufficient amount of Na wilt rapidly.</p> <p>Just like many other nutrients, Na can become toxic for plants in high concentrations, which can</p>	<p>Subbarao <i>et al.</i>, 2003:393-395;</p> <p>Fertasa, 2007:90-94.</p>

Nutrients	Positive symptoms	Negative symptoms	References
		lead to potential growth inhibition.	
Calcium (Ca)	<p>Calcium is located in the middle lamella of cell walls in the form of calcium pectate and is not mobile in the plant.</p> <p>This results in calcium short-comings in young leaves.</p> <p>Calcium improves the forming of proteins, but its main function is cell growth and keeping the quality of fruits and vegetables.</p>	<p>Insufficient concentrations of Ca are seen on younger leaves, as the leaves turn yellowish and are slow to unfold.</p> <p>At a later stage, Ca short-comings cause necrosis on the leaf edges.</p>	Fertasa, 2007:90-94; Hopkins and Hüner, 2009:70.
Magnesium (Mg)	<p>Magnesium forms the core of the complex chlorophyll molecule. Without this molecule, photosynthesis cannot occur.</p> <p>Mg is also involved in the translocation of phosphor and is mobile in the plant.</p>	<p>The concentration of magnesium is mostly insufficient in sandy and highly acidic soils.</p> <p>Mg short-comings cause yellowish leaf veins in older leaves, which may progress into necrotises stains at a later stage.</p>	Fertasa, 2007:90-94; Hopkins and Hüner, 2009:70.
Iron (Fe)	<p>Iron plays a positive role in the oxidation-reduction reactions in plants and in the formation of chlorophyll. Iron is located in some proteins and enzymes. Iron is,</p>	<p>Iron is generally insufficient in alkaline soils. Insufficient concentrations of Fe cause a yellowish effect between the veins on younger leaves, which can look like a “network pattern”.</p>	Fertasa, 2007:90-94; Hopkins and Hüner, 2009:70.

Nutrients	Positive symptoms	Negative symptoms	References
	however, not mobile in plants.		

The essential nutrients that plants requires to growth and develop are absorb through their roots from the soil solution. The soil solution, however, only has sufficient nutrients for a limited time as the replenished nutrients are formed from the organic or inorganic parts of the soil, mainly through chemical and biochemical processes (Mitani & Ma, 2005:1257; Brady & Weil, 2008:25; Guntzer *et al.*, 2012:203). To ensure the nutrients stay in sufficient concentrations in the soil solution ions are used. The exchangeable ions that are present in the soil solution is in equilibrium with the ions on the exchangeable sites from where the nutrients mostly comes from through weathering and organic matter breakdown (Sparks, 2003:187; Brady & Weil, 2008:25). However, the exchangeable ions are not the only process that helps with the nutrients availability. Elements that could be nutrients are kept bound to a soil layer, e.g. clay minerals until it is absorb by plants (Brady & Weil, 2008:25; Wang *et al.*, 2016:12976; Lu *et al.*, 2018:309; Chen *et al.*, 2019:8). Common sources for these elements weathering and organic matter breakdown. Cations are released when clay minerals are formed, such as 1:1 clays like kaolinite (Sparks, 2003:187; Zhang *et al.*, 2015:132; Wang *et al.*, 2016:12981; Lu *et al.*, 2018:314). Additionally, the capability of soil to absorb nutrients and exchange elements is known as cation exchangeable capacity (CEC), which is measured by centimoles of charge per kilogram (cmol_c/kg) (Sparks, 2003:187; Brady & Weil, 2008:337). Therefore, to have sufficient clay minerals in the soil is critical to ensure a sufficient storage capability for the nutrient cycling process.

2.4.2.4 Salinity

The salinity of the gold tailings material can also affect the vegetation establishment, by limiting the diversity of vegetation that can establish. The electrical conductivity (EC) is determined by the 'degree of salinity, which is characterised by the concentration of soluble salts in a solution (Sparks, 2003:290; Brady & Weil, 2008:415). Electrical conductivity (EC) is expressed in the SI units as siemens (S) or as decisiemens per meter (dS/m) (Sparks, 2003:290). For the purpose of this study the SI unit that was used are mS/m. According to Brady and Weil, (2008:418) soils are classified as saline when in a saturated paste extract the EC value is greater than 400 mS/m. However, salt-sensitive (salinity-sensitive) plants are affected by an EC of 200 mS/m or higher (Sparks, 2003:294; Brady & Weil, 2008:418). Due to that the salinity of soils can hinder vegetation establishment by limited the amount of vegetation that can survive under those salinity conditions.

Soils that can be categorised as saline soils have abundance of certain elements when the pH is high. The elements that are usually in high quantities are Ca^{2+} and Mg^{2+} at a pH of about 8.5, as a result, soluble salts can prevent dispersion, as plant growth is not generally inhibited by poor infiltration, aggregate stability or aeration (Brady & Weil, 2008:418; Samiee *et al.*, 2018:233; Shao *et al.*, 2019:196). There are other factor that could hinder vegetation as these noted above and might have a bigger influence. The factor is that evaporation rate is extremely high in saline soils (Brady & Weil, 2008:418; Sparks, 2003:287). Due to the high concentration of Ca^{2+} and Mg^{2+} reduce the concentrations of other elements. The general elements that are present in gold tailings which is commonly saline environments as stated by George *et al.* 2012 (cited by Kruger, 2017:21) are N^+ , Ca^{2+} , Mg^{2+} , and to a lesser extent K^+ and Fe^{2+} , are the common cations present in TSFs. The most abundant anions that are present in TSFs soils are NO_3^- , Cl^- , CO_3^{2-} , SO_4^{2-} , and HCO_3^- . The EC of gold tailings are mostly caused by large concentrations of SO_4^{2-} and not by the mentioned range of anions. A summary of the effects of soil salts on vegetation is presented in Table 2-5.

Table 2-5: Summary of the soil salt levels that affect vegetation (Kruger, 2017:22).

Effect	EC (mS/m)
Insignificant salt quality effects	<200
Salt-sensitive plants are affected	200 – 400
Salinity effects are more prominent when plant growth is affected	400 – 800
Only salt-tolerant plants survive	800 - 1600
Extremely high salinity in which no plant species can survive	>1600

As the high saline condition have high evapotranspiration rates the water uptake rate by vegetation is severely reduced. The process that occurs when this happens are the osmotic potential. The osmotic potential can be defined as the movement of water from a high gradient to a low gradient through a selectively permeable membrane (Hopkins & Hüner, 2008:7; Bidlack & Jansky, 2013:149). As mentioned, the growth rate of vegetation is reduced at an EC value higher than 400 mS/m. Substrate salinity mainly affects plant growth in the following three ways:

- It lowers the water potential, leading to a reduced amount of water in the rooting zone available for plant uptake.
- It can lead to the toxicity of ions due to an excessive uptake of mainly sodium and chlorine or sulphate ions, especially in the material of gold TSFs.

- It creates “nutrient imbalances within plant cells, thus restricting the uptake of nutrients from the soil solution, inhibiting transport of nutrients through the roots and shoot tissues, and disrupting internal distribution thereof throughout plant organs” (Hodson & Donner, 2013:206; Kruger, 2017:22;).

2.4.2.5 Organic matter

All the negative physical and chemical properties discussed above, i.e. fine texture, pH, salinity, nutrient status to name a few, is being improved by the organic matter present in mine tailing material. Hillel (2004:71) and the Fertilizer Handbook (Fertasa, 2007:28) state that soil organic matter is widely accepted as consisting of various particle sizes of soil containing organic substances. Soil organic matter includes living organisms that differ in size, organic residue in different stages of decomposition, and darkly coloured humus consisting of non-humus and humus elements. The reason that organic matter can improve the properties is due to the bulk density. Soil organic matter have a low bulk density (Wijesekara *et al.*, 2016:127; Lan *et al.*, 2019:2). Soil organic matter can improve the physical characteristics of soil in three ways (Fertasa, 2007:35):

- It serves as a binding agent between the different particles of soil, thereby promoting the formation of stable aggregates and enhancing the density and porosity of the soils.
- It improves the soil structure, thereby improving the water-holding capacity, root penetration and gas exchange; and
- It improves soil stability, thereby protecting the soil surface against wind and water erosion.

Regarding the chemical factors, organic matter increases the CEC, which increases the absorption of cations. Soil organic matter also has the ability to buffer the pH value of slightly acidic soils, making them more acceptable for plant growth (Fertasa, 2007:35; Brady & Weil, 2008:516). Organic matter increases the abundance of nutrients for plant uptake and decreases the concentrations of metals, and provides energy to micro-organisms, causing an increase in the diversity and population of the micro-organisms (Fertasa, 2007:35; Brady & Weil, 2008:516). It would seem that the organic matter is the one factor to improve to see improvements in many of the areas that could pose as a potential threat.

2.4.2.6 Micro-organisms

Micro-organisms are sensitive to unfavourable conditions as these that are discussed already of gold TSF's. Gold TSF's have extreme edaphic conditions, such as a lack in water and nutrient availability, an abundance of toxic elements, extreme temperatures, highly acidic pH levels and soil salinity (Akcil & Koldas, 2006:1139; Schimmer, 2017:28). These conditions affect the biological activity, decreasing the presence of micro-organisms and lowering microbial diversity (Schimmer, 2017:28; Shao *et al.*, 2019:196). Due to the sensitivity of the micro-organisms only a few species can survive in the conditions. The micro-organisms that are able to survive could be present in gold TSFs, creating a restricted microbial diversity (Schimmer, 2017:28; Shao *et al.*, 2019:196). Therefore, only a few process that are necessary for vegetation to continue to strive can take place. However, plant growth-promoting rhizobacteria (PGPR) can improve the unfavourable conditions of mine tailings for microbial activity therefore, the vegetation establishment, if it is applied on the tailings (Stockdale *et al.*, 2013:58-59; Burghilea *et al.*, 2015:188; Kruger, 2017:24; Schimmer, 2017:32). This is because these micro-organisms live in a symbiotic relationship with plants and help them to absorb certain nutrients (Stockdale *et al.*, 2013:58-59; Burghilea *et al.*, 2015:188; Kruger, 2017:24; Schimmer, 2017:32). A complex interaction therefore exists between the micro-organisms, the vegetation and the soil in gold TSFs.

2.5 *Cynodon dactylon* (L.) Pers. (Couch grass/ Bermuda grass)

In general, *Cynodon dactylon* is used in the rehabilitation process of gold mine tailings as its able to endure the extremely unfavourable conditions that are associated with gold TSF. *Cynodon dactylon* (Couch grass) is a short, creeping perennial grass with stolons (above-ground) and rhizomes (below ground). The stolons and rhizomes root at the nodes to form dense mats, which make couch grass an excellent soil stabiliser, especially for the rehabilitation of mine TSFs (Muller, 2014:41; Kruger, 2018:74). The inflorescence has flattened spikelets without awns and is exclusively digitate (Muller, 2014:41; Kruger, 2018:74). Couch grass is able to grow in all types of soils and is often found in disturbed areas. For these reasons couch grass can endure heavy grazing. Couch grass is extensively researched by many researchers for rehabilitation or agricultural purposes (Shainberg & Shalhevet, 1984; Ye *et al.*, 2000; Du *et al.*, 2010; Shi *et al.*, 2012; Porqeddu *et al.*, 2012; Singh *et al.*, 2013; Ahmad *et al.*, 2013; Keulder, 2017; Schimmer, 2018).

2.6 The effects of rock flour on soil

Due to the many factors that can influence the establishment vegetation on mine tailings affected by the physical and chemical properties. Therefore, exist a complex interaction between the physical and chemical characteristics present in the soil, with the organisms and the plant rhizosphere that are present in the soil material in TSFs; (Fageria & Stone, 2006:1330; Pieterse *et al.*, 2016:172; Schimmer, 2018:39). The properties of mine waste can differ depending on the mining method and mineral resources, which may create different environmental conditions that need to be rehabilitated (Schimmer, 2018:42; Hasanuzzaman *et al.*, 2018:995, 1000). The common rehabilitation practice globally is re-vegetation, because vegetation increases the stability of the TSF and has a positive effect on the aesthetic value (Huang *et al.*, 2012:234; Schimmer, 2018:50). Amelioration by using waste rocks of mines or quarries, might be used to improve the properties of gold TSFs for vegetation establishment (Drever, 1994:2328; Schimmer, 2018:44; Table 2-6). Rocks can be milled and used as rock flour due to the variety of minerals contained within a single rock type. In general, rocks consist of primary nutrients that plants requires (Martins *et al.*, 2013:197; De Souza *et al.*, 2013:59). The environmental conditions play a vital role in the weathering of the rocks into secondary minerals and nutrients (Harley & Gilkes, 1999:11; Silva *et al.*, 2005:994; Ramos *et al.*, 2015:371; Burghilea *et al.*, 2015:188; Rafael *et al.*, 2017:3-4).

The release of nutrients from that can happen in two stages are mainly controlled by the particle sizes of the soil. There are two stages of nutrient release, i.e. a fast-release phase, followed by a slow-release phase. The release rate can be influenced by the particle sizes of the soil (Harley & Gilkes, 1999:22; Silva *et al.*, 2005:994, 1000; Zhu *et al.*, 2008:262; Rafael *et al.*, 2017:15; Ramos *et al.*, 2017:2700). The ratios of uptake and leaching of minerals will differ between the rocks used, e.g. felsic rocks have a higher concentration of Si and K, whereas volcanic rocks are richer in Mn, Ca, Al, Fe, Ti and Mg (Dippenaar & Van Rooy, 2014:14; Burghilea *et al.*, 2015:192; Vierra *et al.*, 2018:303). Previous studies illustrate that a mixture of ground basalt, bentonite and diabase improves the soil quality where vegetation is present. Even though the soil quality is improved, the texture of the rock still influences the capacity for nutrient uptake (Von Mersi *et al.*, 1991:216; Harley & Gilkes, 1999:12; Silva *et al.*, 2005:999; Silva *et al.*, 2005:994). Table 2-6 gives a comparison between granite, gabbro and andesite, and lists some of the effects these rocks might have on the gold TSFs.

Table 2-6: Comparison between the granitic-, gabbroic-, and andesitic soils in terms of a few parameters such as pH, bulk density, and texture (Melzer et al., 2012:323-329; Usta et al., 2013:16; Yousefifrad et al., 2015:190; Wilson et al., 2017:306; Homolák et al., 2017:1; Kiliç et al., 2018:112, 123-124). The dark grey = worst, medium grey = bad, light grey = good.

Comparison between granitic-, gabbroic- and andesitic soils			
Parameters	Granitic soils	Gabbroic soils	Andesitic soils
Aggregate stability	Less stable aggregates that are smaller	More stable aggregates that are larger	Large aggregates
Organic content	Lower organic material and clay content	Higher content of organic material and clay	High organic carbon content
Sand content	Higher sand content	Lower sand content	High sand content
Bulk density	Higher bulk density	Lower bulk density	Low bulk density
pH	More acidic soils	More alkaline soils	Alkaline soils
Mineral assemblage	Quartz and plagioclase with ferromagnesian	Fine plagioclase with minor phenocrysts of olivine.	Plagioclase and pyroxene minerals
Dominant clay	Clay dominated with kaolinite and mica	Clay dominated with smectite, kaolinite and mica	Dominant clay is kaolinite and smectite, and other 2:1 clays may be present. Other clay minerals such as vermiculite in small percentage may be present.
Texture	Coarser texture	Finer texture	Coarse-fine texture
Hydraulic conductivity	Higher hydraulic conductivity	Lower hydraulic conductivity	High hydraulic conductivity
Leaching potential	More material loss by leaching	Less material loss by leaching	Minimum material loss by leaching

CHAPTER 3

MATERIAL AND METHODS

In this chapter, the material and methods used in this study will be discussed. The preparation of the material used in the trials is explained, as well as the monitoring procedure to determine the germination and growth of *C. dactylon*.

3.1 Material preparation

Two of the three rock types (granite and gabbro) were obtained from Stone Dynamics¹ in Potchefstroom Industria to represent commercially available material. The andesite was collected from outcrops in the Ventersdorp area in the North West Province. The rock flours were prepared using the following methods:

3.1.1 Crushing

The granite, gabbro and andesite were crushed into smaller-sized particles with a hammer and a steel plate. Afterwards, the smaller-sized particles were ground into powder by using a jaw crusher.

3.1.2 Sieving

The crushed material of the three rock types was sieved through a 2 mm sieve and subsequently through a 425 μm sieve. The fine material (<425 μm) was then placed in plastic bags. The particles that passed through neither the 2 mm nor 425 μm sieves were placed into the ball mill (see section 3.1.3).

3.1.3 Ball mill

The ball mill consists of three cylindrical tubes into which the rock particles were placed with ball bearings. The ball bearings ground the rock particles into smaller particles. After approximately two hours, the fine rock particles were sieved again as described in Section 3.1.2 above. The ball mill and sieving method was repeated until 25 kg of rock material of each the three rock types was fine enough (<425 μm) to be used as rock flour to mix with the growth medium by using a cement mixer (see section 3.1.4) in which the *C. dactylon* seed was sown (see Annexures 1 & 2).

¹ Stone Dynamics: 42 Ross street, Potchefstroom Industria. 018 293 2854, www.stone.dynamics.co.za

3.1.4 Experimental design and growth medium preparation

The experiment used 20-litre bags filled with growth medium as explained in Annexure 1. The control (acting as the raw material) consisted of six (6) bags filled with 25 kg gold TSF material each that were mixed with a spoon full of 2:3:2 (14) fertilizer by using a cement mixer. The fertiliser was added to give additional support for the *C. dactylon* seeds in order to enhance the germination potential of the *C. dactylon* seeds in the unfavourable conditions of the gold TSF material. As the growth medium had been tested and had a low pH and high EC with elements that had the potential to be phototoxic for the *C. dactylon* seeds. Three (3) bags were also mixed with 2.57 g of agricultural dolomitic lime sown into the top layer, approximately similar depth of were the *C. dactylon* seeds were sown. The lime was added to improve the unfavourable conditions of the gold TSF material.

The treatments consisted of the three ameliorants (granite, gabbro and andesite), namely 0.5 kg, 1 kg and 2 kg, were each mixed into six (6) bags of growth medium (gold TSF) (i.e. 3 rock flours x 3 concentrations x 6 replicates = 54 bags). With the six (6) controls the experiment consisted of a total of 60 bags.

The first group treatments of each of the three ameliorants consisted of a total of six (6) bags, respectively, consisting of 0.5 kg of each of the three ameliorants with fertilizer. Three (3) bags of the six (6) bags of all three ameliorants were also mixed with 2.57 g of lime, as described above. The second group consisted of 1 kg of the three ameliorants respectively, and three (3) bags of with lime. The third group of treatments consisted of 2 kg of each of the three ameliorants respectively. With three (3) bags with lime. The gold TSF and fertilizer were mixed with a cement mixer for all the treatments. Therefore, 30 bags consisted of gold TSF, fertilizer and lime and the other 30 bags consisted of gold TSF and fertilizer. All the treatments were placed into a greenhouse with an automatic sprinkler system. Where the temperature was only monitored to ensure *C. dactylon* did not experience water stress during the course of the experimental phase. This was done to ensure the amount of water the grass get was enough to offset the evapotranspiration in the greenhouse, as no air flow was used. Visual demonstration is illustrated in Annexures 1.

To summaries the treatments that were used in this study was

- Control (TSF + Fertiliser), Gr1 (Granite = 0.5 kg + Fertiliser), Gr2 (Granite = 1 kg + Fertiliser), Gr3 (Granite = 2 kg + Fertiliser),
- Ga1 (Gabbro = 0.5 kg + Fertiliser), Ga2 (Gabbro = 1 kg + Fertiliser), Ga3 (Gabbro = 2 kg + Fertiliser),

- A1 (Andesite = 0.5 kg + Fertiliser), A2 (Andesite = 1 kg + Fertiliser) and A3 (Andesite = 2 kg + Fertiliser).
- Control (TSF + Lime + Fertiliser),
- Gr1 (Granite = 0.5 kg + Lime + Fertiliser), Gr2 (Granite = 1 kg + Lime + Fertiliser), Gr3 (Granite = 2 kg + Lime + Fertiliser),
- Ga1 (Gabbro = 0.5 kg + Lime + Fertiliser), Ga2 (Gabbro = 1 kg + Lime + Fertiliser), Ga3 (Gabbro = 2 kg + Lime + Fertiliser),
- A1 (Andesite = 0.5 kg + Lime + Fertiliser), A2 (Andesite = 1 kg + Lime + Fertiliser) and A3 (Andesite = 2 kg + Lime + Fertiliser).

3.1.5 Sowing method

Ten seeds were sown in each bag. A total of 600 seeds were therefore sown into the 60 bags. The seed viability was tested by AGT foods^{*2} during laboratory conditions. See Annexure 2 for the seed viability certification by AGT Foods.

3.2 Substrate sample analysis

Two substrate samples were collected for each of the 60 bags in September (Sept.) 2018 (before), and repeated in January (Jan.) 2019 (during) and April (Apr.) 2019 (after) the experimental phase respectively. Thereafter, the soil samples were oven dried at 50°C for 24 hours or until the soil (substrate) samples are dry. Afterwards, the soil samples were sieved through a 2 mm sieve. One of the soil samples of each replicate was used to make composite samples, and the second one was used to determine the pH and EC values and do the linear shrinkage measurements. The composite samples were created by dividing a soil sample by using a riffler (a mechanical device consisting of a metal box with a series of vertical slats through which material is poured and randomly divided into two samples). One of the soil sample sets was used to measure the texture (sieve and hydrometer), whereas the other soil sample set was sent to the Eco Analitica^{**3} soil laboratory for detailed analyses. The detailed analyses included cation exchangeable capacity (CEC), anions (saturated extract) and phosphor Bray-1-method. The Sept. 2018 substrate samples were taken three days after the growth medium were created as discussed in full detail in section 3.1.4. The Jan. 2019 substrate samples were taken in the second week of Jan. 2019.

² *AGT Foods: Jacobs St, Chamdor, Krugersdorp, 1754

³ **Eco Analitica 11 Hoffman St, Potchefstroom, 2520

As *C. dactylon* head reach the adult phase of its life cycle. Lastly, the Apr. 2019 samples were taken in the first week. *C. dactylon* had reached the dominance phase (reproduction phase)

3.2.1 Analysis for pH and EC

A solution was created by taken 20 g of each substrate sample that was mixed with 50 ml distilled water and stirred to create a 1:2.5 soil solution. These samples were then left for 45 minutes and stirred again. The mixture was left for another five minutes, after which the pH (Figure 4-1, Figure 4-2) and EC (Figure 4-4, Figure 4-5) were measured with a multi-parameter instrument (XS Instruments model PC 5 multi-parameter tester), that was calibrated using standardised calibration solutions. The remaining soil sample was used to determine the linear shrinkage (Kruger 2017:89; Schimmer 2018:90).

3.2.2 Linear shrinkage measurements

The remaining substrate samples used were firstly mixed together for each concentration of all three ameliorants (granite, gabbro and andesite) i.e. Gr1, Gr 2 and Gr3 etc. Therefore all six (6) bags of each concentration of the three ameliorant treatments were mixed into one bucket respectively. It was done in this matter to have enough material to conduct the test. Thereafter, a saturated paste were created by added distilled water and mix it until the saturated paste did not fell out of the bucket when turned upside down, due to the high plasticity of saturated paste. Afterwards, the saturated paste was placed into linear shrinkage trays and oven dried at 90 °C until dry according to the ASTM D 427-04 (ASTM, 2004). The shrinkage of the soil sample was measured by a vernier caliper for the length and a g-vernier for the height differences. Each linear shrinkage measurement was replicated three times to get an average and for statistical purposes (Figure 4-7).

3.2.3 Particle size analysis (texture measurements)

The particle size analysis consist of two parts, the first part was a sieved analysis and the second part was hydrometer analysis (Figure 4-11, Figure 4-12, Figure 4-13).

3.2.3.1 Sieve analysis

The particle sizes that were used in the sieve analysis were 0.75 mm – 2 mm. The substrate samples were sieved through a 2 mm sieve after the sample were dried, the part of the samples that fell through were sieved through a 0.75 mm sieve. The particles smaller than 0.75 mm were used for the hydrometer analysis and the particles size from 2 mm – >0.75 mm were used in a sieve analysis. The sieve analysis consist of the following sieves, 2 mm, 1 mm, 0.850 mm, 0.500

mm, 0.425 mm, 0.250 mm, 0.106 mm, 0.75 mm and the pan (hydrometer analysis). The sieve analysis were conducted with a sieve machine for five min.

3.2.3.2 Hydrometer analysis

This test was conducted according to the ASTM D 422 method (ASTM, 1988). The method entails a hydrometer test for which 100 g of the soil (substrate) sample was mixed with 250 ml of a 1M hexametaphosphate (NaPO_3)₆ solution and stirred well. The mixture was left overnight to allow sufficient reaction time. Thereafter, the soil mixture was sieved through a 75 μm sieve and put into a one-litre cylinder. The cylinder was filled to the one-litre mark with distilled water and then tilted a few times after making sure that the opening was securely shut. After placing the cylinder on the table, the hydrometer test started immediately. The hydrometer readings were taken for a 24 hour period (the intervals were as followed, 30 s, 1 min, 2 min, 5 min, 10 min, 15 min, 30 min, 1 hours, 2 hours, 4 hours, 8 hours, 24 hours). The temperature at every reading was also noted since the solution could not be kept at a constant temperature.

3.3 Monitoring and assessment of plant growth

The 60 bags were placed into a greenhouse and the and only the water were regulated because of the used of an automatic sprinkler system to ensure *C. dactylon* are not under water stress. Furthermore, *C. dactylon* were not thinned out, because only ten seeds were planted into each bag and not all ten (10) seeds had germinated.

3.3.1 Germination rate

The germination rate was monitored every second day for a period of 17 days. The total number of seedlings that emerged was recorded for every bag (Table 4-10). A laboratory test was also conducted by AGT Foods*⁴ to test the seed v viability (Table 4-11).

3.3.2 Growth potential

The following criteria were used to determine the growth potential:

- Height (For a period of 25 weeks, Dec 2018 to May 2019 (full growth cycle)),
- Biomass (End of May 2019, and
- Chlorophyll fluorescence (27 April 2019).

⁴ *AGT Foods: Jacobs St, Chamdor, Krugersdorp, 1754

3.3.2.1 Growth rate (cm/week)

The growth rate of *C. dactylon* was measured on a weekly basis (cm/week) from the floor next to the bags to the highest stretched out leaves (Kruger, 2017:90). This method was chosen because the soil surface was not constant, but was dynamic, therefore, changed each week. This method was used to allow *C. dactylon* to complete its entire growth cycle (Figure 4-19 - Figure 4-24).

3.3.2.2 Biomass

Only the above-ground biomass was collected at the end of May 2019 by clipping the leaves, stolons and stems as close to the soil as possible and placing them in a paper bag (Figure 4-26). End of May was the day the experiment was completed and the winter season was fast approaching. It was also when *C. dactylon* life cycle was completed. The grass samples were then air dried and subsequently washed using deionized water to remove any soil particles that may have stuck to the samples. The samples were then air dried again and weighed to determine the above-ground biomass of the *C. dactylon* plants (Habyarimana *et al.*, 2018:189; Muller, 2014:58).

3.3.2.3 Chlorophyll fluorescence

The chlorophyll fluorescence was measured by a Handy PEA Chlorophyll Fluorimeter at night (Cetner *et al.*, 2014:90; Percival, 2004:80). The PEA Chlorophyll Fluorimeter measures the performance Index parameter (PI_{abs}), which can be used to characterise plant vitality by revealing the functionality of both photosystems I and II and giving a good indication of the current state of the plant's potential under stress. Four readings were taken of the plants in each bag, i.e. a total of 240 measurements were taken for the 60 bags (60 x 4 = 240). These readings were all taken at the beginning of May on the same day, (four per plant), due to the winter season that was approaching and the growth cycle of *C. dactylon* was complete.

3.3.2.4 Statistical analysis

The statistical analysis that were used in this study was t-tests and Repeated Measures ANOVA. T-tests were conducted to determine if the samples with lime and the samples without lime had a significant difference in the different treatments individually. The repeated measures ANOVA were conducted to determine if the samples collected in the three samples periods, had a significant difference with each other as the lime and time sampled as the factors. The repeated measures ANOVA was also conducted to determine if there was a significant difference between the three ameliorant treatments.

CHAPTER 4

RESULTS AND DISCUSSION

The results for the germination and growth of *C. dactylon* in the different growth mediums, as well as for the soil analyses will be discussed in this chapter. Firstly, the analysed soil factors that contributed to the changes of *C. dactylon* will be discussed in terms of the pH, electrical conductivity (EC), linear shrinkage and texture of the growth medium. Thereafter, the germination rate, growth and biomass production of *C. dactylon* in the greenhouse. The germination rate was repeated in laboratory conditions to determine the real germination potential of the seeds used in this study. These factors were investigated to determine the success of the three rock types as ameliorants in rehabilitation.

4.1 Soil analyses

4.1.1 pH value

In Figure 4-1, the (soil) substrate pH values for the ten ameliorant treatments that received lime (three concentrations of each of the three types of ameliorants and a control) collected in Sept. 2018, Jan. 2019 and Apr. 2019 are shown. The pH values of the substrates range from 3.6 to 6.5. The control had the lowest pH value for Sept. 2018, but not for Jan. 2019 and Apr. 2019. The first concentration gabbro ameliorant treatment (Ga1) have the lowest values for Jan. 2019 and Apr. 2019. Furthermore, the gabbro ameliorant treatments had illustrated better pH values than the granite ameliorant treatments. However, the andesite ameliorant treatments had shown the best pH values over the three sampled dates. As the three pH values for the three sampling dates did not differ much. This occurrence is due to the calcite phenocrysts that were present in mineral composition of the andesites that were used in this study (Figure 4-1).

In general, the pH values of the substrate increased as time passed for the three times samples were taken. This occurrence could be due to the leaching of salts and heavy elements out of the bags. Another factor could be the weathering of the ameliorants, which release the alkali elements that were present in the composition of the three ameliorants. It seems to increase the pH values. As for the andesite ameliorant treatments, besides the leaching, the weathering of the phenocrysts that were in the composition seems to have a significant effect on the pH values of the substrate (Figure 4-1). The second concentration gabbro ameliorant treatment (Ga2) illustrated higher pH values than the first and third concentration gabbro ameliorant treatments Ga1 and Ga3). This could be that the sampled that were taken for Ga2 had an abundance of alkali elements (e.g. Ca^{2+}) compared to Ga 1 and Ga3. It could also be due to an insufficient mixture of the tailings with the ameliorant, fertilizer and lime. However, it is unlikely because a cement mixer was used to

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ensure that this occurrence could be ruled out as an effect. (Figure 4-1). Furthermore, the Ga2 of Figure 4-2 did not illustrate the same occurrence.

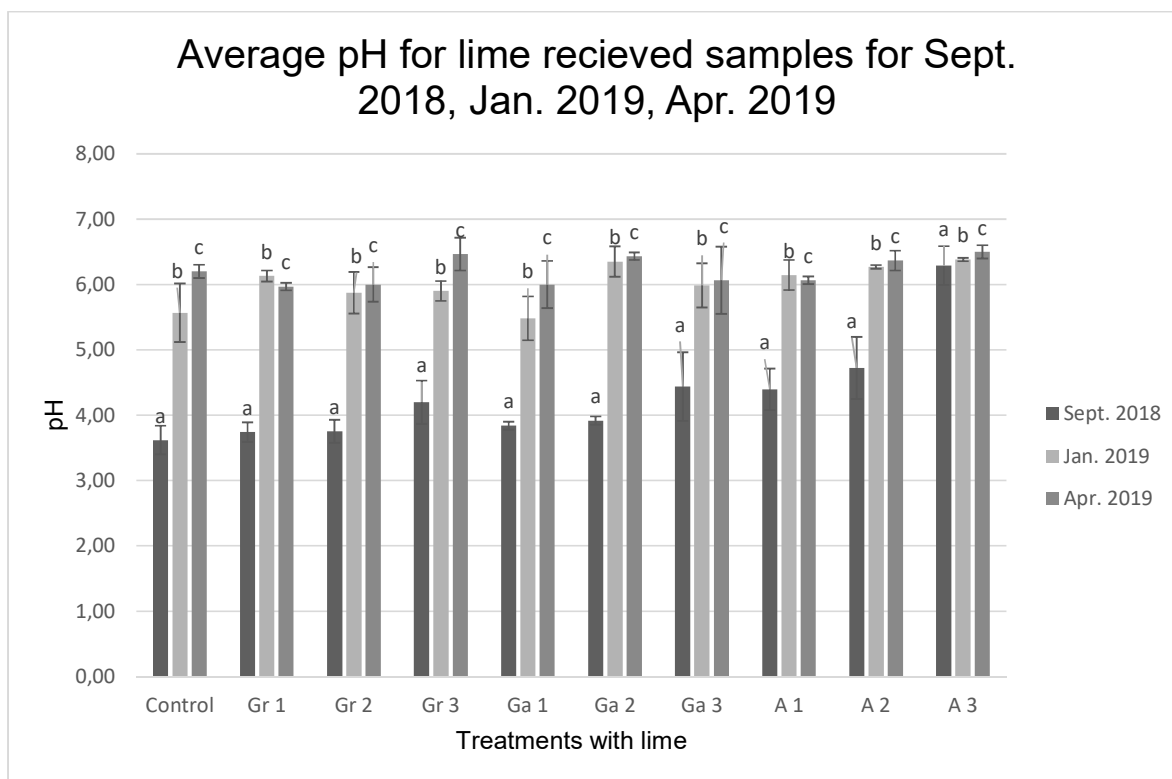


Figure 4-1: The average pH of the samples that received lime for Sept. 2018, Jan. 2019 and Apr. 2019. Gr = Granite, Ga = Gabbro, A = Andesite. The 1 = first concentration, 2 = second concentration and 3 = third concentration.

Figure 4-2 illustrate the average pH values for the samples that not received lime for the three sample dates. It clear that the lime added to the treatments had a significant on the pH values, because there are a significant difference between the pH values for the treatments that received lime and the treatments that did not received lime over the three sampling dates respectively. The control had in general the lowest pH values for the three times samples were taken. The granite ameliorant treatments had similar values as gabbro ameliorant treatments, however, andesite ameliorant treatments had illustrated the highest values over the three sampling times. The pH values had increased as the time passed from Sept. 2018, Jan. 2019 and Apr. 2019 (Figure 4-2).

The fact that the granite ameliorant treatments (Gr1 – Gr3) had illustrated similar pH value to the gabbro ameliorant treatments (Ga1 – Ga3) could indicate that the alkali feldspars in specific had an effect on the pH values of the substrate as gabbro had an abundance of feldspar elements compared to granite (Figure 4-2). The andesite ameliorant treatments (A1 – A3) had illustrated significant higher pH values than the granite and gabbro ameliorant treatments indicated that the

calcite phenocrysts had a significant effect on the pH values. As the pH values were very similar for treatments with lime and without lime that the three dates samples were taken (Figure 4-1 & Figure 4-2).

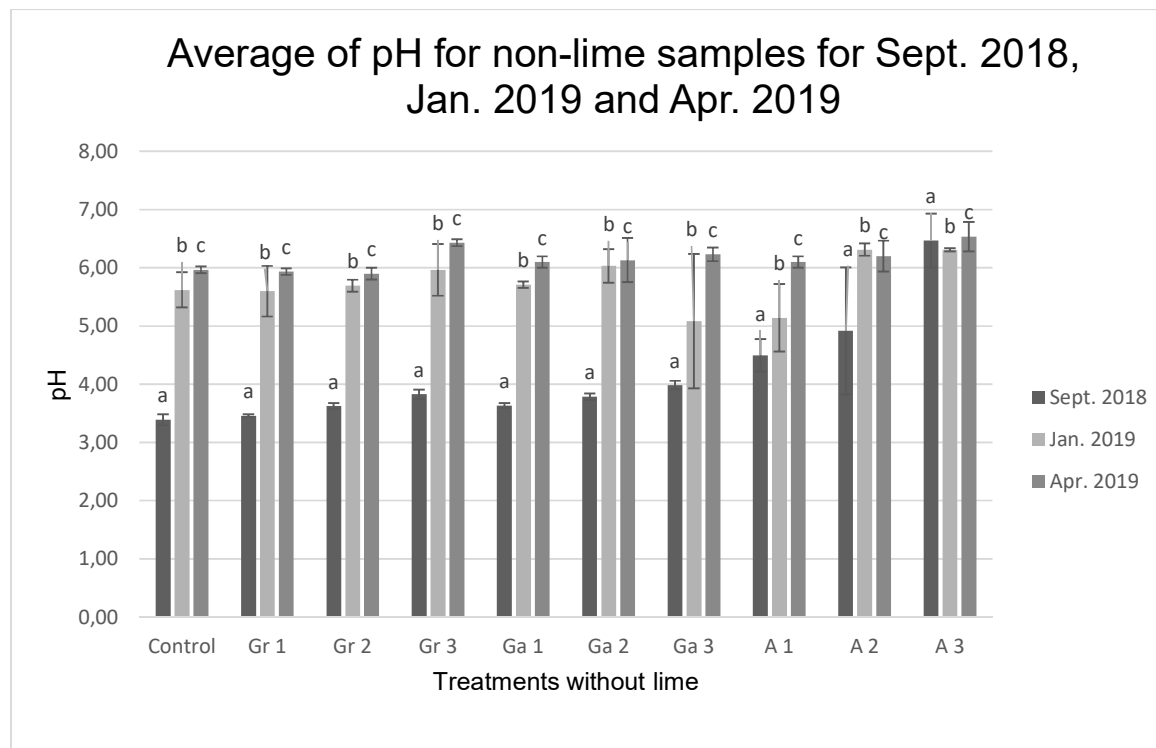


Figure 4-2: The average pH of the samples that did not received lime for Sept. 2018, Jan. 2019 and Apr. 2019. Gr = Granite, Ga = Gabbro, A = Andesite. 1 = first concentration, 2 = second concentration and 3 = third concentration.

Summary

The pH values of the substrate were very acidic at Sept. 2018 but become slightly acidic at Apr 2019. Apr. 2019 indicated that the andesite ameliorant treatments had approximately optimum range, namely a pH value of approximately 6.5 - 8.5 (Schimmer, 2018:45; Neethling, 2015:103). According to the pH values of the three ameliorants (granite, gabbro and andesite) that are higher than the pH values recorded of the control at the three sampling dates for lime and without lime. Indicates that the ameliorants have the ability to increase the pH of gold tailings in different degrees. As the two groups of ameliorants (lime and without lime) had indicated leaching, however, the lime could hide the effects granite and gabbro could had (Figure 4-1 & Figure 4-2). Furthermore, as a result of the calcite phenocrysts that were in the mineral composition of andesite the pH values of the substrate were significant higher compared to granite and gabbro pH values recorded. The difference between granite and gabbro could be the amount of feldspar minerals

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that are a part of their composition respectively. The weathering of the feldspar minerals produce products that had a liming effect on the substrate. Therefore, the gabbro ameliorant treatments had illustrated better pH values than the granite ameliorant treatments, because gabbro have an abundance of feldspar minerals compared to granite. The feldspar can weather into clay minerals and has the potential to remove hydrogen ions from the solution, effectively increasing the pH value. Dannhaus *et al.* (2018:618) and Weyer *et al.* (2008:2901) have proven that gabbro ameliorants have a greater ability to increase the pH value. Another factor is the leaching of the salt and element out the bags due to irrigation.

In conclusion, the ameliorants had illustrated (granite = 3.71%, gabbro = 4.53% and andesite = 15.95%) difference compared to the control for the whole experimental phase. Therefore, the andesite shown the best ability to increase the pH of gold tailings and granite the least.

To determine whether there was a significant difference in the pH values recorded for all ten treatments of the soil samples collected in Sept. 2018, Jan. 2019 and Apr. 2019, a repeated measures (ANOVA) was conducted with samples with and without added lime, and the time of collection as the factors. According to the results, a significant difference ($F_{(2,116)} = 252.568$, $p < 0.0000$) occurred (Figure 4-3 and Table 4-1) when the pH values at Sept. 2018, Jan. 2019 and Apr. 2019 were compared to each other for all ten treatments. It seems that the addition of lime did not have any significant effect on the pH values of the soils for the treatments collected in the three months ($F_{(2,116)} = 0.584$, $p < 0.559433$) (Figure 4-3 and Table 4-1). The rest of the results are illustrated in Annexure 2. Additionally, the affect that the lime should had on the substrate (growth medium) had been masked by the weathering of K^+ , Na^+ and Ca^+ that is part of the three ameliorants' mineral composition. Andesite used in this study, also had calcite phenocrysts in the mineral composition that had a further effect on masking the effects of lime (Yousefifard *et al.*, 2015:187; Kılıç *et al.*, 2018:115).

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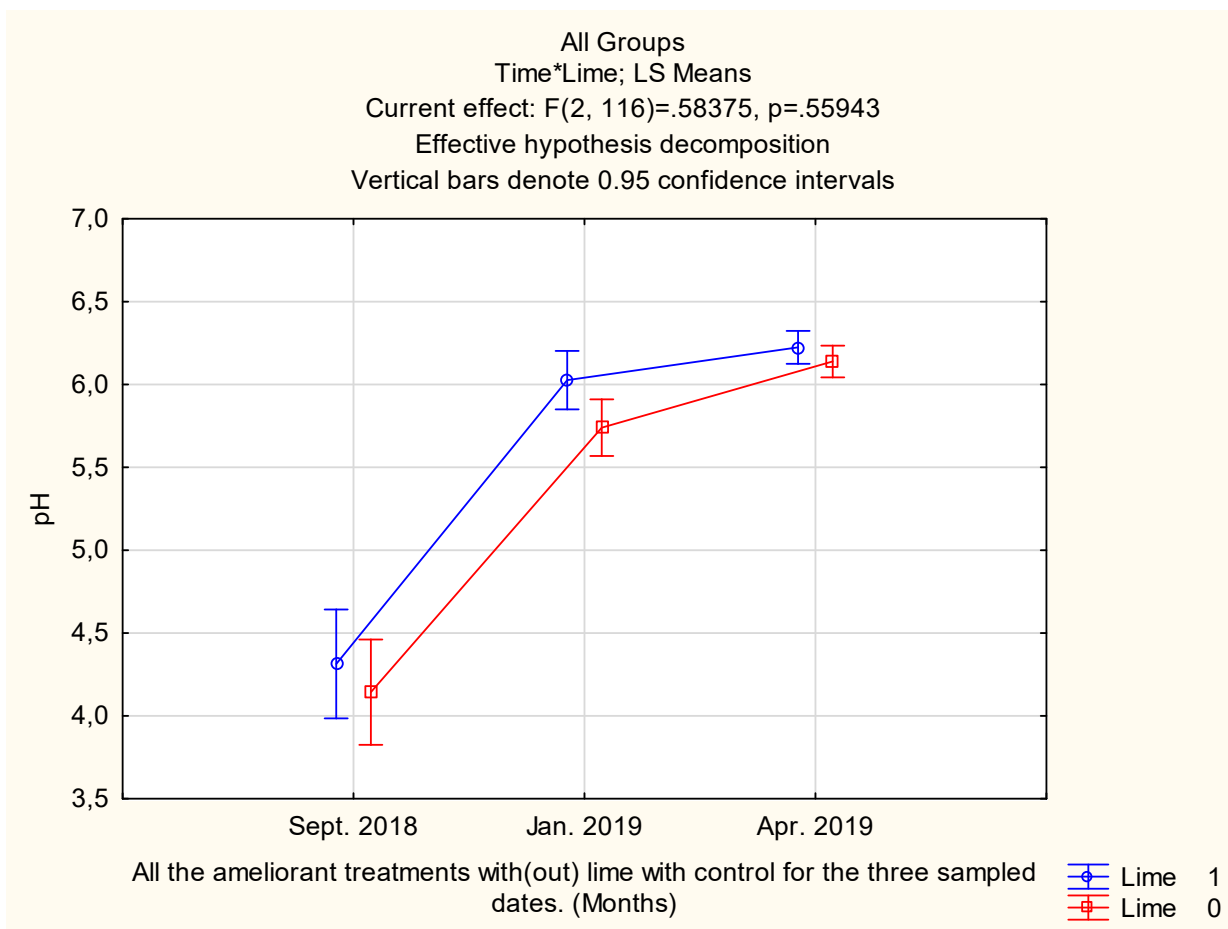


Figure 4-3: The pH values for the three different treatments and control (control, granite, gabbro and andesite) in Sept. 2018, Jan. 2019 and Apr. 2019. Lime 1: samples with added lime, Lime 0: samples that did not receive lime.

Table 4-1: The repeated measures ANOVA of the pH values for the three different treatments and control (control, granite, gabbro and andesite) in Sept. 2018, Jan. 2019 and Apr. 2019.

Effect	All Groups Repeated Measures Analysis of Variance (pH) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degrees of Freedom	MS	F	p
Intercept	5303.144	1	5303.144	9584.723	0.000000
Lime	1.468	1	1.468	2.654	0.108742
Error	32.091	58	0.553		
Time	132.648	2	66.324	252.568	0.000000
Time*Lime	0.307	2	0.153	0.584	0.559433
Error	30.461	116	0.263		

4.1.2 Electrical conductivity (EC)

Figure 4-4 illustrates the treatments that received lime sampled in Sept. 2018, Jan. 2019 and Apr. 2019. The electrical conductivity (EC) ranged from 25 m/mS to 514 m/mS. Therefore, the plant growth could be negatively affected in the beginning of the experiment in all three ameliorant treatments (granite, gabbro and andesite) until adaption to the harsh conditions as stated by Kruger (2017:22) that salt sensitive plants can be affected from >200 mS/m. However, *C. dactylon* is not classified as a salt sensitive plant. The EC had reduce significantly from Sept. 2018 to Apr. 2019, this occurrence could be due to the leaching of elements out the bags. Another factor could be the weathering of the ameliorants, as the granite ameliorant treatments (Gr1 – Gr3) illustrated the most significant reduce in the EC values for the substrate over the three dates sampled (Figure 4-4). The gabbro ameliorant treatments (Ga1 - Ga3) seems to have a better ability to reduce the salinity of the substrate than the andesite ameliorant treatments (A1 – A3). It would seems that the calcite phenchrist that are present in the mineral composition of andesite had increase the salinity rather than reduce the salinity in the beginning of the experiment, if the EC values are compared to those of the granite and gabbro. The elements as product of the weathering could decrease the EC, from the start or after been reformed into new minerals and could leached out.

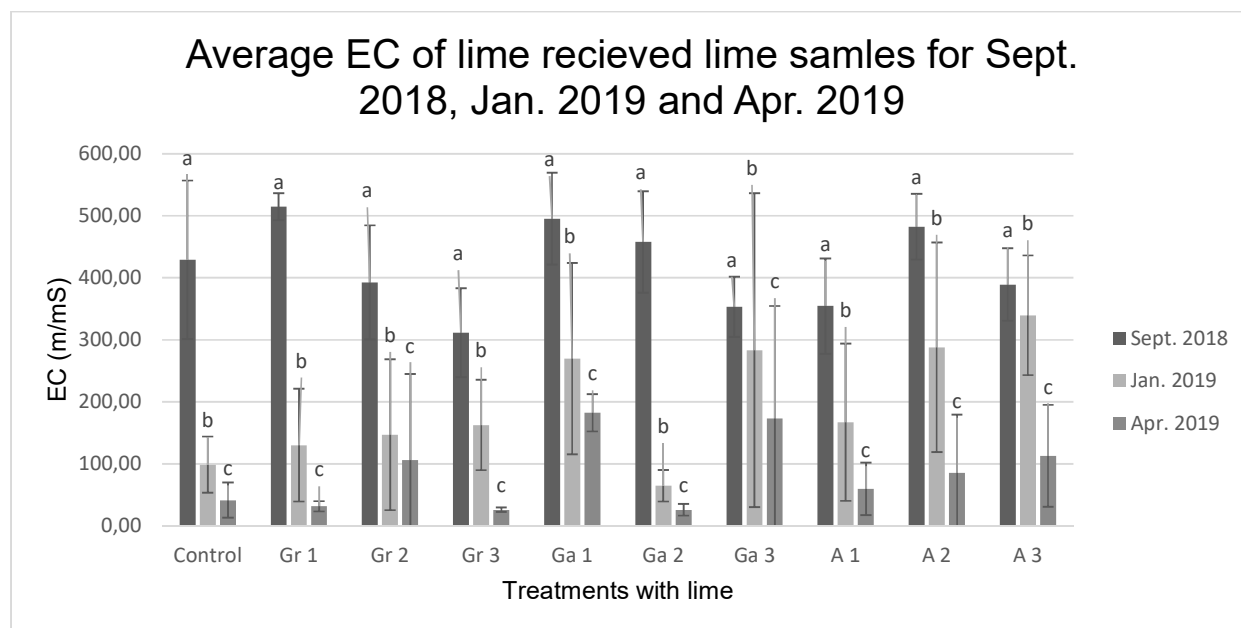


Figure 4-4: The average EC values (m/mS) of the treatments that received lime of Sept. 2018, Jan. 2019 and Apr. 2019. Gr = Granite, Ga = Gabbro, A = Andesite. The 1 = first concentration, 2 = second concentration and 3 = third concentration.

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Figure 4-5 illustrates the EC values of the treatments that did not received lime for the three dates sampled. The EC values range from 0 m/mS to 560 m/mS. Therefore, the salt sensitive plant will still be affected Kruger (2017:22). The EC values had reduce significantly form Sept. 2018 to Apr. 2019. Again the granite ameliorant treatments (Gr1 – Gr3) had illustrated the best ability to reduce the salinity of the substrate. Gabbro ameliorant treatments (Ga1 – Ga3) had illustrated better ability to reduce the salinity of the substrate than the andesite ameliorant treatments (A1 – A3).

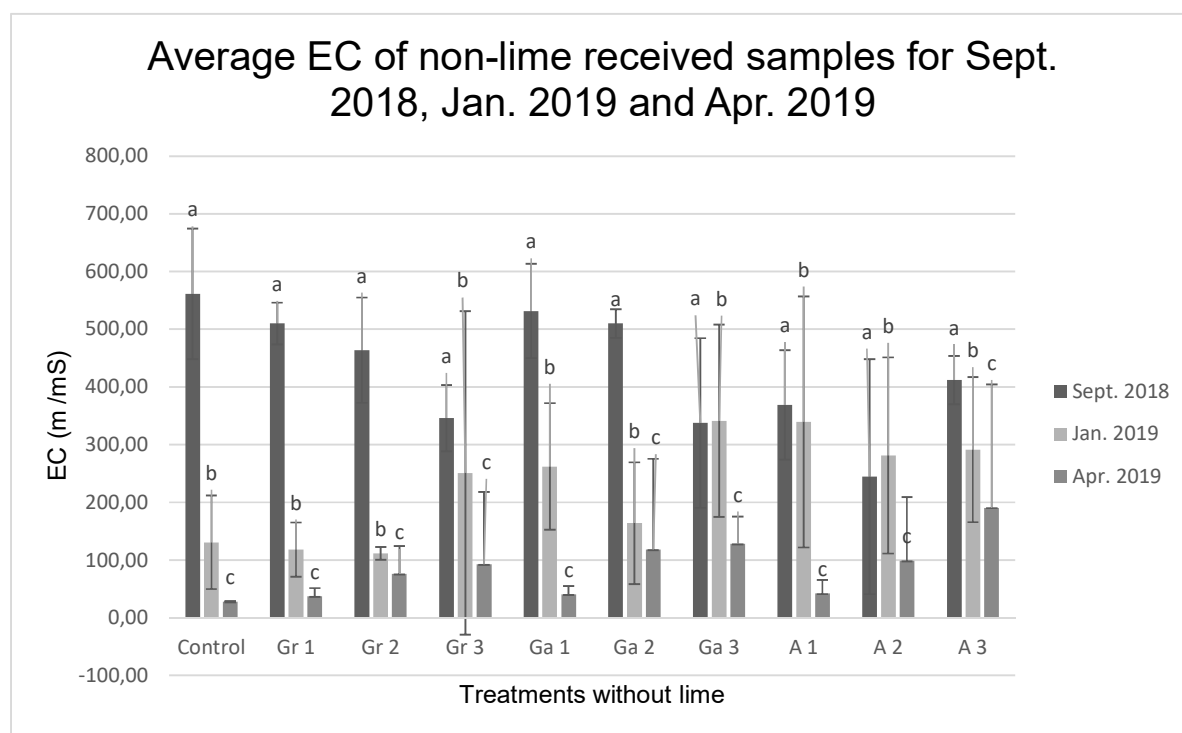


Figure 4-5: The average EC values (m/mS) of the treatments that did not received lime of Sept. 2018, Jan. 2019 and Apr. 2019. Gr = Granite, Ga = Gabbro, A = Andesite. 1 = first concentration, 2 = second concentration and 3 = third concentration.

Summary

The decline in EC values from the control to the ameliorants treatments (granite, gabbro and andesite) might be explained by the fact of the extensive leaching of the salts from the bags. This occurred due to the irrigation. Another source for the decline of EC values could be the process of grinding caused an increase in the charge of the particles through the development of broken crystal edges. The increased charge allows soluble ions to be adsorbed onto the surface of the minerals (Weyer *et al.*, 2008:2901; Silva *et al.*, 2005:997) (Figure 4-4 and Figure 4-5). The grinding process could affect the EC values at the first samples (Sept. 2018). The significant difference in EC of Ga3 compared to Ga1 and Ga2 might be due to the weathering products of the abundance of alkaline minerals in the gabbro which had an effect on the salinity, as well as

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the increased surface charge produced through grinding the minerals into ameliorants (Dannhaus *et al.*, 2018:6108; Weyer *et al.*, 2008:2901) (Figure 4-4 and Figure 4-5).

Furthermore, the andesite ameliorant treatments (A1 – A3) had a direct relationship with the EC values, mainly due to calcite neutralisation that increases the soluble salts but neutralises the pH (Figure 4-4 and Figure 4-5). The EC values dropped considerably from Jan. 2019 to Apr. 2019, especially those of the granite ameliorant treatments. This might be due to a combination of the leaching of elements and the effect of granite ameliorant treatments in particular. (Weyer *et al.*, 2008:2901; Silva *et al.*, 2005:997) (Figure 4-4 and Figure 4-5). The average results (granite= 1.03%, gabbro= -22.52% and andesite= -17.56%) revealed that the granite ameliorant treatment was the best suited to decrease the EC values of the growth mediums.

A repeated measures ANOVA with the treatments and time periods as the factors was carried out to determine if there was a significant difference between the soil samples collected in Sept. 2018, Jan. 2019 and Apr. 2019 regarding the EC values. The results revealed that there was a significant difference ($F(2, 116) = 126.74$, $p < 0.0000$) for the EC values recorded for the substrate samples collected in Sept. 2018, Jan. 2019 and Apr. 2019 when all the treatments (control, granite, gabbro and andesite) were compared (Figure 4-6, Table 4-2). On the other hand, the addition of lime showed no significant effect ($F(2, 116) = 0.267$, $p < 0.766$) on the EC values for the substrate samples collected in Sept. 2018, Jan. 2019 and Apr. 2019 for all the treatments (control, granite, gabbro and andesite) (Figure 4-6, Table 4-2). Even though, that the lime is a salt that dissolves it did not affect the EC values.

When all the treatments (control, granite gabbro and andesite) were individually tested, the results illustrated that the EC values recorded for the samples collected in Sept. 2018, Jan. 2019 and Apr. 2019 all but one had significant differences in EC values over the three periods. The third concentration gabbro ameliorant treatment (Ga3) did not have a significant difference in EC values over the three periods. The lime addition had no significant influence on the EC values recorded for the soils collected for all ten treatments (control, granite, gabbro and andesite) (Annexure 3). Additionally, the significant decrease of the EC values for the three times sampling were done respectively (Sept. 2018 until Apr. 2019) seems to be dominantly affected by the leaching of the salts out the bags. Therefore, the time seems to have the biggest effect on the EC values recorded at the three times.

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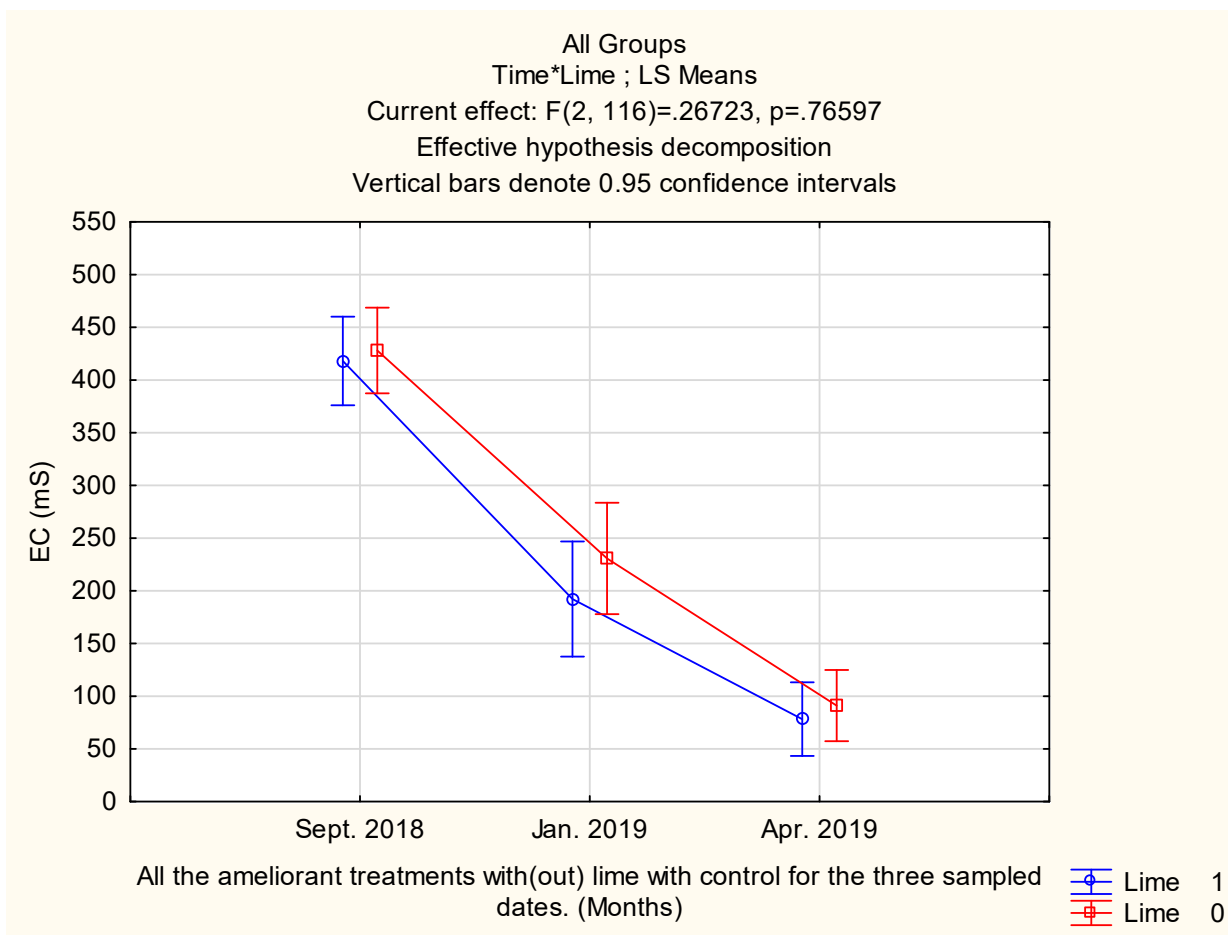


Figure 4-6: The EC values (mS/m) of all the treatments (control, granite, gabbro and andesite) (Sept. 2018, Jan. 2019 and Apr. 2019). Lime 1: Lime added to samples, Lime 0: Samples that did not receive lime.

Table 4-2: The repeated measures ANOVA of all the treatments (control, granite, gabbro and andesite) of the EC values (Sept. 2018, Jan. 2019 and Apr. 2019).

Effect	All Groups Repeated Measures Analysis of Variance (EC) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degrees of Freedom	MS	F	p
Intercept	10331432	1	10331432	663.7210	0.000000
Lime	18721	1	18721	1.2027	0.277318
Error	902824	58	15566		
Time	3503069	2	1751535	126.7407	0.000000
Time*Lime	7386	2	3693	0.2672	0.765966
Error	1603100	116	13820		

4.1.3 Linear shrinkage

Figure 4-7 illustrates the average values of the linear shrinkage of all three ameliorant treatments and the control (granite, gabbro and andesite) with and without lime. This was done this way to have enough sample to perform the test. As a result, no standard variation could be calculated. The linear shrinkage of all the treatments range from 4.5% to 12%. The control had the highest linear shrinkage over the three dates samples were taken, therefore, the ameliorants had reduce the linear shrinkage potential of the substrate over the course of the experiment (Figure 4-7). The first concentration granite (Gr1) and second concentration andesite (A2) had a negative effect on the linear shrinkage of the substrate as the shrinkage potential had increase over the three dates samples were taken. Furthermore, the linear shrinkage potential of granite ameliorant had increase for Sept. 2018 as the concentration increased. However, for the other two dates samples were taken the linear shrinkage decreased, even, over the three concentrations. The linear shrinkage potential for the second and third concentration granite ameliorant treatments (Gr2 and Gr3) had indicated less than compared to the control for Ar. 2019. The third concentration andesite (A3) had illustrated mix picture for the three dates samples were taken. This could be that the mineral composition of these ameliorants could have the potential to produce clay minerals end-produces through weathering that as the potential to increase the linear shrinkage of the substrate. However, only the first and second concentration andesite (A1 & A2) had illustrated higher linear shrinkage potential than the control over the three dates samples were taken (Figure 4-7).

On the other hand, third concentration granite, first concentration gabbro and andesite (Gr3, Ga1 and A1) had a positive effect on the linear shrinkage of the substrate, as the linear shrinkage potential of the substrate had decrease over the three sampling dates.

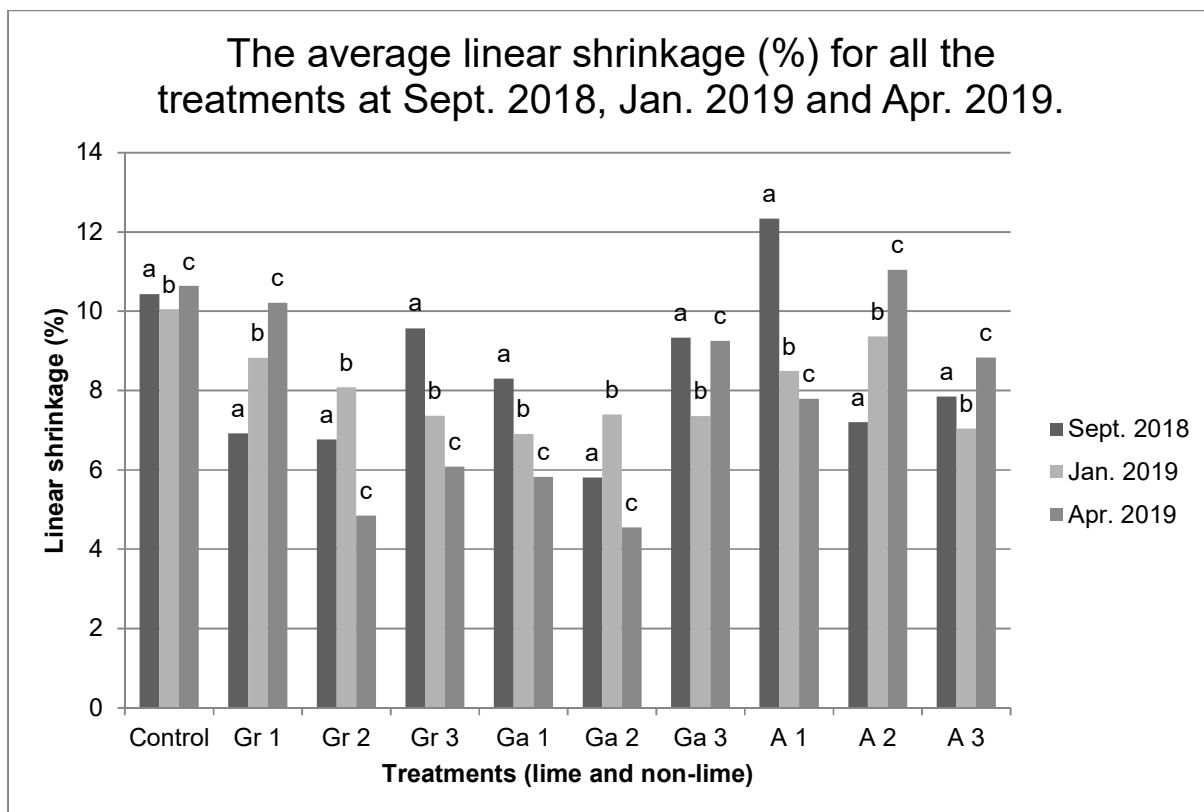


Figure 4-7: The average of all three ameliorants for the three sampling dates. Gr = Granite, Ga = Gabbro, A = Andesite. The 1 = first concentration, 2 = second concentration and 3 = third concentration.

Summary

Linear shrinkage occurs when 2:1 clays like smectite is present in the growth medium. The fact that the first concentration andesite ameliorant treatment (A1) had more linear shrinkage than the control for the substrate samples collected in Sept. 2018 was mainly because of the addition of rock flour mineral matter that produced minerals with clay like properties. The rock flour matter started transforming into secondary minerals over the short term. This means that the rock flour matter had increased the charge of the material through broken crystal edges that do not produce shrinkage to the same extent as clay particles (Figure 4-7). However, over the long-term the rock ameliorants had reduce the shrinking potential of the growth medium. The reason why the granite ameliorant treatments (Gr1 – Gr3) for the soil collected in Sept. 2018 increased the linear shrinkage potential was because the rock flour mineral that was added had enough time to weather down into secondary minerals. This means that granite ameliorant treatments were able to increase the charge of the material through the broken crystal edges and produce shrinkage to the same extent as clay. This was, however, not to the same extent as A1 (Figure 4-7). On the contrary, granite might make the texture coarser, therefore increasing the amount of water that can force the soil to expand in volume for a short period (Liu *et al.*, 2017:6; Aarthi & Arunachalam, 2018:250-251) (Figure 4-7). Lastly, the average results (granite= 26.45%, gabbro= 30.66% and

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andesite= 14.36%) revealed that the gabbro ameliorant treatments were the best suited to decrease the linear shrinkage potential of the growth mediums (Figure 4-7).

A repeated measures ANOVA with the treatments and time periods as the factors was conducted to determine if there was a significant difference between the substrate samples collected for the three dates regarding the linear shrinkage. The test revealed that there was a significant difference in the linear shrinkage for the three dates the substrate collected ($F_{(18,40)} = 2.676$, $p < 0.00479$) when all the treatments (control, granite, gabbro and andesite) were compared to each other (Figure 4-8, Figure 4-9; Figure 4-10 and Table 4-3). No significant difference ($F_{(2,40)} = 0.985$, $p > 0.382$), however, existed when comparing the linear shrinkage results for the substrate samples collected within the three treatments and control (control, granite, gabbro and andesite) (Figure 4-8, Figure 4-9; Figure 4-10 and Table 4-3).

Furthermore, when the three different ameliorant treatments and control (control, granite, gabbro and andesite) were compared to each other, no significant differences were found ($F_{(6,52)} = 0.498$, $p > 0.807$) (Figure 4-8, Figure 4-9; Figure 4-10 and Table 4-3). Even if the difference in silt size particles improved the physical and chemical properties of the growth medium over the seven-month period of the trial, no statistical differences could be found when comparing the ameliorant treatments (granite, gabbro and andesite) to the control (Annexure 5).

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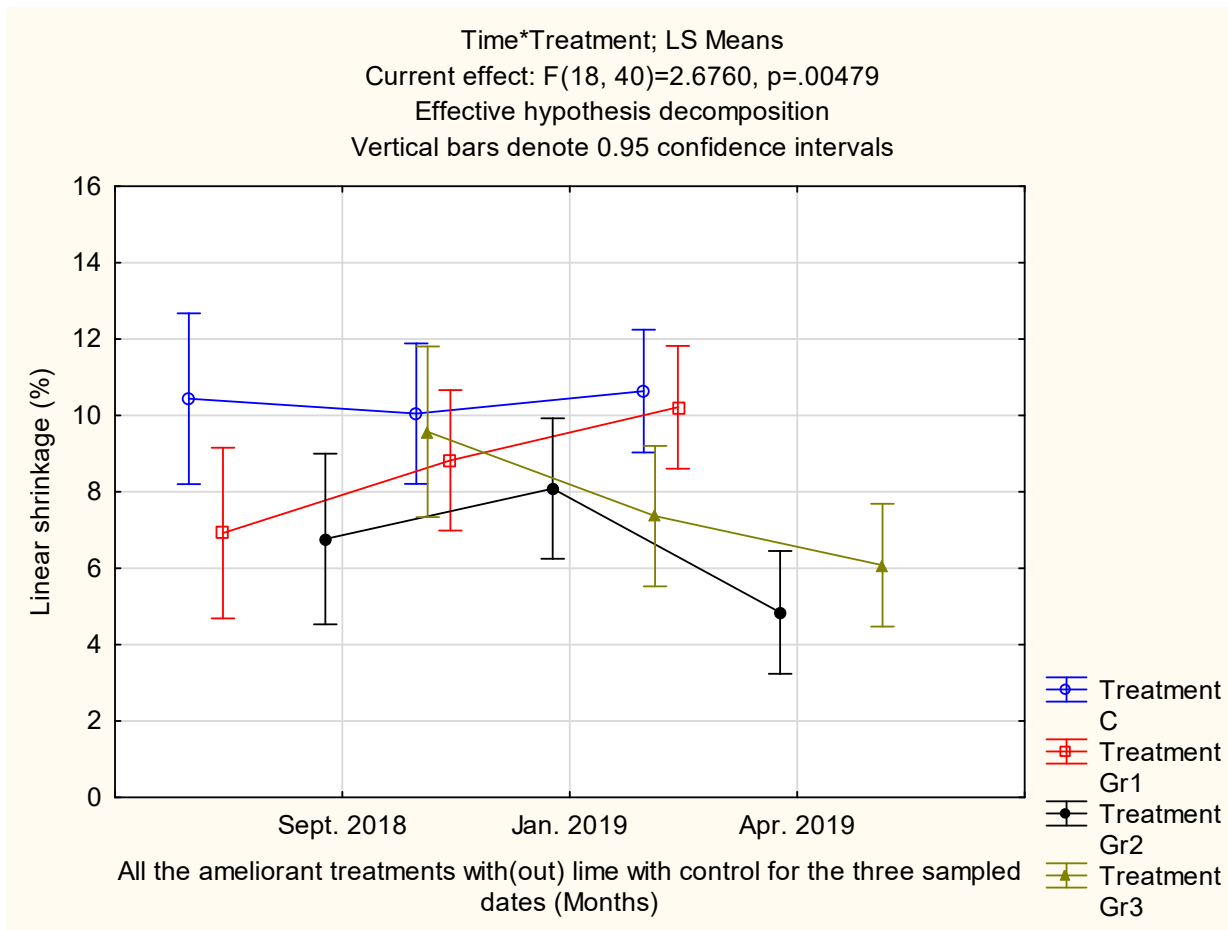


Figure 4-8: The average linear shrinkage (%) of all three concentrations of the granite ameliorant treatment (C – Control, Gr – Granite (1, 2, 3 – the three concentrations respectively) in Sept 2018, Jan 2019 and Apr 2019.

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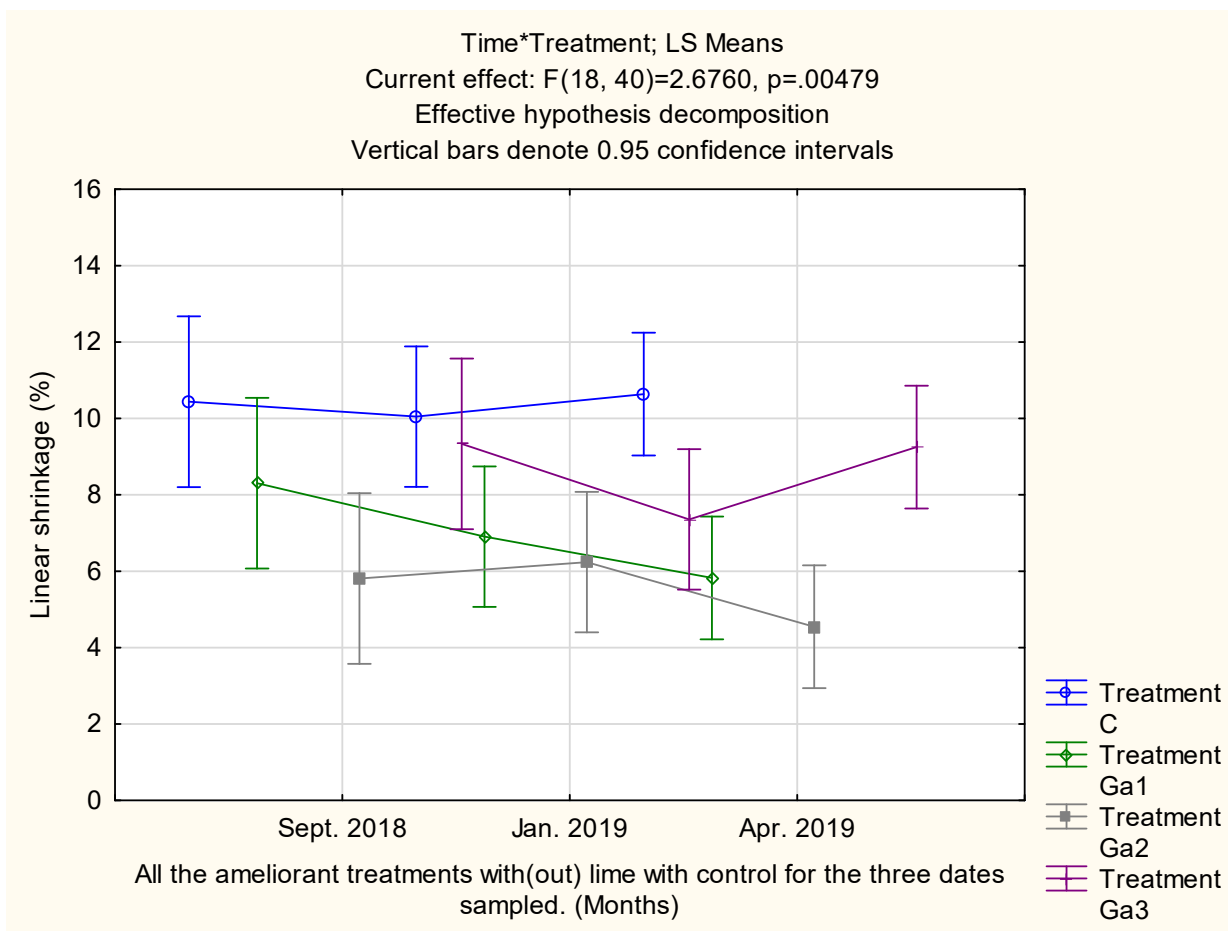


Figure 4-9: The average linear shrinkage of all three concentrations of the gabbro ameliorant treatment (C – Control, Ga – Gabbro (1, 2, 3 – the three concentrations respectively) in Sept 2018, Jan 2019 and Apr 2019.

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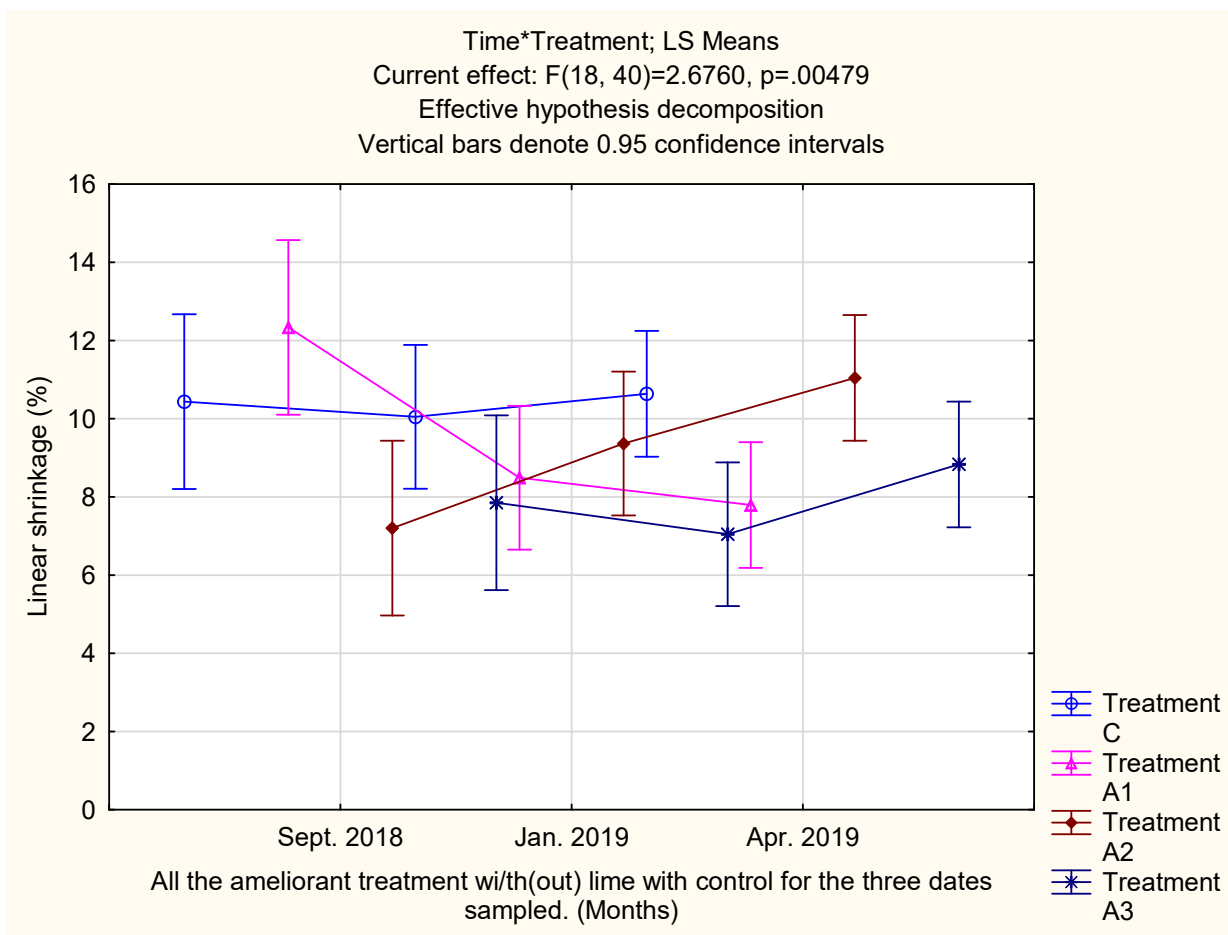


Figure 4-10: The average linear shrinkage of all three concentrations of the andesite ameliorant treatment (C – Control, A – Andesite (1, 2, 3 – the three concentrations respectively) in Sept 2018, Jan 2019 and Apr 2019.

Table 4-3: The repeated measures ANOVA for the linear shrinkage results of all three concentrations for all the treatments (control, granite, gabbro and andesite). Significant values were smaller than 0.05.

Effect	Repeated Measures Analysis of Variance (Linear shrinkage) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degrees of Freedom	MS	F	p
Intercept	5920.726	1	5920.726	2780.274	0.000000
Treatment	174.817	9	19.424	9.121	0.000023
Error	42.591	20	2.130		
Time	5.344	2	2.672	0.985	0.382253
Time*Treatment	130.635	18	7.258	2.676	0.004785
Error	108.484	40	2.712		

4.1.4 Texture

To could conduct the hydrometer and sieve analysis the two groups of treatments (lime and non-lime) had to be mixed together). Figure 4-11 illustrates the particle size distribution graph of all the treatments for Sept. 2018. It is clear that the growth media is dominant by slit and clay particle sizes (>0.002 mm). The addition of the three rock types had increased the amount of slit- (0.002 mm) and clay particles (0.001 mm) in the growth medium, compared to the control. The control had less particles in the 0.05 mm size compared to the three ameliorant treatments. From the three ameliorant treatments the granite ameliorant had illustrated the most particles in 0.002 mm and 0.001 mm sizes (Figure 4-11). The three ameliorant treatments had indicated similar concentration of 0.05 mm particle sizes.

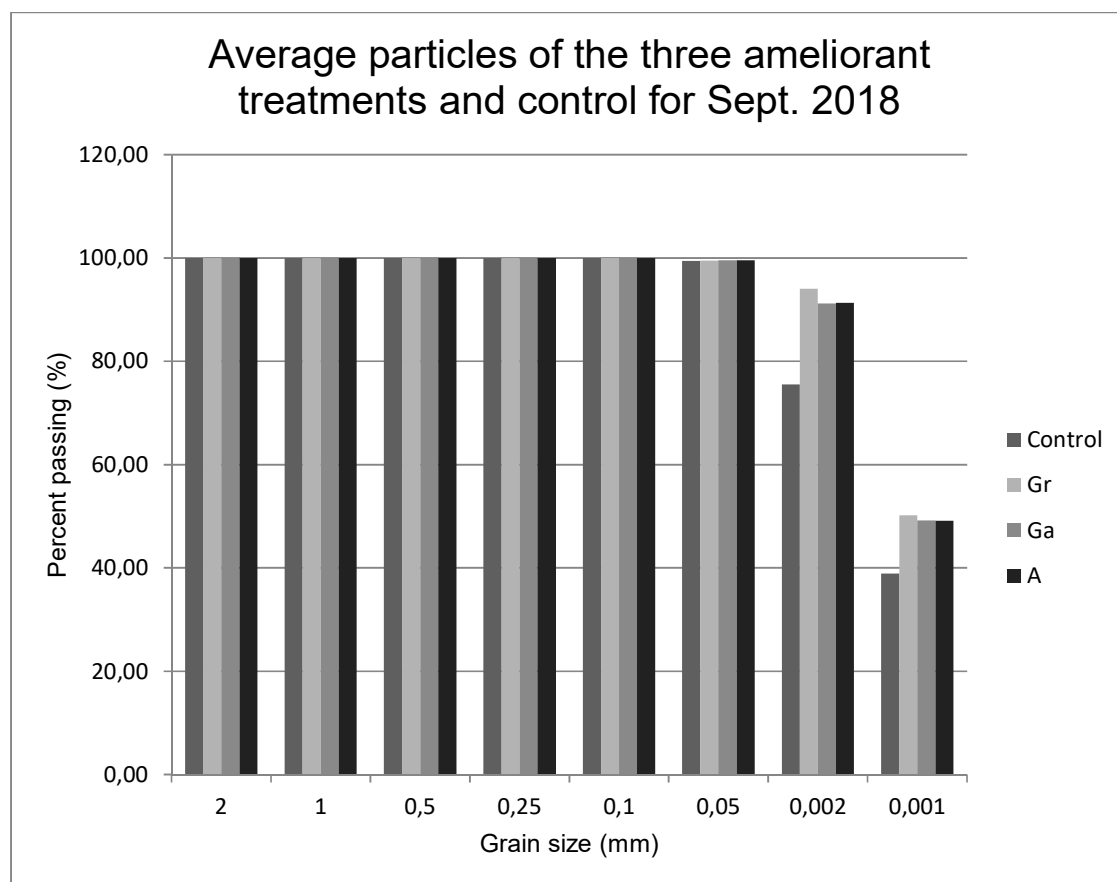


Figure 4-11: The particle size distribution of the growth medium for the three ameliorants and control (C = Control, Gr = Granite, Ga= Gabbro and A = Andesite) for Sept. 2018.

Figure 4-12 illustrates the particle size distribution of all the treatments for Jan. 2019. The control had indicated similar concentrations of the 0.05 mm – 0.001 mm particles as the three ameliorant treatments. Which could indicate that the weathering of the growth medium had occurred at a rapid pace. The granite ameliorant treatment (Gr) had indicated the most slit size particles (0.002

mm) with the andesite ameliorant treatment (A) had the second highest concentration. The andesite ameliorant treatment had indicated the most clay size particles (0.001 mm) of all the treatments (Figure 4-12).

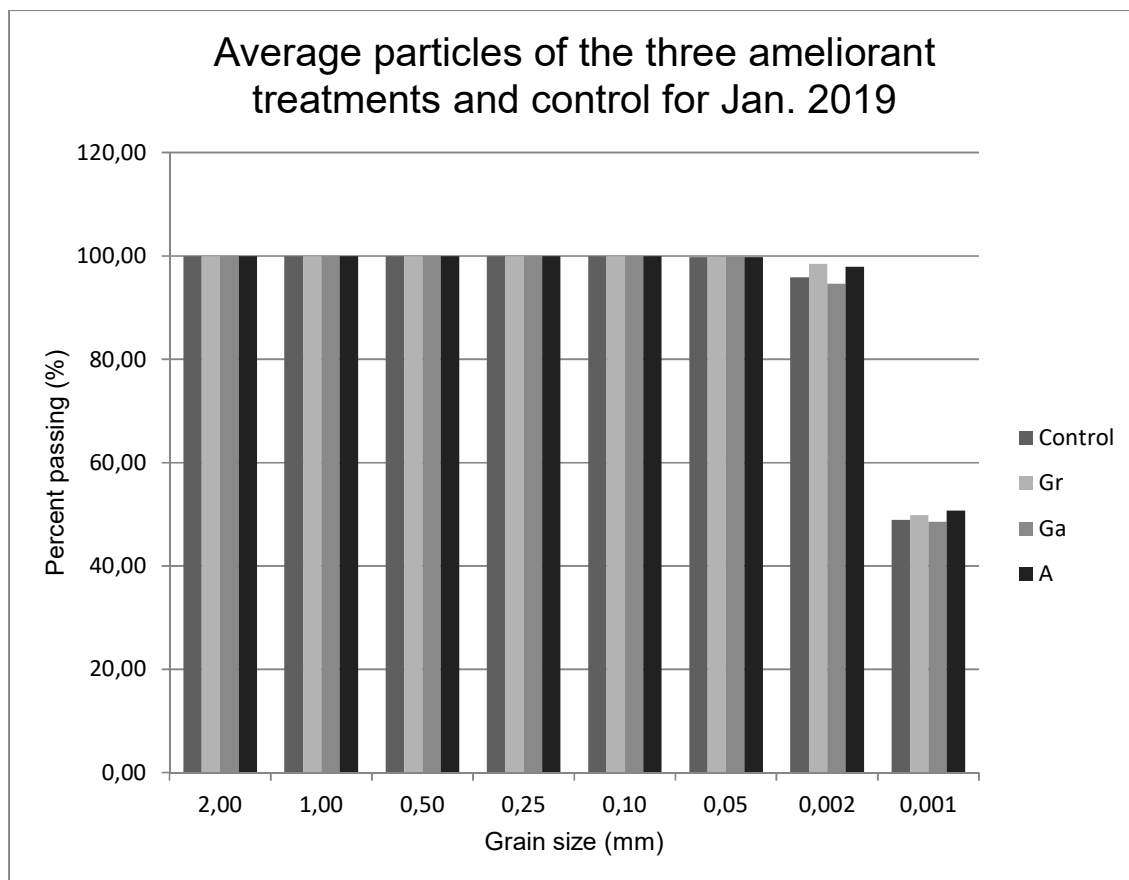


Figure 4-12: The particle size distribution of the growth medium for the three ameliorants and control (C = Control, Gr = Granite, Ga= Gabbro and A = Andesite) for Jan. 2019.

Figure 4-13 illustrates the particle size distribution of all the treatments for Apr. 2019. The three ameliorant treatments (Gr, Ga and A) had indicate more slit- (0.002 mm) and clay size particles (0.001 mm). This could be explained by the weathering of the growth medium as the ameliorants have a higher surface area than the growth medium of the control. The gabbro and andesite ameliorant treatments (Ga and A) indicated the most slit- and clay size particles. The control and granite ameliorant treatment had indicated more clay size particles than slit size particles compared to gabbro and andesite ameliorant treatments (Figure 4-13).

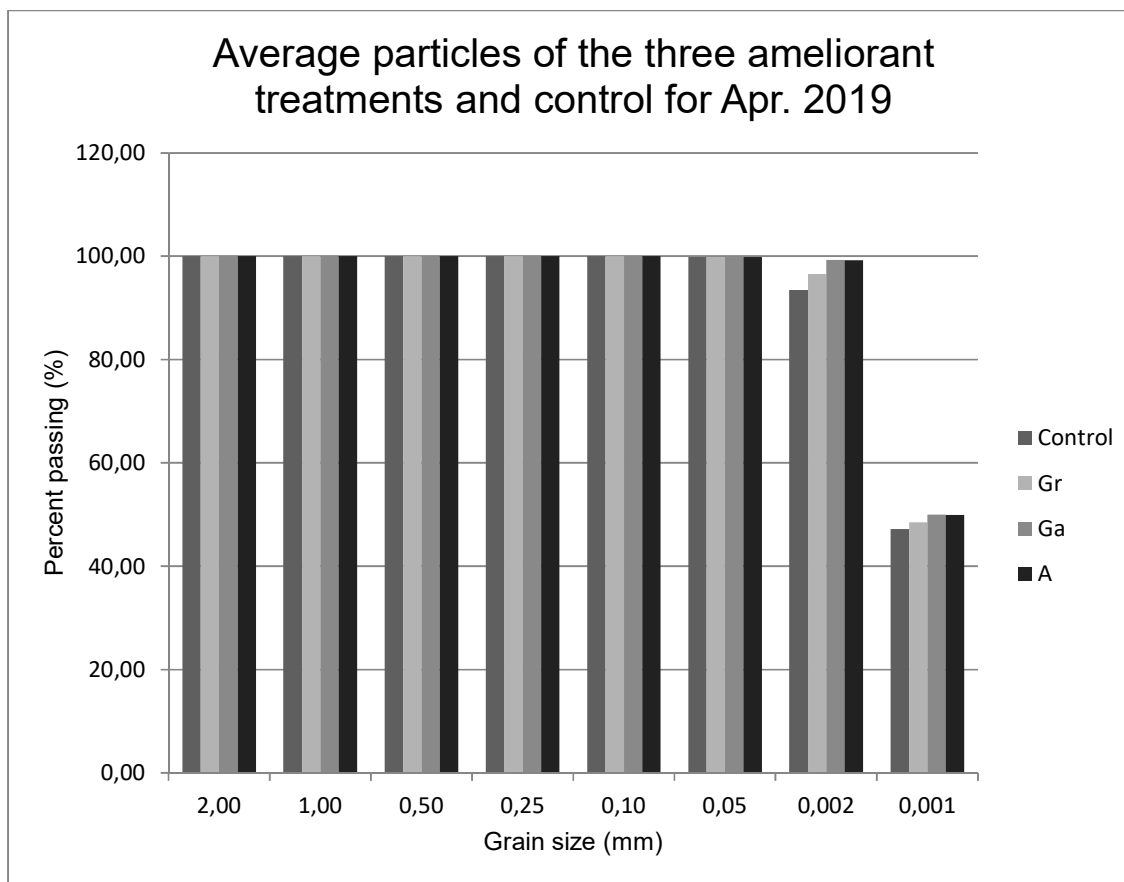


Figure 4-13: The particle size distribution of the growth medium for the three ameliorants and control (C = Control, Gr = Granite, Ga= Gabbro and A = Andesite) for Apr. 2019.

Summary

To conclude this section, the three ameliorants that were added to the growth medium had increased the silt- and clay size particles of the growth medium (Figure 4-11, Figure 4-12, Figure 4-13). However, the rate at which weathering had occurred the control had indicated similar results to the three ameliorant treatments, especially, from Sept. 2018 to Jan. 2019 with the 0.002 mm and 0.001 mm size particles. The growth medium of all the treatments (control, granite, gabbro and andesite) was classified as having a “well-sorted texture” for the sampled collected in Sept. 2018 (Table 4-4). “Well sorted” can be described as a soil that has an abundance of similar particle sizes (Brady & Weil, 2008:151). In Apr. 2019, the growth medium shifted towards “well graded”, which refers to a growth medium consisting of an abundance of different particle sizes (Table 4-4). This mainly means that weathering occurred with the three types of ameliorants (granite, gabbro and andesite) from Sept. 2018 to Apr. 2019, resulting in the bigger particles becoming smaller as time passed. This can be seen on the particle size distribution graphs of Sept. 2019, Jan. 2019 and Apr. 2019, i.e. the slope at 0.075 mm became more gradual as time passed (Figure 4-11, Figure 4-12, Figure 4-13).

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Table 4-4: The coefficient of uniformity and gradation of the texture of the growth mediums for Sept. 2018, Jan. 2019 and Apr. 2019 for all treatments (control, Gr – Granite, Ga – Gabbro, A – Andesite). Light grey = well-graded, medium grey = medium graded and dark grey = poorly graded.

Treatments	Sept. 2018		Jan. 2019		Apr. 2019	
	Coefficient of uniformity	Coefficient of gradation	Coefficient of uniformity	Coefficient of gradation	Coefficient of uniformity	Coefficient of gradation
Control	3,647657489	2,018759202	5,666255784	3,267675324	8,776174568	4,984665323
Gr1	4,525854813	1,921012693	6,116680803	3,278863617	8,330779406	4,052197064
Ga1	4,494112392	1,964554656	8,460101139	4,49933011	9,700465275	2,528609714
A1	2,577628877	1,247665809	6,218220013	3,520857639	7,204181647	3,913554917
Gr2	1,998419765	0,795117189	6,153065689	3,491092273	10,09051455	4,598453941
Ga2	4,083526012	1,607305508	8,26257067	4,336856027	8,933149258	3,982033389
A2	2,058201679	0,749278811	5,833381934	3,201107403	5,697324762	3,361549284
Gr3	3,055212176	1,375272238	5,549996613	2,678350411	5,021716061	2,840438442
Ga3	3,152652768	1,516990695	5,446972147	2,964770533	6,334363932	3,515141525
A3	4,473552045	1,931627218	5,251923309	2,871152171	4,902298548	2,880824503

A repeated measures ANOVA with the treatments and time periods as the factors was carried out to determine if there was a significant difference between the soil samples collected in Sept. 2018, Jan. 2019 and Apr. 2019 regarding the texture of the growth medium. The results revealed that there was a significant difference ($F(2,12) = 20.801, p < 0.0001$) for the change the texture undergo for the three dates substrate samples were taken for all the fractions (Figure 4-14, Table 4-5). No significant difference ($F(6,12) = 0.325, p < 0.9113$) existed between the three ameliorant treatments over the three sampled dates respectively (Annexures 6). As the abbreviated graphs add shown with the silt size particles.

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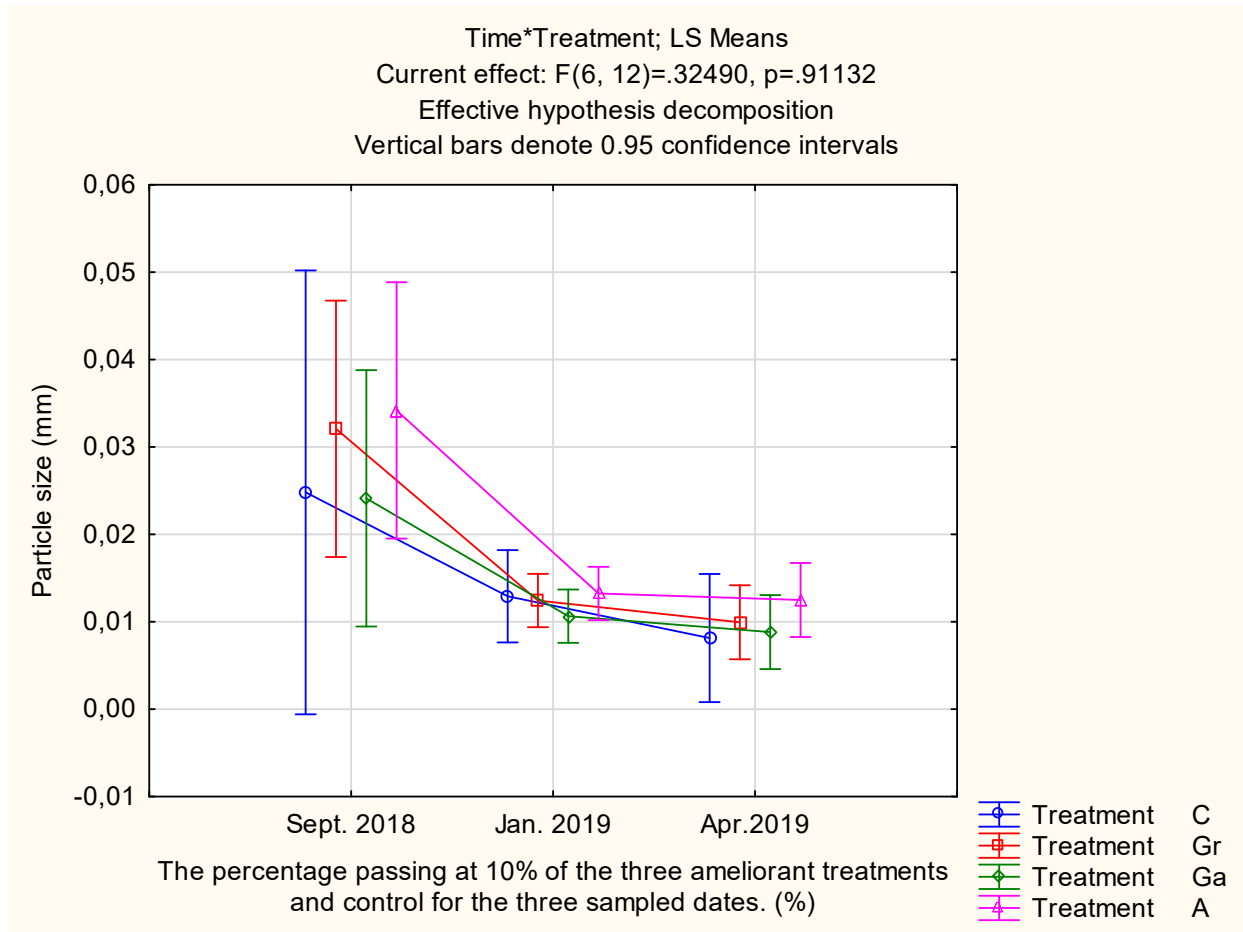


Figure 4-14: The particle size (mm) at D 10 (10% passing) of the three different treatments and control (C: Control, Gr: Granite, Ga: Gabbro and A: Andesite) (Sept. 2018, Jan. 2019 and Apr. 2019)

Table 4-5: The repeated measures ANOVA results of the texture of the growth mediums at 10% passing for the three different treatments and control (control, granite, gabbro, andesite) (Sept. 2018, Jan. 2019 and Apr. 2019).

Effect	Repeated Measures Analysis of Variance (Texture) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degrees of Freedom	MS	F	p
Intercept	0.006926	1	0.006926	174.3483	0.000012
Treatment	0.000152	3	0.000051	1.2760	0.364421
Error	0.000238	6	0.000040		
Time	0.001699	2	0.000849	20.8014	0.000126
Time*Treatment	0.000080	6	0.000013	0.3249	0.911315
Error	0.000490	12	0.000041		

4.1.5 Soil analyses

The substrate texture was influenced by the percentage of clay, slit, sand particles and the amount of colloids. The percentage of clay, slit and sand particles can differ but, will always add up to 100%. Therefore, the weathering of the ameliorants resulting in the percentage of slit and clay particles to change as seen in the previous section (4.1.4). As the percentage of clay and slit change the amount of plant nutrients that are bound by these particles and colloids (Loide, 2004:74; FSSA, 2007:3). This process occurs due to the fact that the rock flour weathers into smaller particles over time. The soil nutrient binding capacity is influenced by the soil texture (explained above) and illustrates the degree of difficulty for nutrients that are bound to be released in the soil solution for plant uptake (Loide, 2004:74; FSSA, 2007:3). One way to determine the amount of active colloidal material that is present in the soil is the exchangeable cation capacity (CEC). The substrate samples taken at the three dates indicated that, in general, the amount of CEC increased (Table 4-6, Table 4-7, Table 4-8, Figure 4-15 and Figure 4-16).

Table 4-6: The exchangeable cation ratios which include Ca:Mg, Mg:K and Ca+ Mg/K (cmol/kg) for the treatments and control (C- Control, Gr- Granite, Ga- Gabbro, A- Andesite) (Sept. 2018).

Sept 2018			
	Ca:Mg	Mg:K	Ca+Mg/K
Sample	(cmol(+)/kg)		
C	2,10	488,05	1514,38
Gr 1	2,27	144,38	472,61
Gr 2	2,99	5466,30	21831,19
Gr 3	5,79	284,39	1931,78
Ga 1	2,27	18,64	60,93
Ga 2	2,14	545,22	1713,43
Ga 3	5,30	500,50	3151,38
A 1	4,27	201,73	1062,55
A 2	3,90	445,62	2182,83
A 3	12,84	53,69	742,98

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Table 4-7: The exchangeable cation ratios which include Ca:Mg, Mg:K and Ca+ Mg/K (cmol/kg) for the three treatments and control (C- Control, Gr- Granite, Ga- Gabbro, A- Andesite) (Jan. 2019).

Jan. 2019			
	Ca:Mg	Mg:K	Ca+Mg/K
Sample	(cmol(+)/kg)		
C	5,48	46,91	304,17
Gr 1	5,80	29,55	200,84
Gr 2	9,30	39,66	408,52
Gr 3	4,33	38,70	206,08
Ga 1	8,59	32,83	314,79
Ga 2	5,13	47,73	292,65
Ga 3	8,27	73,01	676,55
A 1	7,86	28,58	253,17
A 2	11,10	16,62	201,07
A 3	19,30	21,44	435,22

Table 4-8: The exchangeable cation ratios which include Ca:Mg, Mg:K and Ca+ Mg/K (cmol/kg) of the three treatments and control (C- Control, Gr- Granite, Ga- Gabbro, A- Andesite) (Apr. 2019).

Apr. 2019			
	Ca:Mg	Mg:K	Ca+Mg/K
Sample	(cmol(+)/kg)		
C	5,42	14,63	93,95
Gr 1	3,87	16,19	78,81
Gr 2	4,24	28,89	151,35
Gr 3	5,51	17,81	116,03
Ga 1	26,14	16,07	436,08
Ga 2	4,87	25,22	147,96
Ga 3	11,84	25,59	328,42
A 1	4,06	24,18	122,30
A 2	8,60	19,55	187,75
A 3	14,12	27,37	413,89

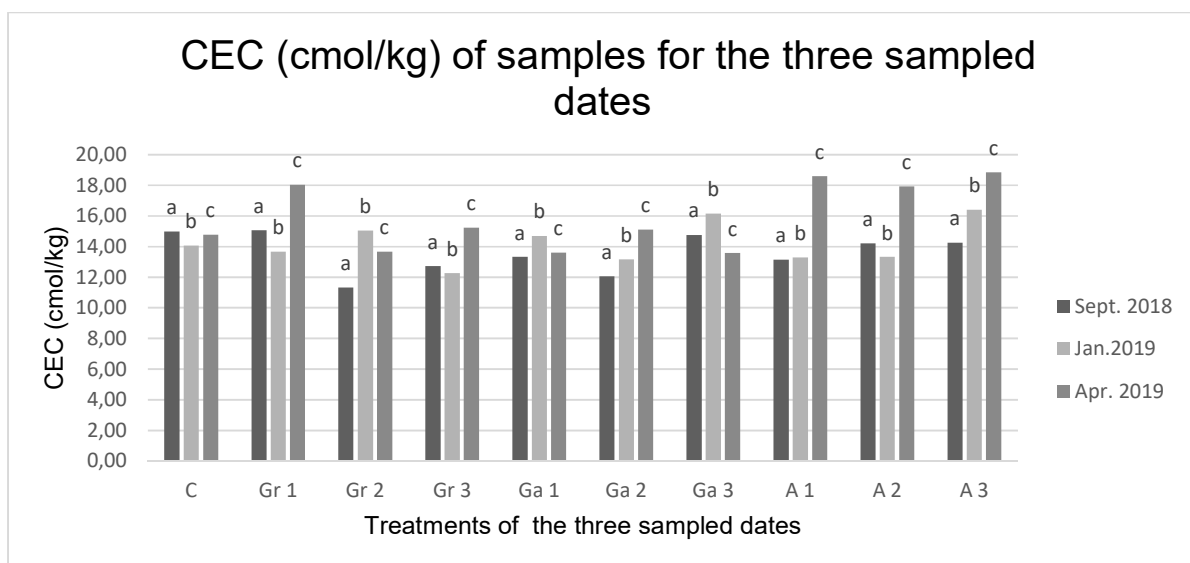


Figure 4-15: The CEC (cmol/kg) of the three sampled dates for all the treatments (Sept. 2018, Jan. 2019 and Apr. 2019).

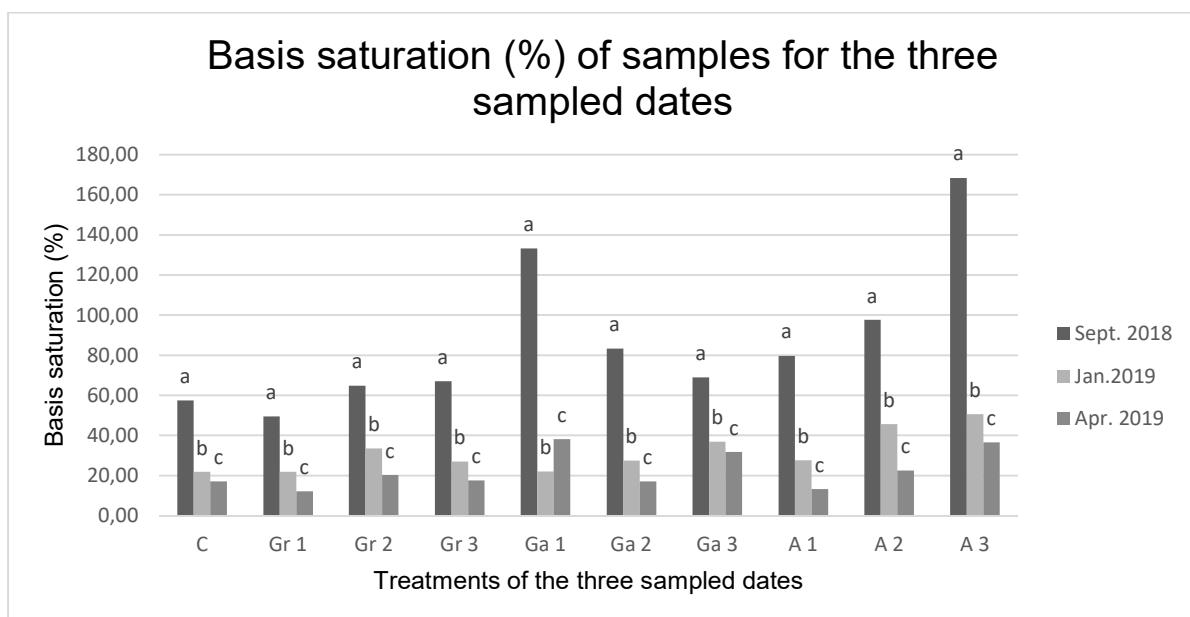


Figure 4-16: The base saturation (%) of the three sampled dates for all the treatments (Sept. 2018, Jan. 2019 and Apr. 2019).

Furthermore, the Ca:Mg ratio for the three sampled dates illustrated that the ratio had generally decreased, could be that *C. dactylon* absorbed some nutrients as needed for growth and development. The Ca:Mg and Mg:K ratios are affected by the physical properties of the soil and its clay minerals. Ca^{2+} and K^+ enhance the attraction between the clay particles, producing flocculation, which is the basis of stable aggregates (Vargas *et al.*, 2019:159-160; Hojjatnooghi

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et al., 2019:1995; Rengasamy *et al.*, 2016:660). On the contrary, in some cases the Mg^{2+} reduces the flocculation efficiency due to the small ionic radius with the large hydrated radius (Vargas *et al.*, 2019:160; Rengasamy *et al.*, 2016:660). The threshold of the Ca:Mg ratio ranges from 2:1 to 8:1 (average 5.6:1). Most of the ameliorant treatments were in the threshold over the three dates samples were taken. A value of 26.14 cmol/kg was recorded for Ga1 in Apr. 2019 and a value of 19.30 cmol/kg for A3 in Jan. 2019 due to an undissolved calcium particle (Table 4-7, Table 4-8).

As seen in section 4.1.4, the dominant texture of the growth medium was fine silt and clay particles. The threshold for the Mg:K ratio is on average about 3:1. The Mg: K ratio indicated that K was present at small concentrations in the growth medium. The Mg:K ratio also indicated that A3 was the only treatment for which the ratio that did not decline in the soil samples between Sept. 2018 and Apr. 2019 (Table 4-6, Table 4-7, Table 4-8). This indicated that there was a small amount of clay particles present in the growth medium despite the fact that the number of clay particles were increasing at a very slow rate.

In general the base saturation percentage (BSP) that gives an indication of the sum of the four basic cations (Ca, Mg, Na and K) relative to the CEC. The BSP is illustrated in Figure 4-15 and Figure 4-16 for the three sampled dates. The BSP indicated a dramatically decrease for the three sampled dates. This occurrence could be explained that as the pH had increased, more of the (base) elements become bioavailable. The strong leaching that were seen throughout the experiment is controlled by the particle size distribution, climatic and environmental conditions, in this case, the irrigation system the (base) elements each leached with a rapid rate out the bags. Therefore, even though the pH values increased over the three sampled dates the BS decreased. This is in correlation with the CEC that had rapidly decreased as well over the three sampled dates. As the CEC is measured by the base elements present in the soil. Therefore, the leaching observe had a significant effect.

To determine whether there were significant differences in the substrate analyses of the three treatments and the control (control, granite, gabbro and andesite), a repeated measures ANOVA was conducted with the respective element and time (Sept. 2018, Jan. 2019 and Apr. 2019) as the factors. There were no significant deference for Ca^{2+} content between the three ameliorants and the control for all three dates sampled taken place ($F_{(6,12)} = 1.647$, $p > 0.217$) (Figure 4-17). However, the Ca^{2+} content of all the samples differed significantly between the three sampling dates ($F_{(2,16)} = 19.444$, $p < 0.002$) (Figure 4-17, Table 4-9). This is because some of the Ca^{2+} could have been leached out and/or was absorbed by *C. dactylon*.

Significant difference for Mg^{2+} , Na^+ and P^{3+} contents between the ameliorants and control (C: control, Gr: granite, Ga: gabbro and A: andesite) for all three dates sampled were revealed

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(Annexure 10). However, no significant difference for the Mg^{2+} , Na^+ , P^{3+} and K^+ concentrations between the three ameliorants and control for the three dates sampled the Mg^{2+} , Na^+ , P^{3+} and K^+ concentrations (Annexure 10).

There were also a significant difference for the Ca^{2+} , Mg^{2+} , K^+ and Na^+ contents in the cation exchange capacity (CEC) and base saturation tests between the three ameliorant concentrations (C: control, Gr: granite, Ga: gabbro and A: andesite) but, there were no significant difference between Ca^{2+} , Mg^{2+} , K^+ and Na^+ contents for all three ameliorants and the control collected at the three sampling dates (Annexures 10).

The last group of soil analyses carried out included the saturated paste where the sulphate (SO_4^{2-}), nitrate (NO_3^-) and chloride (Cl^-) were tested. The results indicated that there was a significant difference in SO_4^{2-} and NO_3^- contents between the three ameliorant concentrations (e.g. Gr1 – Gr3) and that Cl^- differed significantly between the substrate samples collected at the three dates (Annexure 10). No significant differences were found for the Cl^- concentrations between the three ameliorants and control (C: control, Gr: granite, Ga: gabbro and A: andesite) (Annexure 10).

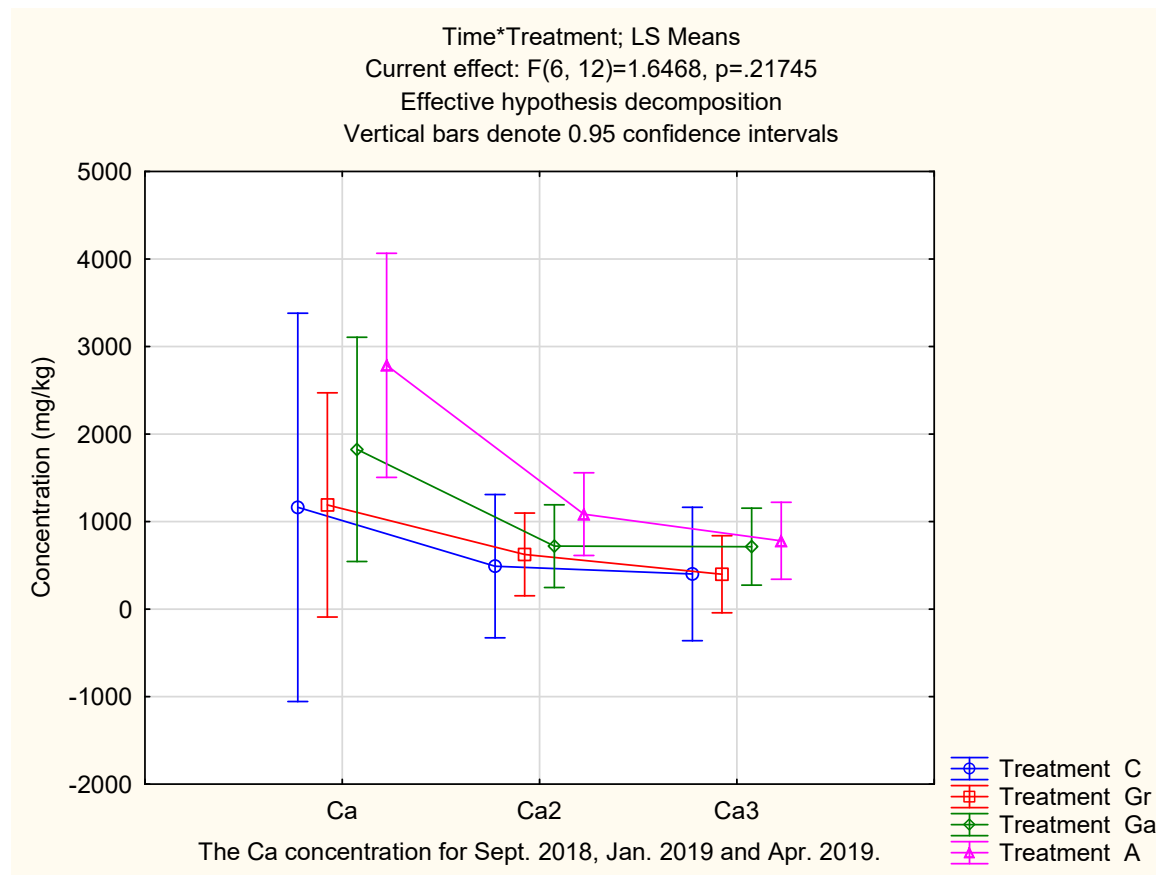


Figure 4-17: The repeated measures ANOVA for the concentration (mg/kg) of extractable calcium of the growth medium for the three treatments and control (Sept. 2018, Jan. 2019 and Apr. 2019).

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Table 4-9: The repeated measures ANOVA for the concentration of calcium in the cation exchangeable capacity (CEC) of the growth medium for the three treatment and control (Sept. 2018, Jan. 2019 and Apr. 2019).

Effect	Repeated Measures Analysis of Variance (Nutrient status) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degrees of Freedom	MS	F	p
Intercept	24715346	1	24715346	35.30630	0.001015
Treatment	3515611	3	1171870	1.67404	0.270416
Error	4200160	6	700027		
Time	6427875	2	3213937	19.44400	0.000172
Time*Treatment	1633185	6	272198	1.64677	0.217453
Error	1983504	12	165292		

4.2 Biological analyses

4.2.1 Germination rate of *C. dactylon*

Table 4-10: The germination rate of 600 *C. dactylon* seeds for the three concentrations of each of the three treatments (granite, gabbro and andesite) compared to the control for the 17-day pot trail.

Groups (60 seeds)	Germination rate (%) of <i>C. dactylon</i> seeds			
	Controls (60 seeds)	Granite (180 seeds)	Gabbro (180 seeds)	Andesite (180 seeds)
1 (0.5 kg)	1.66	0	10	1.66
2 (1 kg)		1.66	3.33	21.66
3 (2 kg)		1.66	18.33	21.66
Total (600 seeds) (%)	0.166	0.33	3.17	4.50

Table 4-11: The germination rate of *C. dactylon* in a 21-day trail, indicating the percentage (%) of normal-, abnormal- and dead seeds in the laboratory (adapted from AGT Foods Africa (Pty) Ltd). (Annexure 2)

Germination (% calculated by number)					
Duration of the test (days)	Normal seedlings	Hard seeds	Fresh seeds	Abnormal seedlings	Dead seeds
21	87	0	0	4	9

The results of the experiments carried out in the pot trail and laboratory to determine the germination rate of *C. dactylon* are shown in Table 4-10 and Table 4-11. The highest germination rate of *C. dactylon* seeds in the bags was 45 % out the 180 seeds for the andesite ameliorant treatments. The granite ameliorant treatments had the lowest germination rate of 0.33 % for the 600 seeds (Table 4-10). Furthermore, the granite ameliorant had the same germination potential than the control. The laboratory test conducted with the *C. dactylon* seeds indicated that out the 100 seeds used, some of the seeds were dead (9) or abnormal seeds (4) (Table 4.11). Besides the dead or abnormal seeds that could lower the germination rate of *C. dactylon* seeds in the field

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trail, environmental conditions could also had an effect. Some of the environmental factors could be the acidity (51% of the seeds germinated in limed substrate) of the tailing material, or the poor nutrient status of tailings, surface temperatures and toxic levels of heavy metals present in the gold TSF. The extremely acidic pH values prevent the essential nutrients to be available for the seedling when germinated (Figure 2-3). High surface temperatures dry out the surface of the growth medium and therefore, the seedlings did not have the necessary water for growth. The three concentrations of the granite ameliorant treatments (Gr1 – Gr3) were the least successful, which might be due to the fact that, even though granites have a buffering capability, it was not strong enough to make an acidity correction, which can be shown by the low pH values of all three concentrations of the granite ameliorant treatments (Gr1 – Gr3) (Section 4.1.1) (Weyer *et al.*, 2008:2889; Danhaus *et al.*, 2018:618; Silva *et al.*, 2005:995). The difference between the laboratory and field germination rate was 78, 83% (total % seeds) (Table 4-10 & Table 4-11).

During the 17 day trail not many seedlings germinated, however after approximately a month into the experimental phase the other seedlings germinated. This indicated the unfavourable environment the gold TSF was for the *C. dactylon* seed to germinated in, grow and develop.

The cumulative nature of the germination data, a dependency exists between results for each day of the 17-day monitoring trial. In other words, the number of seedlings accounted for on day 11 is dependent on the number of seedlings counted on day nine, because some of the seedlings counted on day 11 had already been counted on day nine. For this reason, the statistical model used was Repeated Measures ANOVA (a repeated measures analysis of variance), which takes the dependency of each variable into account.

T-tests were conducted to compare the samples that received lime against the samples without lime for the three ameliorant treatments and control (control, granite, gabbro and andesite). The analyses indicated that there was no significant t-value ($t_{(58)} = 0.588$, $p > 0.0559$) between the three ameliorant treatments and control (control, granite, gabbro and andesite) (Table 4-12). An examination of the means revealed that the samples that received lime ($M_1 = 5.345$) had more success with germination rates than the samples without lime ($M_0 = 3.871$) (Table 4-12). Furthermore, the three treatments and control (control, granite, gabbro and andesite) was individually tested and none of these treatments had a significant t-value. The t-values were as follows: control ($t_{(4)} = 1.00$, $p > 0.374$), Gr ($t_{(16)} = -0.593$, $p > 0.561$), Ga ($t_{(16)} = 0.242$, $p > 0.812$) and A ($t_{(16)} = 0.268$, $p > 0.792$) (Annexure 9). This mainly means that the lime had no significant influence on any of the three different treatments and control (control, granite, gabbro and andesite), and there were no significant differences within the treatments.

However, there was a significant difference ($p = 0.0188$) over the period at which germination was monitored for the three different treatments and control (C: control, Gr: granite, Ga: gabbro and

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A): andesite) (Figure 4-18). This indicated that the andesite ameliorant treatment performed the best and the gabbro ameliorant treatment is the second best ameliorant treatment. The control illustrated better germination rates than the three concentrations of the granite ameliorant treatment in the first few weeks (Figure 4-18). However, due to the harsh environmental conditions of the growth medium, the seedlings only survived a few days. The three concentrations of the granite ameliorant treatments gave the worst germination rate results and the seedlings germinated after the 17-day monitoring trail. The reason why A2 and A3 performed the best might be due to the calcite phenocrysts that helped increased the pH to a level where the seeds could germinate. The three concentrations of the granite ameliorant did not have such a buffer ability, whereas the gabbro ameliorant treatment had a better buffer capability than the granite ameliorant treatment (Figure 4-18). Figure 4-18 illustrate the average germination rate of all the seeds for all three ameliorant treatments and control, over the 17 day monitoring phase. The rest of the results are given in Annexures 9.

Table 4-12: The t-test of the field germination rate of all three treatments and control (control, granite, gabbro and andesite) in a17-day trail.

Variable	All Groups T-tests; Grouping: Lime (Germination rate) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Total	5.344828	3.870968	0.587676	58	0.559031	29	31	10.30699

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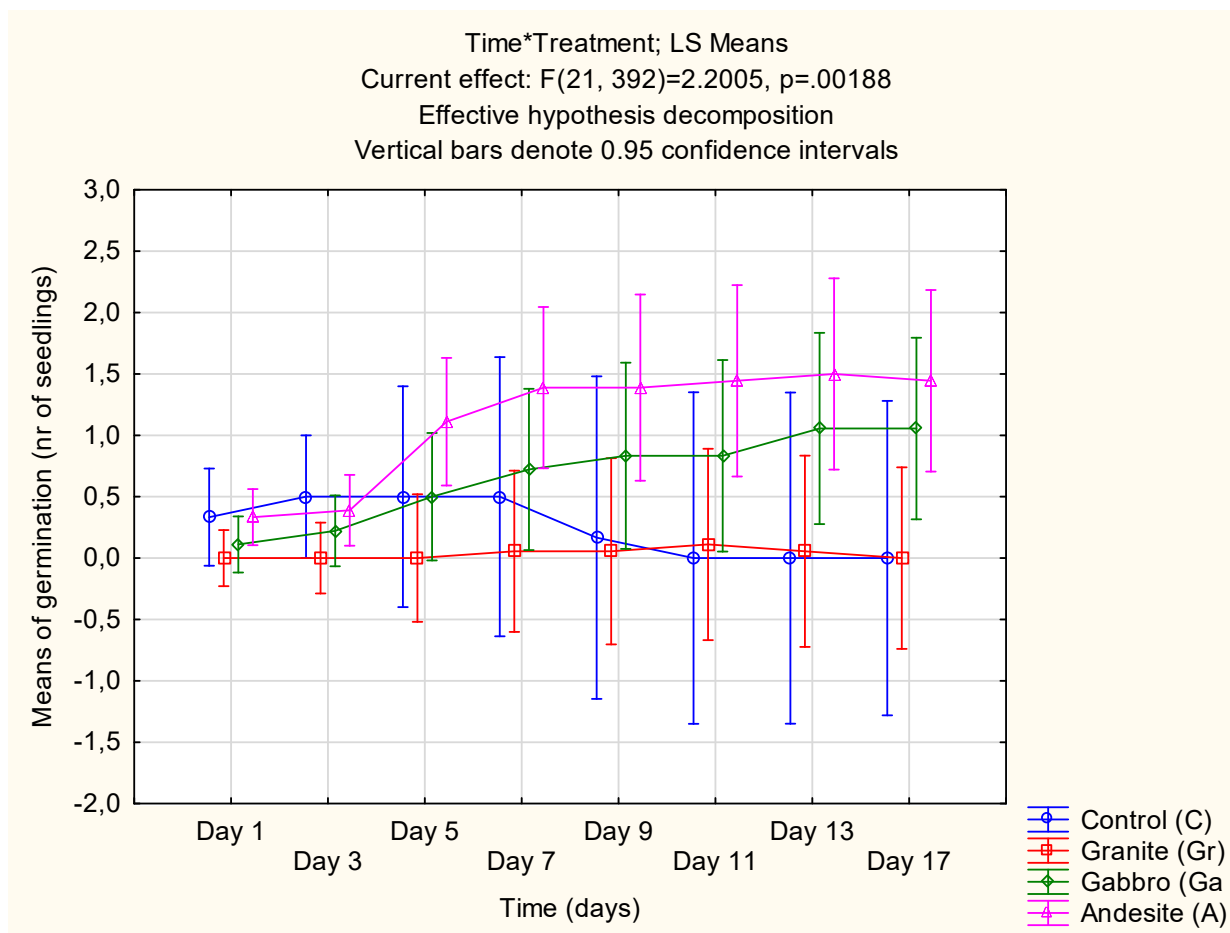


Figure 4-18: The pot trail average germination results of the three treatments and control (C: Control, Gr: Granite, Ga: Gabbro and A: Andesite) (17-day monitoring trial).

4.2.2 Growth rate (cm/week)

Even though, there were no germination in all the bags within the germination period test of 21 days. The seeds did germinated a while after the time for the test had expired. The growth rate of the plants results for the granite, gabbro and andesite ameliorants treatments and control (C, Gr1 – Gr3, Ga1 – Ga3, A1 – A3), were measured in centimetres (cm) from the floor next to the bags to the highest stretched leaves, were similar to the control). It was done by this method because the surface of the growth medium were not constant to take accurate measurements for a 25 week monitoring phase. The measurements of the growth rate were done from December 2018 until the end of April 2019.

With the knowledge that *C. dactylon* is classified as a creeping (stoloniferous) grass, therefore, the grass grow close to the ground and can form 'mats' in densely population areas, due to the stolons and rhizomes. The stolons were not measured, due to that *C. dactylon* produce stolons

when a certain height and/or certain phase in the life cycle had be reached. This life cycle is the adult phase. The growth of *C. dactylon* have declined at the end of the graphs, because the winter season were approaching. The monitoring phase had ended at the end of May 2019. Another reason was that the *C. dactylon* was starting to show signs of dying due to the temperature that was steadily declining. The temperature were not kept constant throughout the 25 weeks (Figure 4-25).

The granite ameliorant treatments without added lime had indicated in general lower growth rate potential than the control. However, the third concentration granite ameliorant treatment (Gr3) had illustrated higher growth rate potential than the control for the first four weeks only (Figure 4-19). This might be due to the buffer capability of granite rock to increase the pH values. On the other hand, the first and second concentrations granite ameliorant treatment (Gr1 & Gr2) had illustrated identical growth rate potential which compared to the control is lower growth potential. Therefore, the lower concentrations granite ameliorant did not had a significant effect on the growth rate of *C. dactylon* (Figure 4-19).

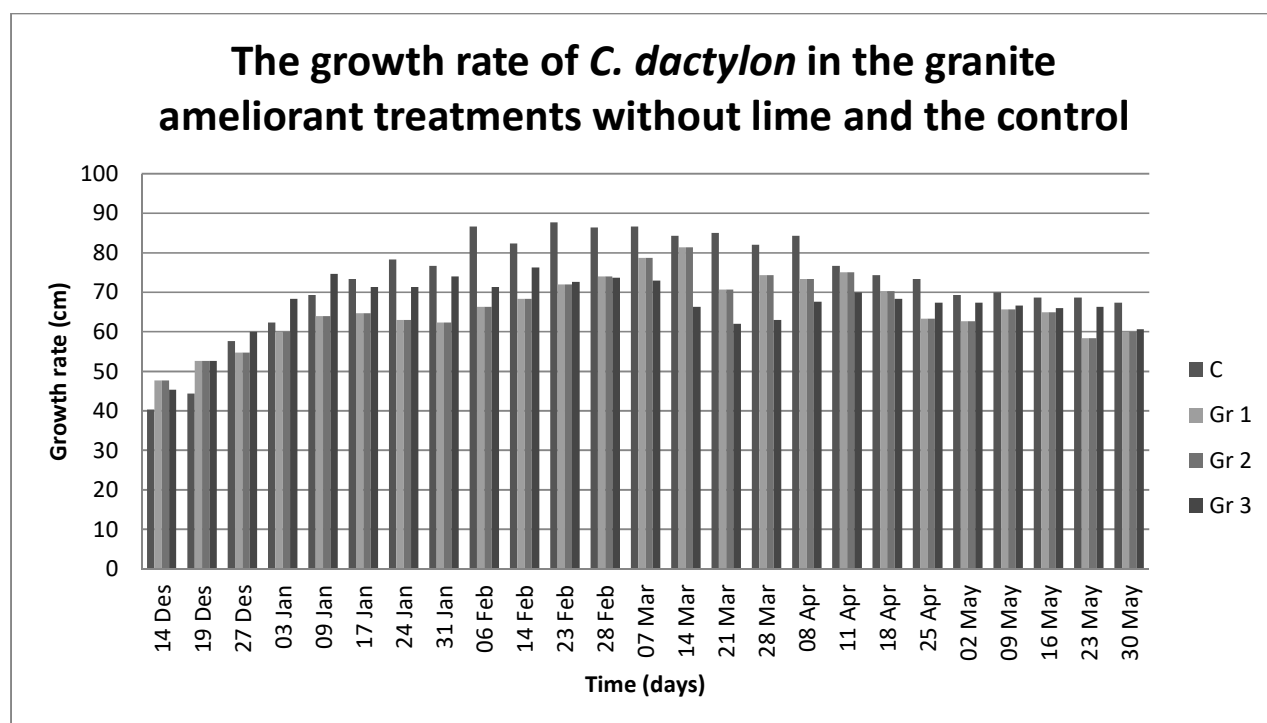


Figure 4-19: The growth rate (cm) of *C. dactylon* grown in the subgroup of the granite ameliorant treatment (Gr1 – Gr3) that did not receive lime during the monitoring phase and the control (Sept. 2018 – May 2019).

Some of the gabbro ameliorant treatments without added lime (Ga1 – Ga3) had illustrated lower growth rate potential compared to the granite ameliorant treatments for the 25 weeks (Figure 4-20). That said, Ga1 and Ga3 performed similarly to the control for the first few weeks. The three concentrations of gabbro ameliorant treatments (Ga1 – Ga3) had illustrated similar growth rate

potential to each other (Figure 4-20). This could be explained that gabbro ameliorant did not had the necessary capabilities to improve the unfavourable conditions the gold TSF had significantly above the conditions the control had. These conditions were like the buffer capability for the acidic pH or the saline environment that were present in the growth medium.

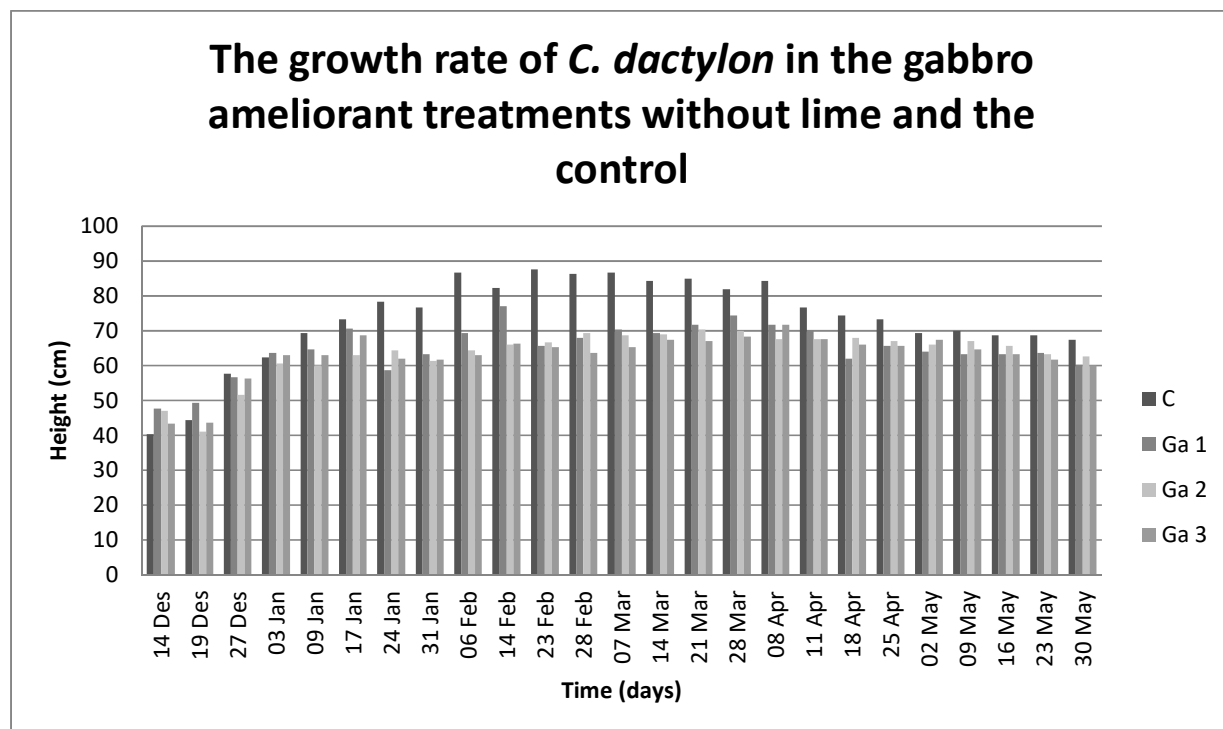


Figure 4-20: The growth rate (cm) of *C. dactylon* grown in the subgroup of the gabbro ameliorant treatment (Ga1 – Ga3) that did not receive lime and the control (Sept. 2018 – May 2019).

The andesite ameliorant treatments (A1 – A3) and the control without added lime are illustrated in Figure 4-21. The andesite ameliorant treatments had in general, indicated better growth rate potential than the control, especially in the first few weeks and in the last few weeks Figure 4-21). However, the second concentration of andesite ameliorant treatment (A2) illustrated the best growth rate potential especially during the first and last few weeks, whereas the third concentration and the control (A3 & C) indicated the better growth rate potential during the rest of the 25 weeks (Figure 4-21). The calcite phenocrysts that were determined to be part of the mineral composition of the andesite could improve the unfavourable conditions to more acceptable conditions for the growth of *C. dactylon* in the gold TSF.

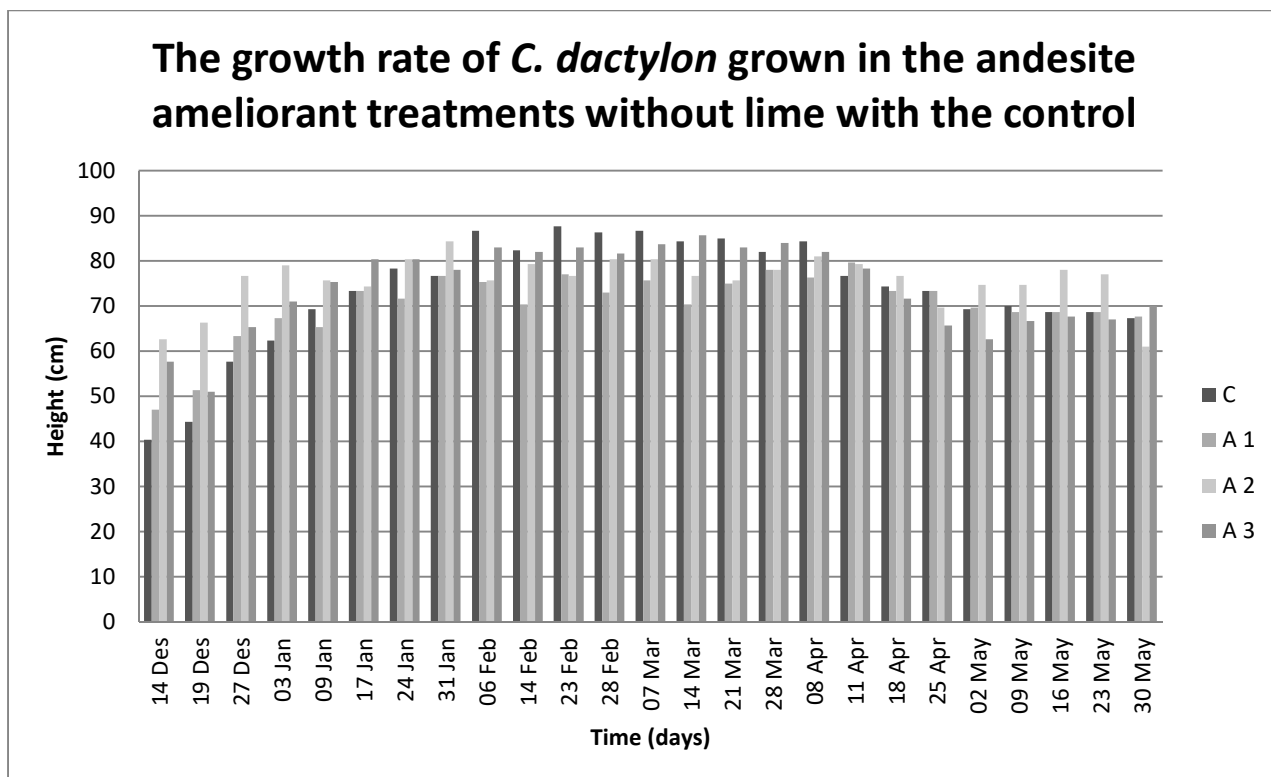


Figure 4-21: The growth rate (cm) of *C. dactylon* grown in the subgroup of the andesite ameliorant treatment (A1 – A3) that did not receive lime and control (Sept. 2018 – May 2019).

The granite ameliorant treatments that did received lime had indicated better growth rate potential, in general, than the control for the same period (Figure 4-22). However, the first concentration (Gr1) had illustrated the best growth potential rather than the third concentration (Gr3). The second and third concentrations granite ameliorant treatments (Gr2 & Gr3) had illustrated similar growth rate potentials compared to the control (Figure 4-22). This occurrence could be explained that the lime that were added with the granite ameliorant had improve the condition significantly.

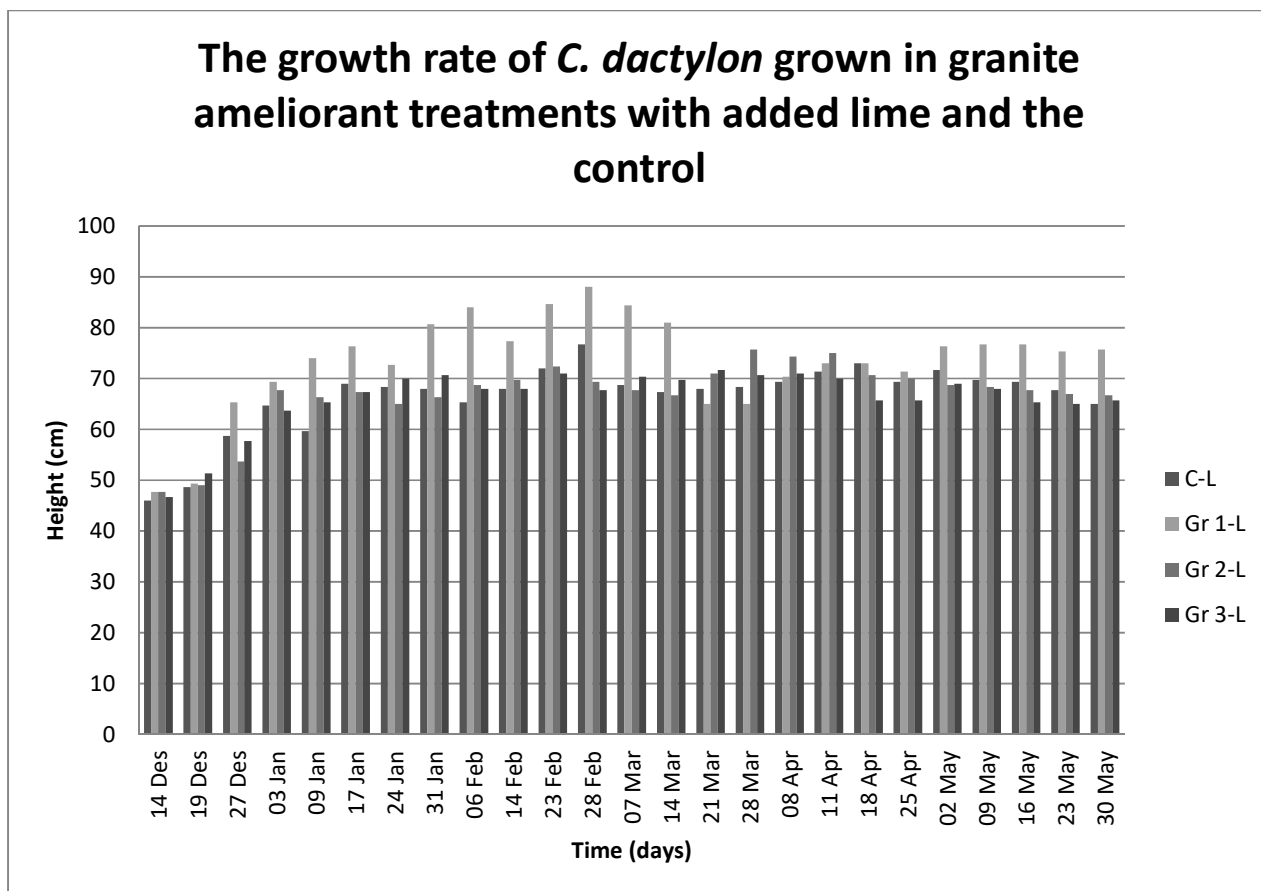


Figure 4-22: The growth rate (cm) of *C. dactylon* grown in granite ameliorant treatments with added lime (Gr1 – Gr3) and the control (Sept. 2018 – May 2019)

The gabbro ameliorant treatment samples that had received lime (Ga1 – Ga3) gave, in general, better growth rate potential than the control (Figure 4-23). It would seem that a calcium abundance were present in the second gabbro ameliorant treatments (Ga2) that drastically improve the growth rate potential besides the lime that were added to improve the harsh conditions. Therefore, Ga2 had indicated better growth rate potential than the third concentration gabbro ameliorant treatment (Ga3), which had the worst growth rate potential in the last few weeks (Figure 4-23).

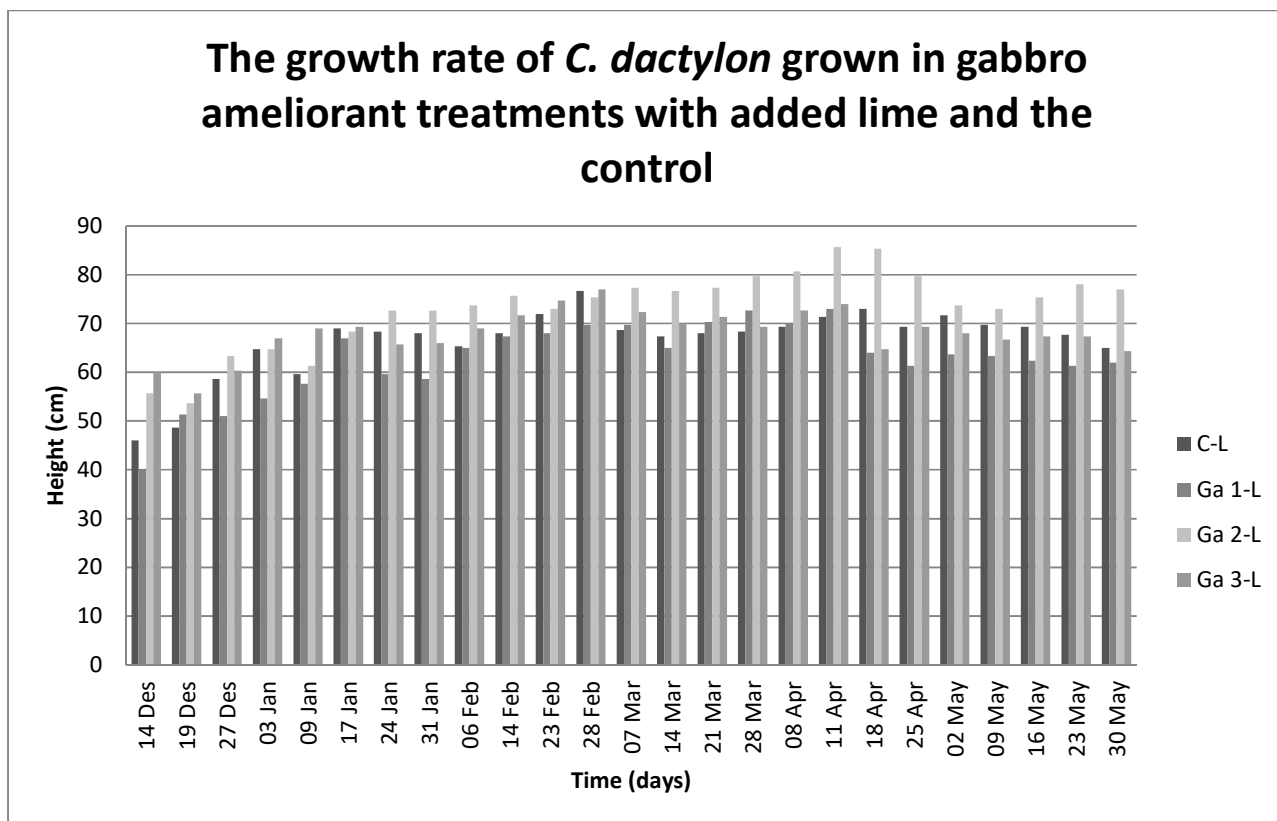


Figure 4-23: The growth rate (cm) of *C. dactylon* grown in gabbro ameliorant treatments with added lime (Ga1 - Ga3) and the control (Sept. 2018 – May 2019).

The andesite ameliorant treatment samples that had received lime (A1 – A3) illustrated somewhat better growth potential than the control for the 25 weeks (Figure 4-24). The third concentration andesite ameliorant treatment (A3) had indicated in general, the worst growth rate potential. The reason behind this could be that the lime that were added had masked the ability of the andesite ameliorant. As a result, the growth rate potential of the three concentrations (A1 – A3) had showed a mixture picture of the growth rate potential (Figure 4-24).

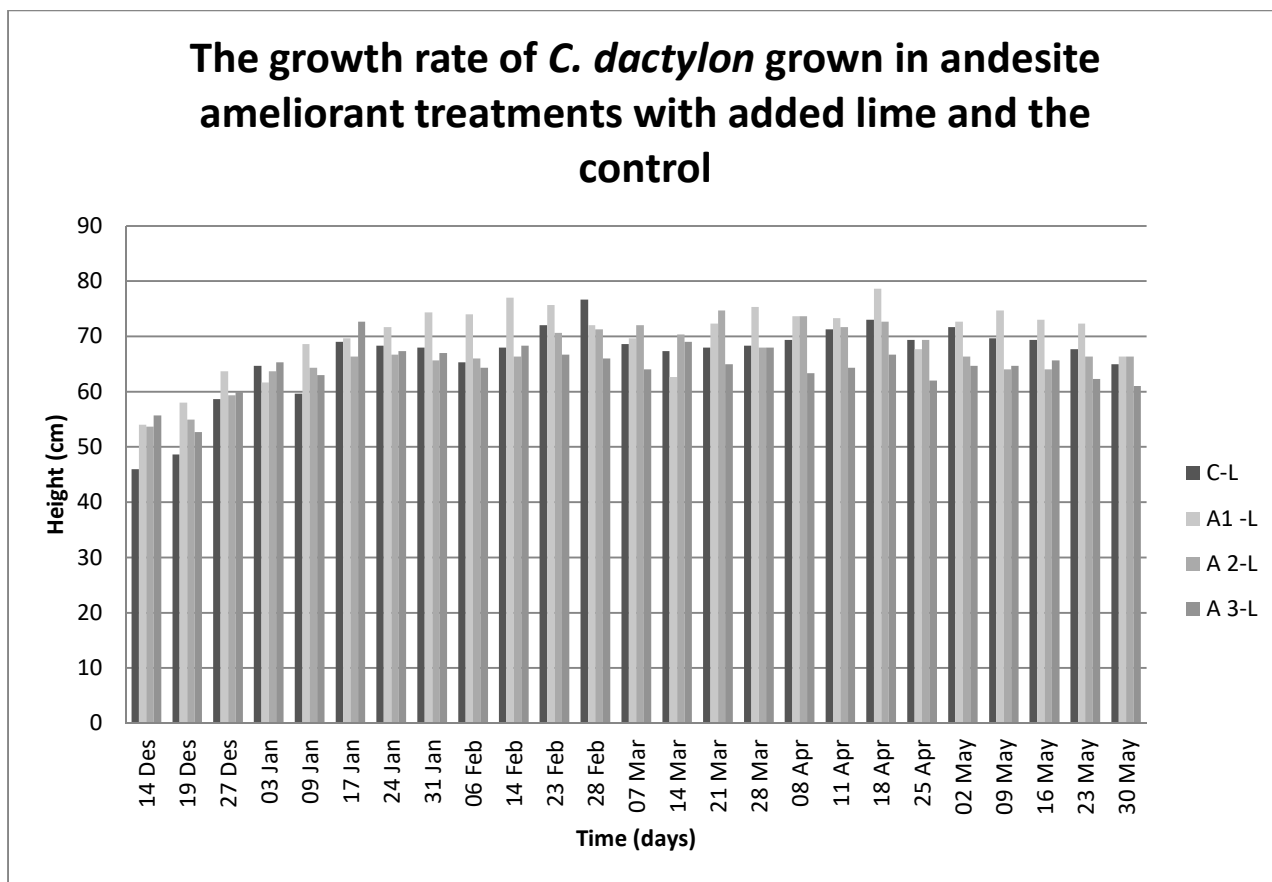


Figure 4-24: The growth rate (cm) of *C. dactylon* grown in andesite ameliorant treatments with added lime (A1–A3) and the control (Sept. 2018 – May 2019).

Summary

To summarize the growth rate of *C. dactylon* the lime that were added had affect the growth rate significantly for all three the ameliorant treatments (granite, gabbro and andesite). Granite ameliorant had illustrated that granite had a buffer capacity to improve the growth rate of *C. dactylon* high concentrations. The gabbro ameliorant did not illustrated the same ability as the granite ameliorant to improve the growth rate by buffer capacity. The andesite ameliorant without added lime was the only treatment that indicated better growth rate potential than the control. This could be contributed to the calcite phenocrysts that were determined to be part of the mineral composition of the andesite could improve the unfavourable conditions to more acceptable conditions for the growth of *C. dactylon* in the gold TSF.

To examine whether there was a difference in the height results of all the treatments (control, granite, gabbro and andesite) for the 25 weeks, a repeated measures ANOVA was conducted with lime and time as the factors. The results revealed that there was a significant difference ($F(24, 1392) = 1.612, p < 0.0310$) in the growth rate potential recorded during the 25 weeks, between

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samples with lime and the samples without lime for all the treatments (control, granite, gabbro and andesite) (Figure 4-25). Therefore, the lime had a positive effect on the growth potential in all the treatments. There was also a significant difference ($F(24, 1392) = 51.323, p < 0.0000$) in the height differences between the different treatments across the monitoring phase (Table 4-13).

When the three treatments and control (control, granite, gabbro and andesite) were individually tested for the effect of lime on the growth potential, the following results were revealed. The control was the only treatment that illustrated a significant difference ($F(24, 96) = 2.764, p > 0.000241$), whereas all three concentrations of the granite, gabbro and andesite ameliorant treatments showed no significant difference. However, all the treatments had a significant difference in the height recorded from Sept. 2018 until May 2019 (Annexure 9).

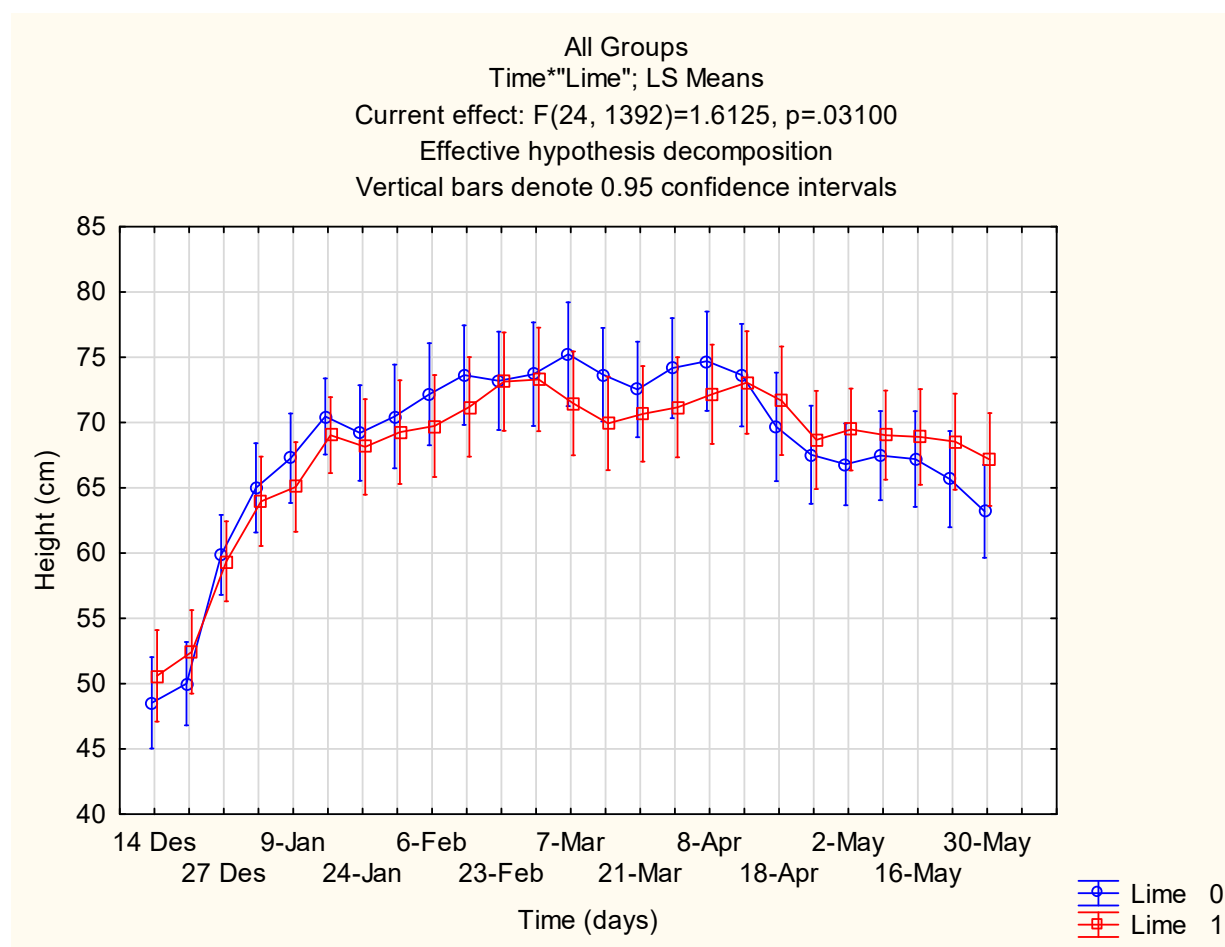


Figure 4-25: The growth rate (cm) of *C. dactylon* grown in the three treatments and the control (control, granite, gabbro and andesite) (Sept. 2018 until May 2019).

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Table 4-13: The repeated measures ANOVA of the growth rate of *C. dactylon* for all three the treatments and control (control, granite, gabbro and andesite) (Sept. 2018 until May 2019).

Effect	All Groups Repeated Measures Analysis of Variance (Height) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degrees of Freedom	MS	F	p
Intercept	6944571	1	6944571	5065.428	0.000000
Lime	37	1	37	0.027	0.870401
Error	79516	58	1371		
Time	57088	24	2379	51.323	0.000000
Time*"Lime"	1794	24	75	1.612	0.030999
Error	64515	1392	46		

4.2.3 Chlorophyll fluorescence

The chlorophyll fluorescence results were inconclusive and therefore only an indication can be drawn from these results. This is because only a fraction of all the Bermuda grass from the three treatments and control (control, granite, gabbro and andesite) was still able to undergo photosynthesis at the normal level at the end of May 2019. Some of the reasons why this occurred might be that the grass started to experience winter dormancy or even stress resulting in the reduced activity earlier than expected.

4.2.4 Biomass

The average above-ground biomass produced by all the treatments through the experimental phase (Sept. 2018 to May 2019), ranged from 25 g to 49 g (Figure 4-26). The control treatment that received lime had produced less above-ground biomass than the control treatment that did not received lime. The granite ameliorant treatments (Gr1 – Gr3) had only the first concentration (Gr1) illustrated more above-ground biomass as the control for the lime treatments. All the other treatments had illustrated less above-ground biomass than the control (lime and non-lime). As for the gabbro ameliorant treatments (Ga1 – Ga3), the first concentration treatment with lime (Ga1) and second concentration without lime (Ga2) had produced less above-ground biomass as the control for the respective treatments. The andesite ameliorant treatments (A1 – A3) had only the first concentration treatment with lime (A1) indicated less above-ground biomass as the control (Figure 4-26). All the other treatments with(out) lime had indicated more above-ground biomass as the control. Therefore, the andesite ameliorant had produced the most above-ground biomass. Furthermore, the lime treatments of the three ameliorants had indicated (granite = -6.88%, gabbro = 15.22% and andesite = 4.35%) average above-ground biomass compared to the average above-ground biomass production of the control with added lime, whereas, the non-lime treatments had indicated (granite = -18.21, gabbro = 18.56% and

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andesite = 25.43%) compared the respective control. Therefore, the gabbro ameliorant produced the most above-ground biomass for the lime treatments and the andesite ameliorant produced the most above-ground biomass for the treatments without lime.

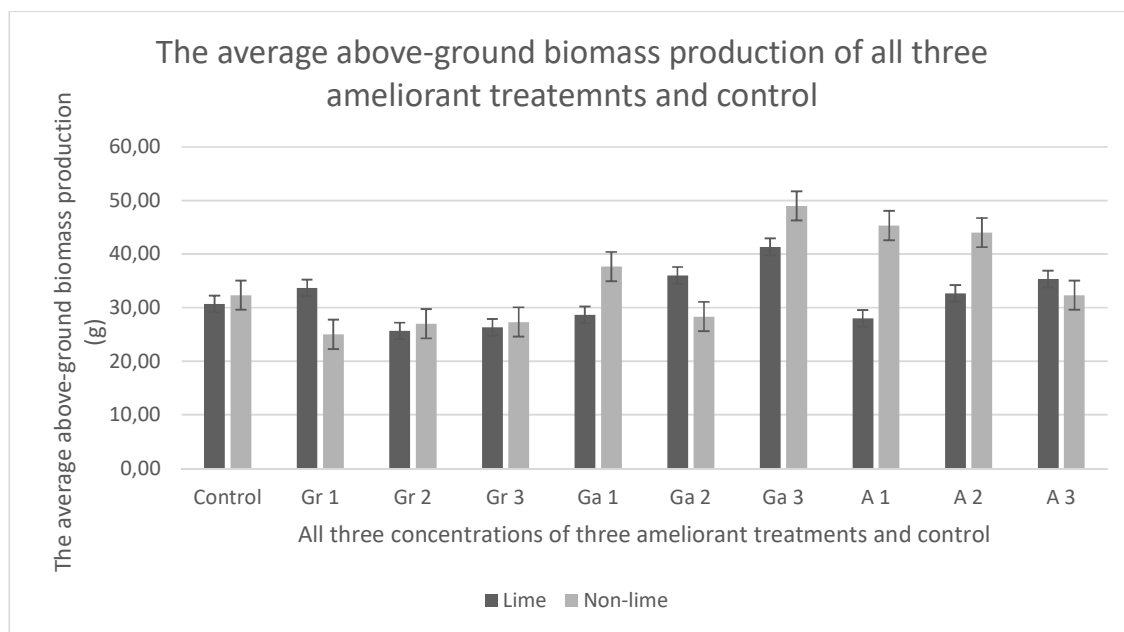


Figure 4-26: The above-ground biomass (g/bag) of *C. dactylon* for the three ameliorant treatments and control (Gr - Granite, Ga - Gabbro, A - Andesite) (Sept. 2018 – May 2019).

To determine whether there was a significant difference between the three ameliorant treatments and the control (control, granite, gabbro and andesite), a repeated measures ANOVA was conducted with the average above-ground biomass production and ameliorant treatments as the factors. The results revealed that there was a significant difference ($F_{(3,56)} = 3.434$, $p < 0.023$) for the biomass production produced from the three ameliorants and the control when the concentrations of each ameliorant were lumped together (Figure 4-27, Table 4-14). When the three ameliorants treatments and the control were compared against the control and each other (the three concentrations of each treatment) there were no significant difference ($F_{(9,50)} = 2.017$, $p > 0.567$) between the three ameliorant treatments and the control, i.e. Gr1 vs Ga3, Ga3 vs A3 etc. (Annexure 10). From a statistical view the three ameliorant treatments and the control did not improve the above-ground biomass production.

Furthermore, t-tests were conducted to compare the biomass production of the three treatments and control (control, granite, gabbro and andesite) to determine whether the lime made any significant difference to the biomass production (Table 4-15). The results indicated that the lime did not have a significant effect on the biomass production in any of the three concentrations of

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the three ameliorant treatments and the control (control, granite, gabbro and andesite) (Annexure 11).

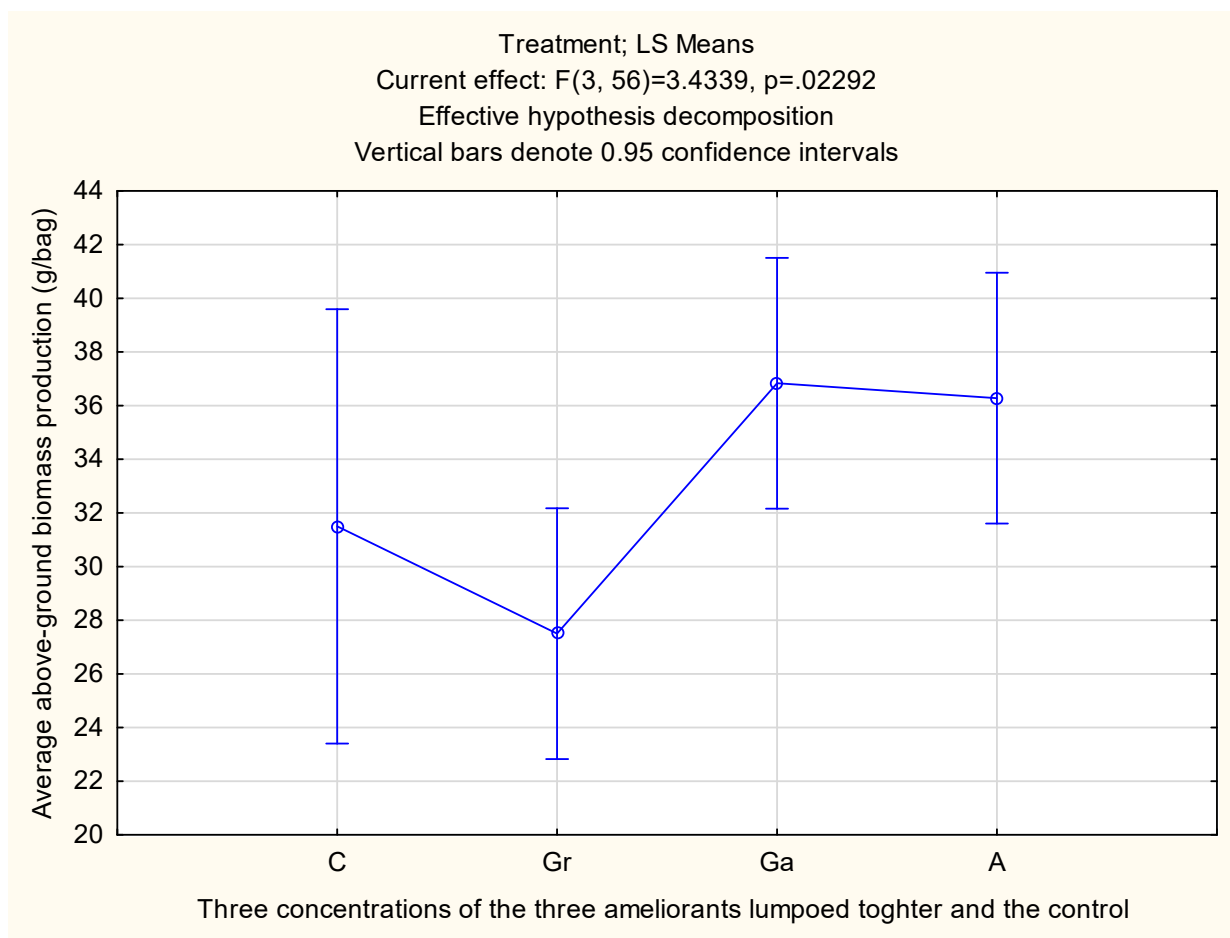


Figure 4-27: The *C. dactylon* average above-ground biomass production (g/bag) of the three different treatments and control (C: Control, Gr: Granite, Ga: Gabbro, A: Andesite) at the end of the project.

Table 4-14: The repeated measures ANOVA results of the biomass of the three different treatments and control (control, granite, gabbro and andesite).

Effect	Univariate Tests of Significance for Biomass only (Biomass) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degrees of Freedom	MS	F	p
Intercept	52360.04	1	52360.04	534.4700	0.000000
Treatment	1009.22	3	336.41	3.4339	0.022920
Error	5486.11	56	97.97		

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Table 4-15: The T-test of the biomass production of *C. dactylon* for the three different treatments and control (control, granite, gabbro and andesite).

Variable	All Groups T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Biomass only	31.89655	34.67742	-1.02638	58	0.308976	29	31	8.636901

4.3 Germination, growth rate and biomass comparison

To summaries the germination, growth rate potential and the biomass production tests, the ameliorant treatments that illustrated the highest germination rate were similar to those treatments that showed exceptional growth rate potential in the growth rate until adulthood and the biomass production tests (Table 4-16). The germination rate, growth rate and biomass production tests were compared to each other for the growth cycle of *C. dactylon* over the course of the experimental phase (Table 4-16). These treatment that indicated the most success across the three tests. The four ameliorant treatments that did well in the germination rate test were similar to the ameliorant treatments that indicated the most success in the growth rate potential test until *C. dactylon* reached adulthood. Those four ameliorant treatments that did well in the growth rate potential were same four ameliorant treatments in the above-ground biomass production test (Ga3, A2, A1, A3), but in a different order (Table 4-16). Besides, the germination rate of the first concentration andesite ameliorant treatment (A1), the andesite ameliorant treatments (A1 – A3) and the third concentration gabbro ameliorant treatment (Ga3) gave the best overall results for the three tests.

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Table 4-16: The comparison between the germination rates, height and biomass production of *C. dactylon* for the three treatments and control (C: Control, Gr: Granite, Ga: Gabbro, A: Andesite) (1: first concentration, 2: second concentration, 3: third concentration).

	Groups	Germination (seeds)
1	A3	13
2	A2	13
3	Ga3	11
4	Ga1	6
5	Ga2	2
6	A1	1
6	Gr3	1
6	C	1
6	Gr2	1
7	Gr1	0

	Groups	Growth rate potential (cm)
1	A2	62
2	A3	57
3	A1	56
4	Ga3	53
5	Gr3	52
5	Ga2	52
5	Gr1	52
6	Gr2	51
7	Ga1	49
7	C	49

	Groups	Biomass (g/bag)
1	Ga3	45
2	A2	38
3	A1	37
4	A3	34
5	Ga1	33
6	Ga2	32
6	C	32
7	Gr1	29
8	Gr3	27
9	Gr2	26

CHAPTER 5

CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

The main aim of the study was to determine whether granite, gabbro and andesite could be used as ameliorants in order to improve the growth potential of *C. dactylon* used in the rehabilitation of gold tailings. The secondary aim was to determine the effectiveness of each type of rock flour to serve as an ameliorant for the rehabilitation of gold mine tailings. The hypothesis was that these rock flours can be used as ameliorants to improve the properties of the tailings storage facilities as a growth medium, and as a base to improve the sustainability, establishment, and cover of the vegetation during the rehabilitation process. In order to reach the aims, the following tests were carried out. The basic soil parameters were determined, which included the monitoring of pH, electrical conductivity (EC), linear shrinkage, and texture, as well as the soil nutrient availability prior to, during, and after trials. The elements that were tested in this study included Ca^{2+} , N^+ , Mg^{2+} , K^+ , Cl^- , K^+ , SO_4^{2-} and NO_3^- . In addition, the germination potential of *C. dactylon* seed on gold tailings material as a growth medium was determined.

In order to reach these objectives, the following methods materials were implemented. Granite, gabbro and andesite were crushed into smaller particles, after which they were sieved through a 2 mm and 425 μm sieves. The process was repeated until enough rock flours were produced from the granite, gabbro and andesite. Afterwards, the rock flours were mixed with the gold tailing material, fertilizer and lime (30 bags only) and placed into 54 bags. Six bags were only filled with material from the gold TSF which served as control. The *C. dactylon* seeds were sown into the bags and a germination rate test conducted over a 17-day trial period. Substrate samples were collected prior, during and after the experimental phase for multiple tests that included the pH, EC, linear shrinkage and texture. Substrate samples were also sent for detailed soil analyses the tests included CEC, anions (saturated extract) and the phosphor Bray-1-method. Other tests that were conducted were the above ground biomass production, growth rate potential and chlorophyll fluorescence

From the tests conducted the results indicated that granite, gabbro and andesite had shown to be promising to be used as ameliorants in the rehabilitation process of gold tailings storage facilities (TSF). Even though the results indicated of the pH and EC tests that leaching and the lime had a significant effect, which could have masked the effect of the three ameliorants. Of the three ameliorants the andesite were the best suited

5.1 Effectiveness of rock flours on basic soil parameters (Objective 1)

Besides the effect leaching had, the three ameliorants had illustrated to have a positive effect on the basic soil parameters, which was the pH, EC, linear shrinkage and texture. The pH values of the three ameliorants compared to the control indicated (granite = 3.71%, gabbro = 4.53% and andesite = 15.95%) improvement throughout the experimental phase. Therefore, the andesite had increased the pH values the most out the three ameliorants, to such a pH value that were near neutral condition from the start of the experiment, due to the calcite that are in the composition.

The EC values of the three ameliorants indicated (granite = 1.03%, gabbro = -22.52% and andesite = -17.56%) difference compared to the control EC values throughout the experimental phase. The granite ameliorant did indicated a positive value compared to the control, whereas, the gabbro and andesite indicated a negative effect to the EC values. The granite ameliorant indicated the slight positive effect due to the grinding of the rocks and the leaching of the elements out of the bags, as well as the buffer capacity of granite.

The linear shrinkage results of the three ameliorant treatments had illustrated (granite = 26.45%, gabbro = 30.66% and andesite = 145.36%) difference compared to the control. The gabbro ameliorant treatment decreased the linear shrinkage of the growth medium the most. This can be attributed that the added inert material had enough time to weather down to secondary minerals, which do not produce shrinkage in the same extent than clay minerals. As gabbro consist out of pyroxene and plagioclase which do not have a strong resistance against weathering.

The texture results of the three ameliorants (granite, gabbro and andesite) had illustrated that the three ameliorants had significantly increase the medium to fine silt particle sizes. Therefore, the growth medium was classified as a "well-sorted texture" in Sept. 2018, when the first substrate samples were taken. The texture of the growth medium had change in Apr. 2019 as a "well graded" texture, when the last substrate samples were taken. This result can be contributed to the ameliorants that were added.

5.2 The germination rate of *C. dactylon* seed on gold tailings material as a growth medium (Objective 2)

The germination rate of the *C. dactylon* seeds of the three ameliorants had illustrated (granite = 0%, gabbro = 535.74% and andesite = 803.21%) compared to the amount of seeds that germinated in the control. Even thought that the quantity of seeds that germinated where of small amounts during the monitoring phase, some of the other seeds had germinated, but could have been hindered by the unfavourable environmental conditions of the growth medium. This stated

Chapter 5 Conclusion, Limitations and Recommendations

is further motivated by the amount of seeds that germinated under lab conditions, which was significant higher than the field trial. From the three ameliorants the andesite ameliorant treatments had the highest germination rate, therefore, the best suited, due to the calcite in the mineral composition.

The growth rate of *C. dactylon* had indicated that the lime had a significant effect on the growth rate potential. The granite ameliorant had illustrated to have a buffer capacity towards the salinity in the growth medium, whereas, the gabbro ameliorant did not seem to have that ability. Andesite ameliorant had illustrated to have better growth rate potential than the control, especially, with the treatments without added lime. This could be contributed to the calcite phenocrysts that are in the mineral composition.

Lastly, the above-ground biomass had illustrated that the lime that were added had a significant effect on the biomass production of the three ameliorants. The biomass production of the three ameliorants had illustrated the treatments with added lime (granite = - 6.88%, gabbro = 15.22% and andesite = 4.35%) production compared to the control. The treatments without added lime had illustrated (granite = -18.26%, gabbro = 18.56% and andesite = 25.43%) production compared to the control. Therefore, the gabbro ameliorant had the most biomass production of the three ameliorants, as a result, were better suited.

5.3 Soil nutrient availability (Objective 3)

The soil analyses that were conducted (four base elements (Ca^{2+} , Mg^{2+} , Na^+ and K^+) and CEC, revealed that the nutrient availability of the growth mediums declined from Sept. 2018 to Apr. 2019 for all three ameliorant treatments (granite, gabbro and andesite) and control . However, the ameliorant treatments in general, seems to withhold the nutrients and only release the quantity that are needed for the growth and development of *c. dactylon*. The Ca^{2+} , Mg^{2+} , Na^+ and K^+ was significant different for the three sampled dates. As for the CEC had significant differences for the three sampled dates. This can be attributed to the absorption of nutrients by *C. dactylon* and the leaching of the nutrients out the bags due to the irrigation.

5.4 Conclusion

In the light of the findings of this current study, it is clear that rocks could be used as rock flours in rehabilitation programmes to have a higher success rate and to decrease the footprint of mines, especially, gold mines. The rocks used in this study illustrated that there are promising results, the rock types included granite, gabbro and andesite. Out the three ameliorants, the andesite ameliorant had indicated to be the most suited ameliorant for gold TSF.

5.5 Limitations of this study and recommendations for future study

The limitation that stand out the most was the leaching of the elements out the bags, which was not measured. As it seems to have a significant effect on the study. The germination rate of *C. dactylon* seeds were of low success rate. Therefore, the tests need to be done again, however, the three ameliorant treatments have to be incorporated about three months before the seeds have to be planted. This should increase the germination rate significantly. Afterwards, the study could move on to a field trial.

5.6 Recommendations

Gold tailings are in general categorised as acidic and saline environments resulting in rehabilitation of these areas to be very difficult and challenging. This study determined that these unflavoured environmental conditions could be improved by adding rock flour to the tailing material. Of these rock flours, andesite and granite were investigated and proofed to have promising effects on the gold TSF and to consider leaching by irrigation.

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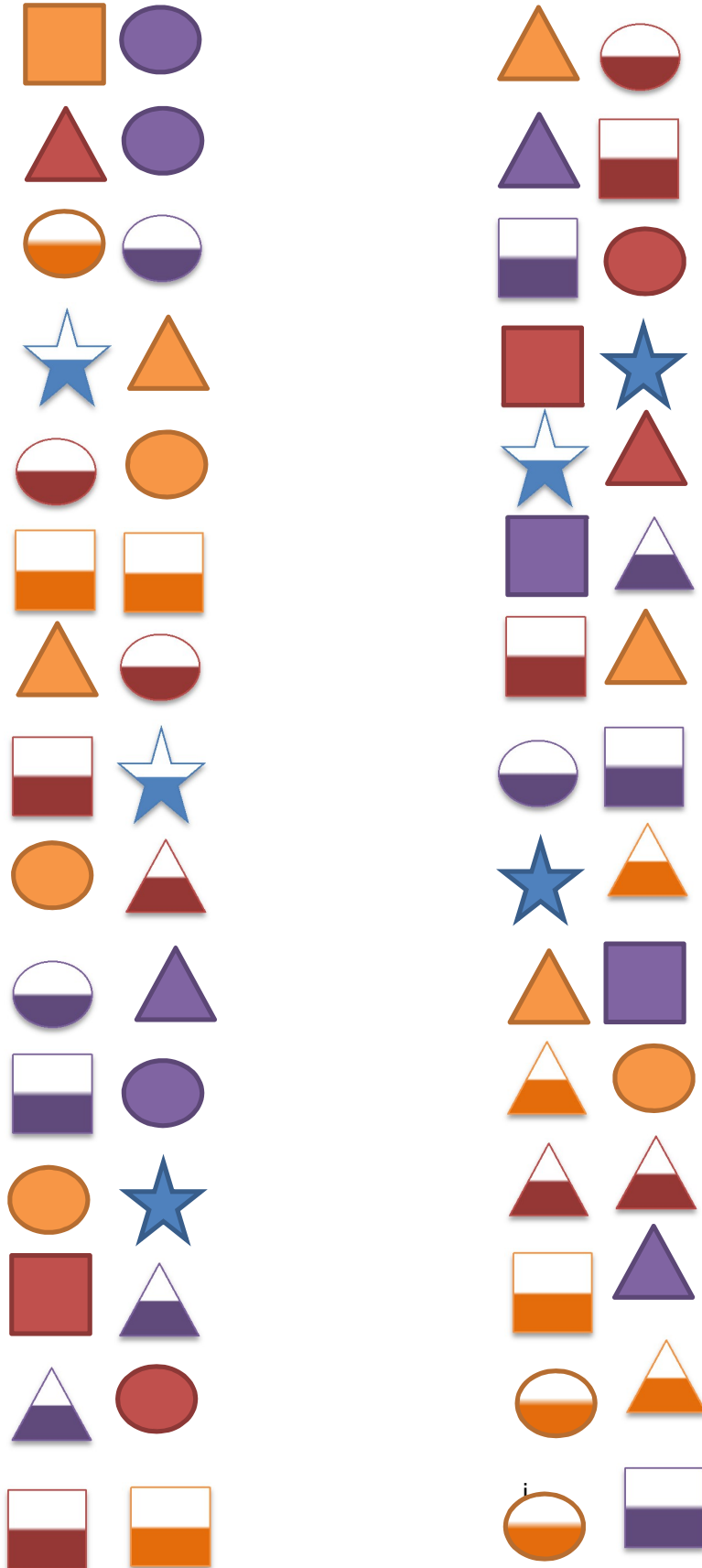
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ANNEXURES

Annexure 1: The experimental design of this study



The order of the 60 bags.

Blue = controls,

Red = Granite,

Purple = Gabbro and

Orange = Andesite.

The white with the colours indicate the bags with lime.

Square = 1st concentration,

Circle = 2nd concentration,

Triangle = 3rd concentration.

Annexures

Annexure 2: The germination test of *Cynodon dactylon* by AGT Foods

NORTH WEST UNIVERSITY
PRIVATE BAG X6001
POTCHEFSTROOM
2520

SEED TEST LABORATORY
AGT Foods Africa (Pty) Ltd
PO Box 414, Krugersdorp 1740
Tel: +2711-762 5281
Fax: +2711-762 4111

as registered with the National Department of
Agriculture's ISTA Accredited Seed Testing
Station in terms of the Plant Improvement Act,
1976 (Act 53 of 1976)
Reg. No. 1994/031259/67
DIV. Seed Control Reg. No. 68050001

ANALYSIS OF SEED SAMPLE

INFORMATION AS STATED BY SENDER:

Kind and Variety: Bermuda grass
Botanical Name: *Cynodon dactylon*
Date sample received: 2019-06-19
Weight of submitted sample (gram): 117.5 gram

Code Number: N.W.U
Reference Number: C3937
Test concluded: 2019-07-10

PHYSICAL PURITY (% Calculated by Mass)				GERMINATION (% Calculated by Number)					
Pure seed	Inert matter	Other seeds	Other material (Total of 2 and 3)	Duration of test (days)	Normal seedlings	Hard seeds	Fresh seeds	Abnormal seedlings	Dead seeds
1	2	3	4	5	6	7	8	9	10
X	X	X	X	21	-87-	-0-	-0-	-4-	-9-

Inert matter:
Other seed:

Germination method: TP; 20<=>30°C

Remarks: Only germination Test

SEED TEST LABORATORY
P.O. BOX 414
KRUGERSDORP 1740
REGISTRATION No. 09650082

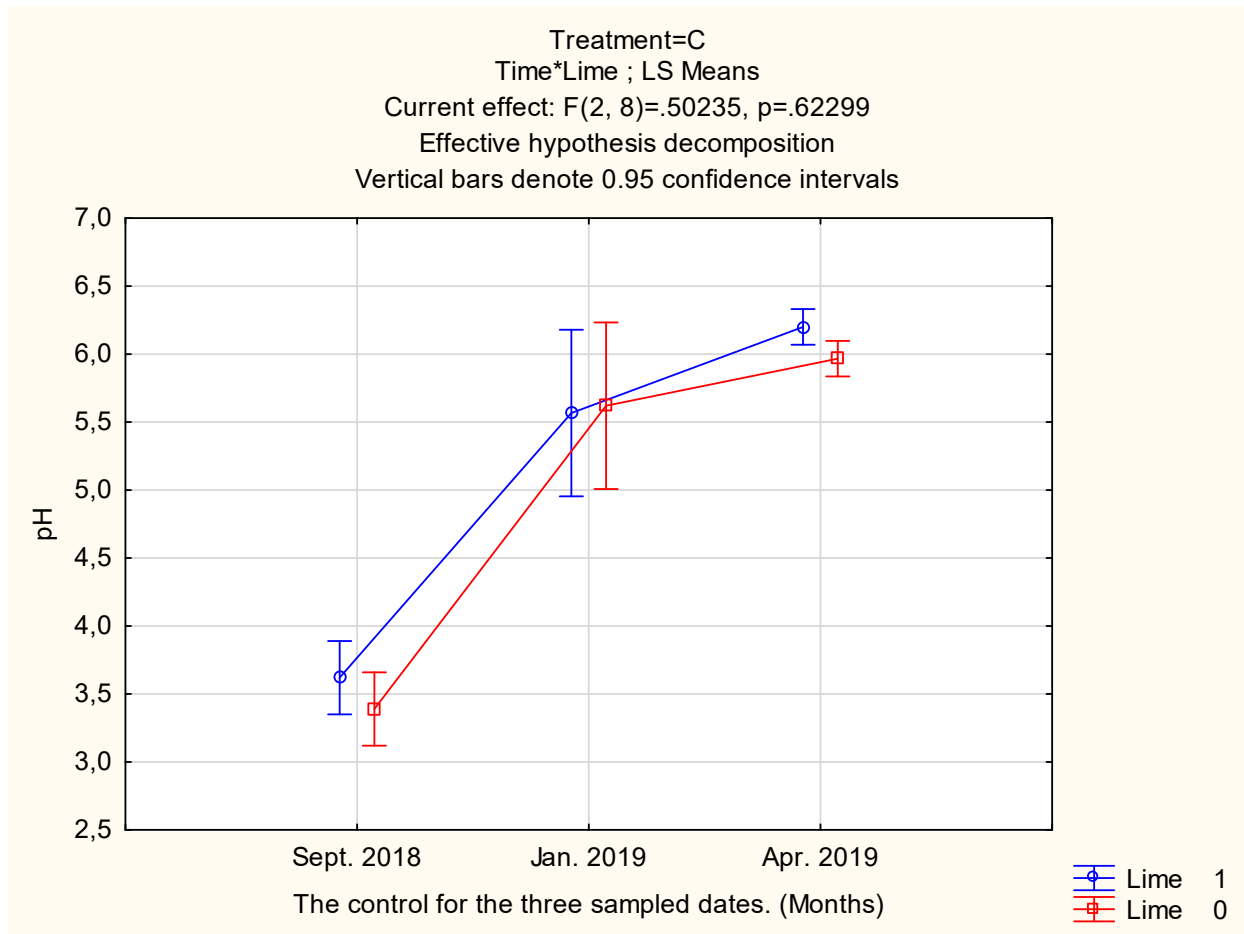
2019-07-10

SKG. *K. Smith*

Disclaimer: These results are applicable to the submitted sample and not necessarily to the seed lot, from which the sample was taken. The percentage seed indicated in column 1 may include seeds from other species, not visually distinguishable from the seed and indicated against the botanical name.

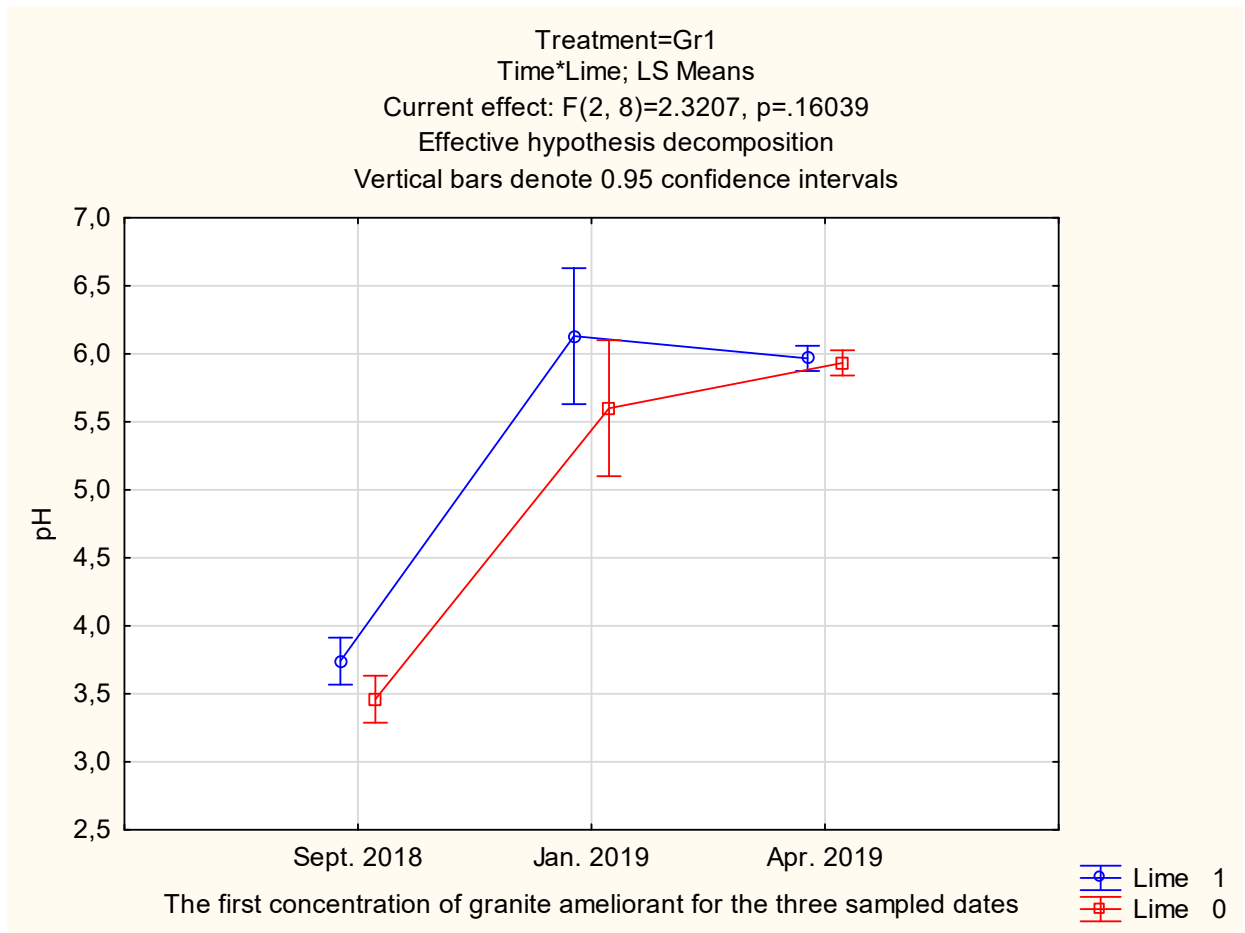
Annexures

Annexure 3: The statistical results of the pH results for all the treatments (control, granite, gabbro and andesite).



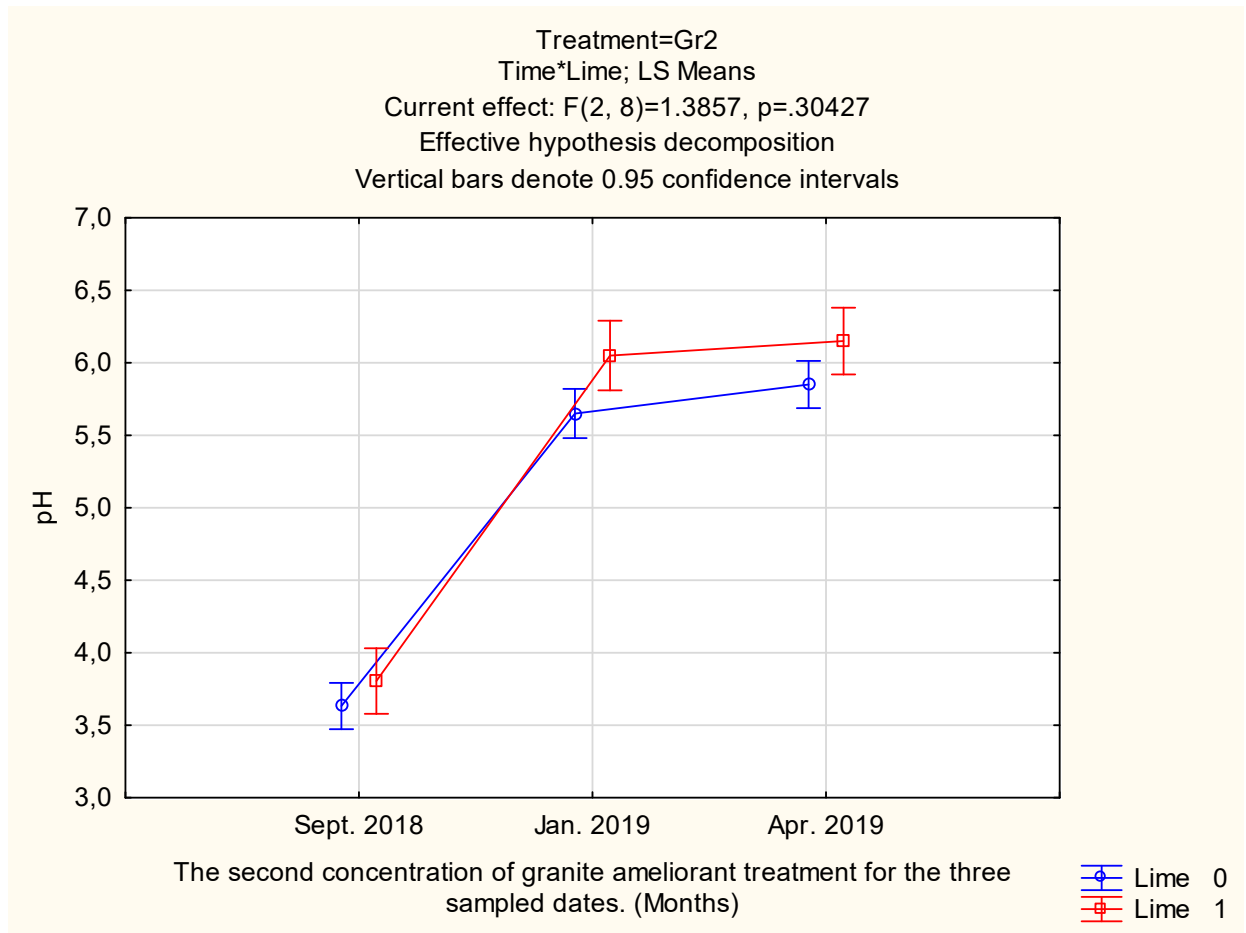
Effect	Treatment=C Repeated Measures Analysis of Variance (pH) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	460.9660	1	460.9660	23788.38	0.000000
Lime	0.0841	1	0.0841	4.34	0.105705
Error	0.0775	4	0.0194		
Time	22.4981	2	11.2490	139.13	0.000001
Time*Lime	0.0812	2	0.0406	0.50	0.622991
Error	0.6468	8	0.0809		

Annexures



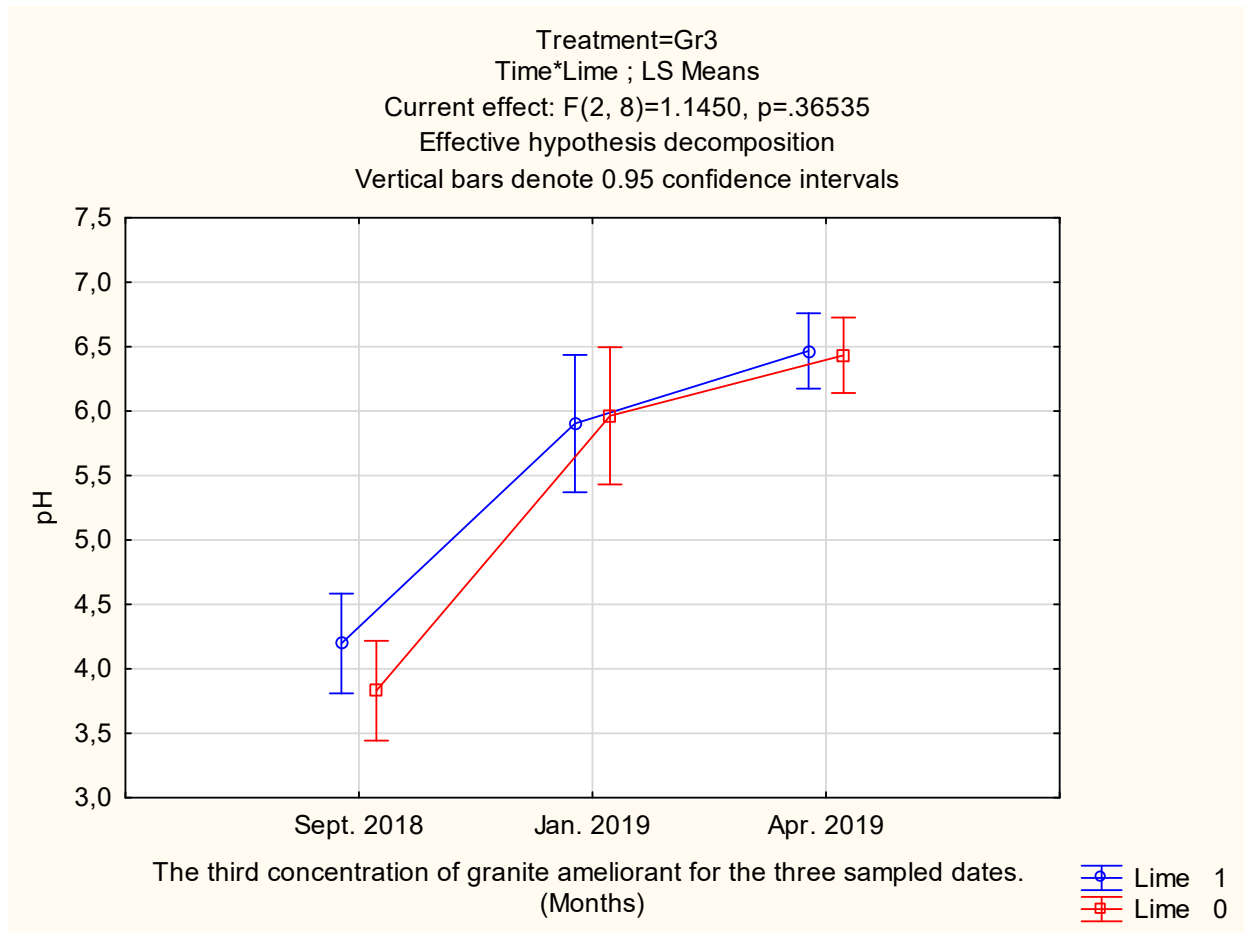
Effect	Treatment=Gr1 Repeated Measures Analysis of Variance (pH) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	475.2445	1	475.2445	14573.08	0.000000
Lime	0.3556	1	0.3556	10.90	0.029872
Error	0.1304	4	0.0326		
Time	21.3199	2	10.6599	267.43	0.000000
Time*Lime	0.1850	2	0.0925	2.32	0.160391
Error	0.3189	8	0.0399		

Annexures



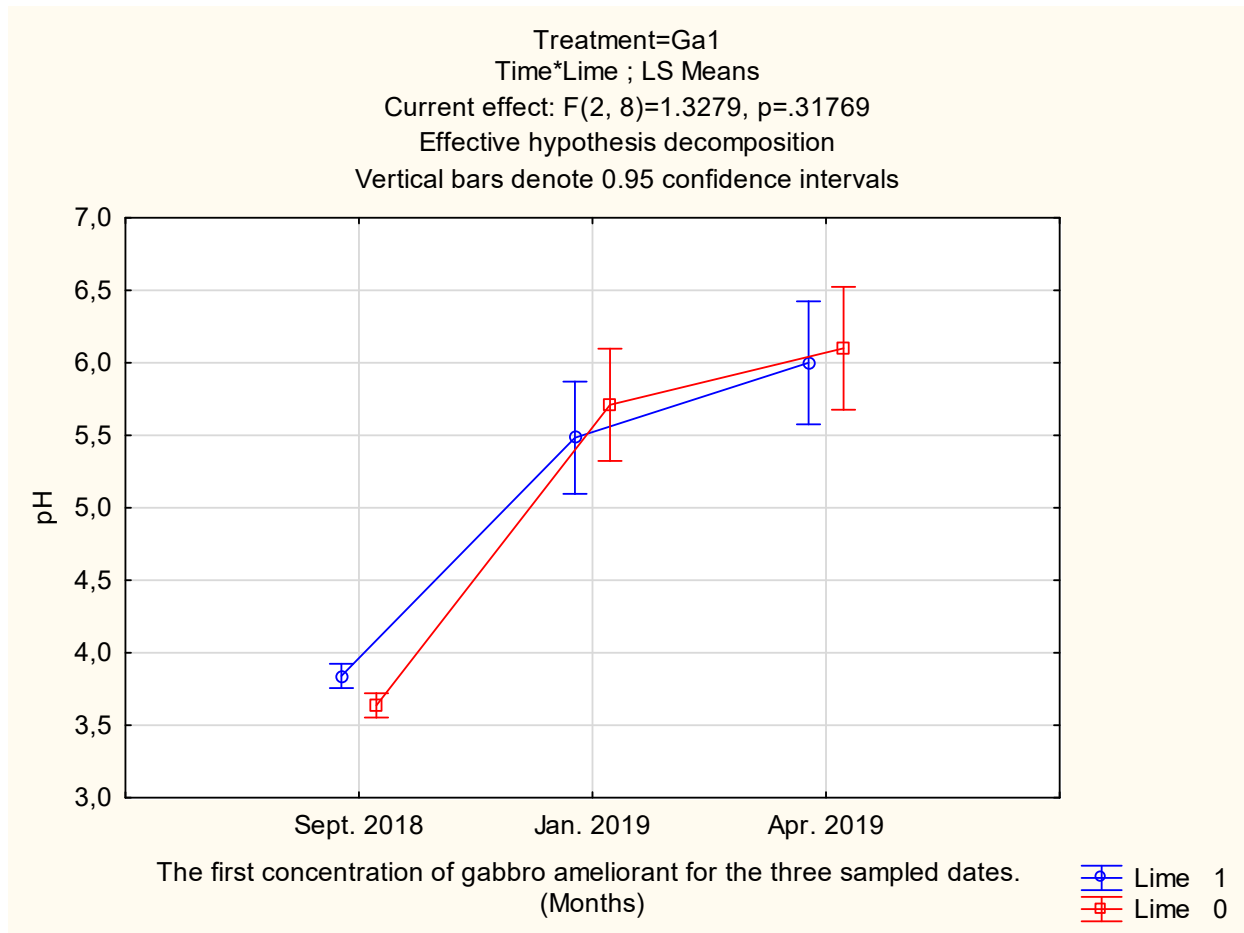
Effect	Treatment=Gr2 Repeated Measures Analysis of Variance (pH) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	430.9084	1	430.9084	25481.83	0.000000
Lime	0.3383	1	0.3383	20.01	0.011049
Error	0.0676	4	0.0169		
Time	17.3668	2	8.6834	694.09	0.000000
Time*Lime	0.0347	2	0.0173	1.39	0.304271
Error	0.1001	8	0.0125		

Annexures



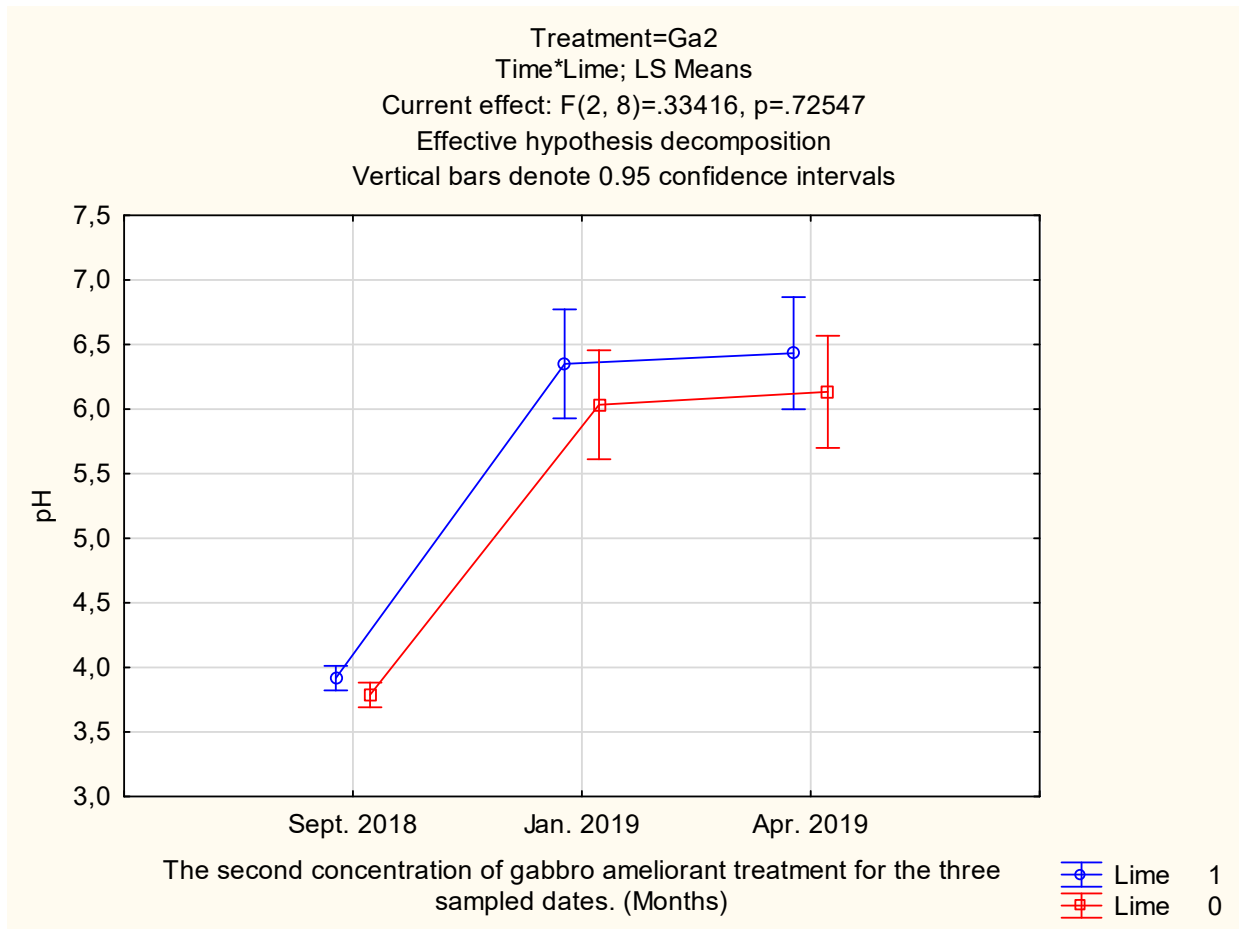
Effect	Treatment=Gr3 Repeated Measures Analysis of Variance (pH) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	537.7014	1	537.7014	7663.809	0.000000
Lime	0.0578	1	0.0578	0.824	0.415403
Error	0.2806	4	0.0702		
Time	19.7814	2	9.8907	150.061	0.000000
Time*Lime	0.1509	2	0.0755	1.145	0.365348
Error	0.5273	8	0.0659		

Annexures



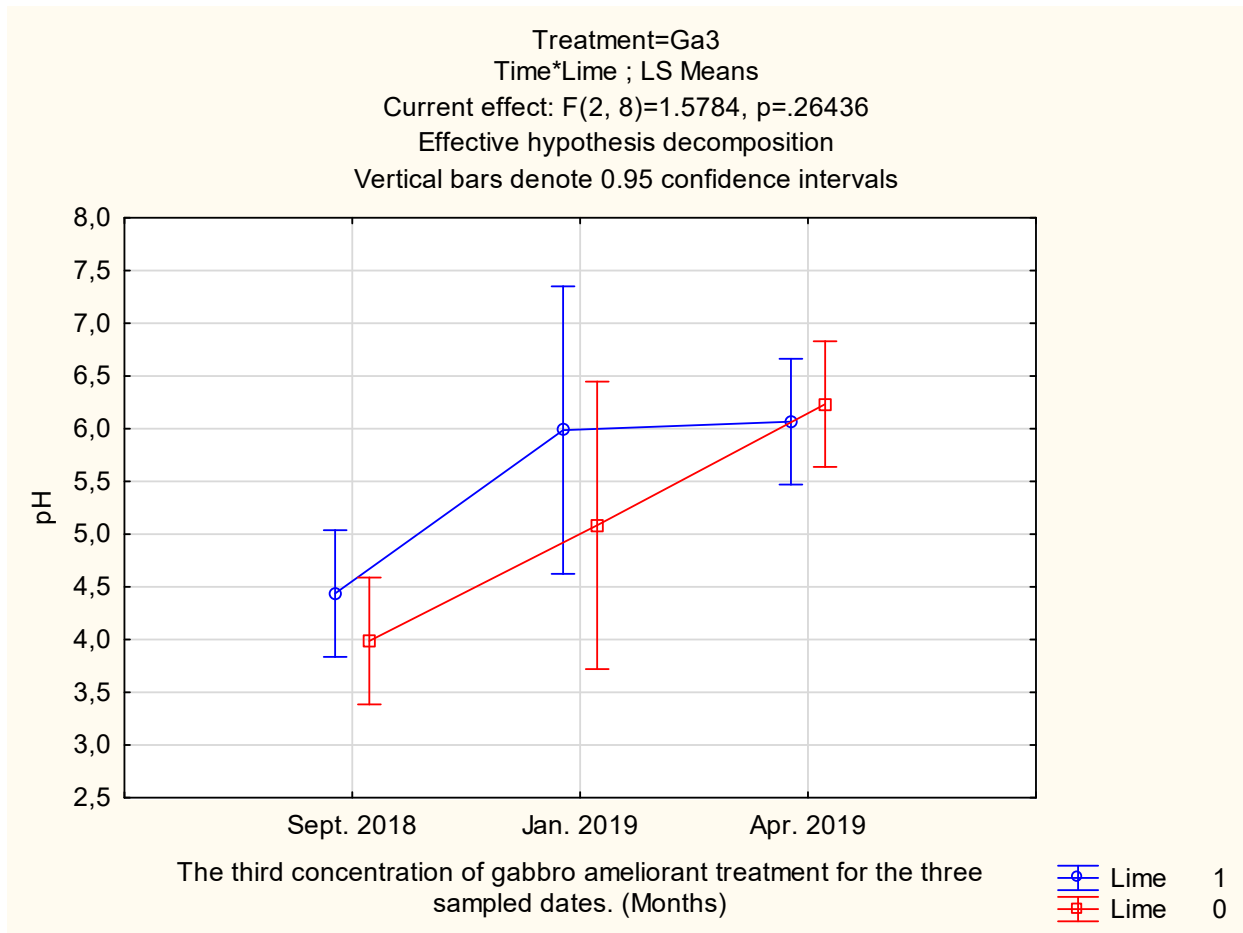
Effect	Treatment=Ga1 Repeated Measures Analysis of Variance (pH) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	473.3965	1	473.3965	22783.79	0.000000
Lime	0.0076	1	0.0076	0.37	0.577814
Error	0.0831	4	0.0208		
Time	18.0054	2	9.0027	163.23	0.000000
Time*Lime	0.1465	2	0.0732	1.33	0.317692
Error	0.4412	8	0.0552		

Annexures



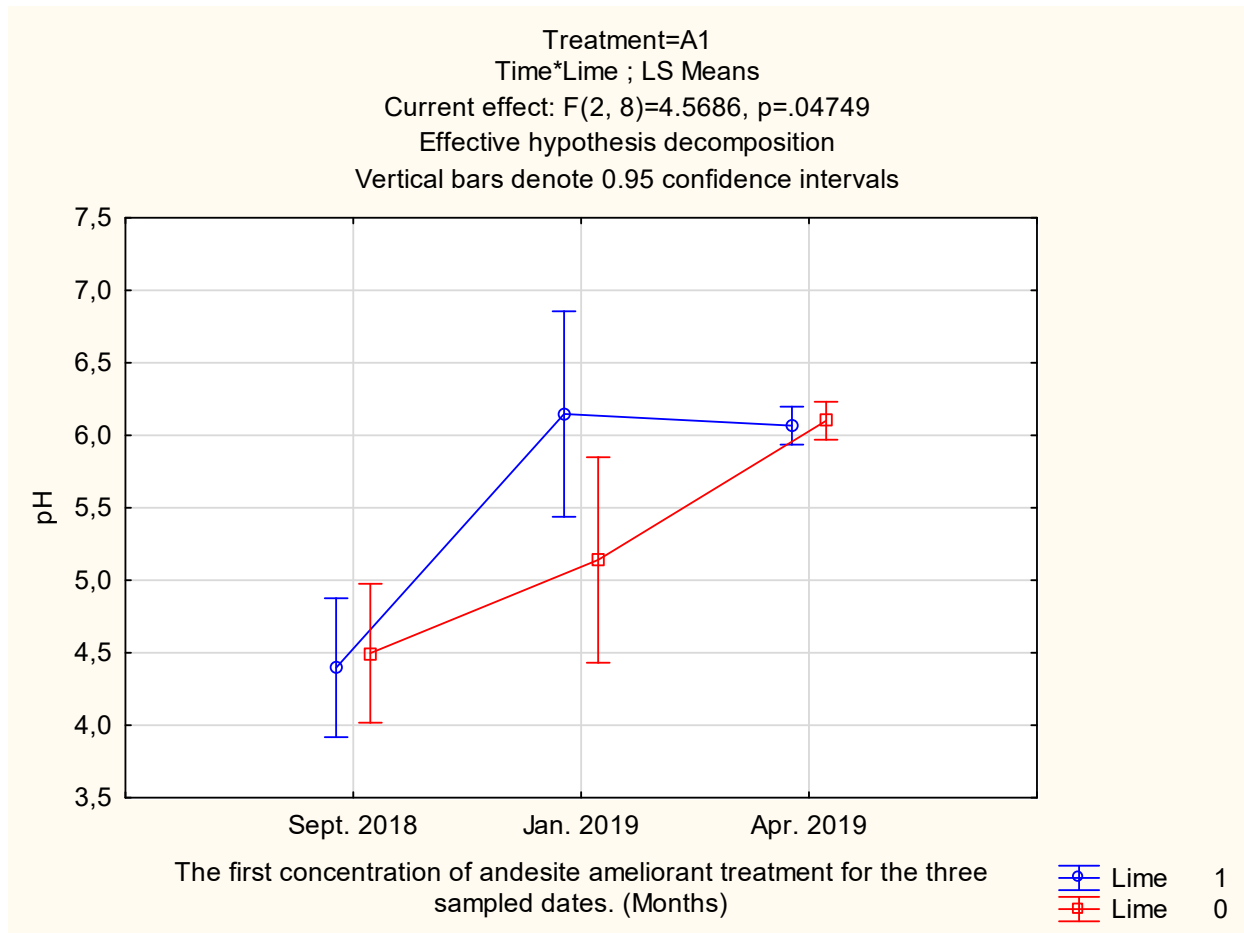
Effect	Treatment=Ga2 Repeated Measures Analysis of Variance (pH) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	533.1201	1	533.1201	10590.62	0.000000
Lime	0.2788	1	0.2788	5.54	0.078241
Error	0.2014	4	0.0503		
Time	22.7940	2	11.3970	237.95	0.000000
Time*Lime	0.0320	2	0.0160	0.33	0.725468
Error	0.3832	8	0.0479		

Annexures



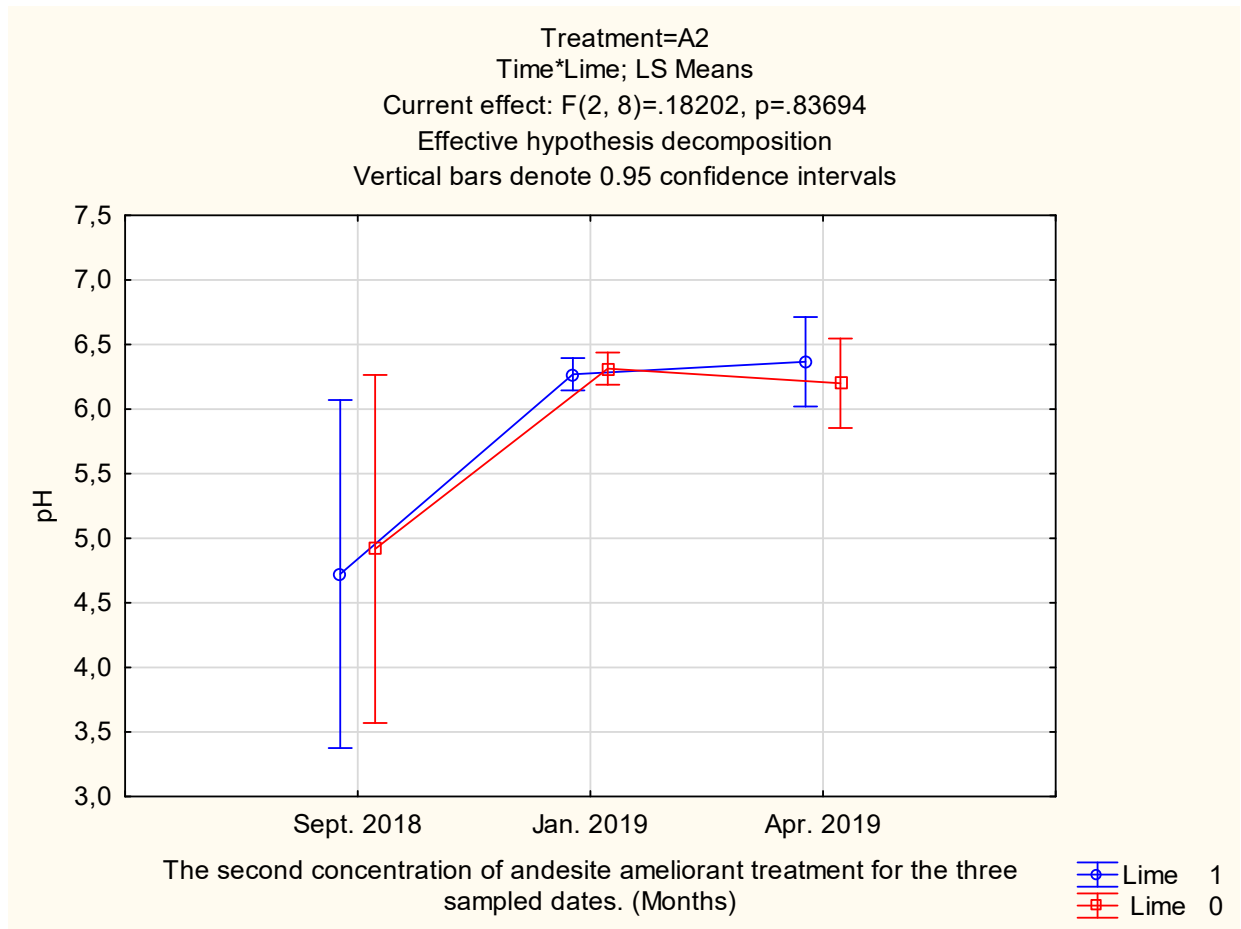
Effect	Treatment=Ga3 Repeated Measures Analysis of Variance (pH) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	505.4080	1	505.4080	1112.077	0.000005
Lime	0.7041	1	0.7041	1.549	0.281192
Error	1.8179	4	0.4545		
Time	11.7731	2	5.8866	21.475	0.000608
Time*Lime	0.8653	2	0.4327	1.578	0.264356
Error	2.1929	8	0.2741		

Annexures



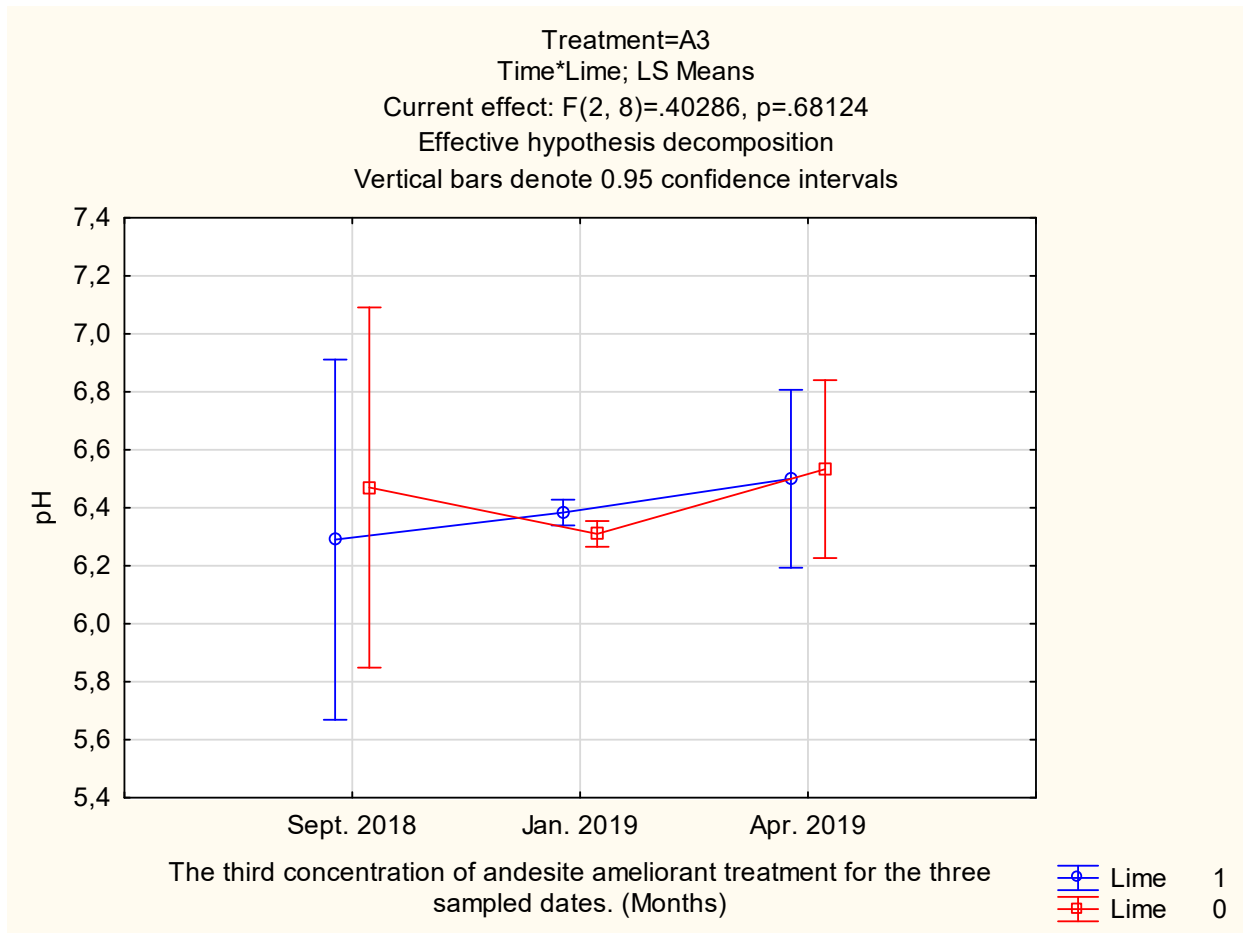
Effect	Treatment=A1 Repeated Measures Analysis of Variance (pH) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	523.1534	1	523.1534	13527.89	0.000000
Lime	0.3814	1	0.3814	9.86	0.034839
Error	0.1547	4	0.0387		
Time	8.6086	2	4.3043	34.04	0.000122
Time*Lime	1.1554	2	0.5777	4.57	0.047489
Error	1.0116	8	0.1264		

Annexures



Effect	Treatment=A2 Repeated Measures Analysis of Variance (pH) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	605.1721	1	605.1721	2746.205	0.000001
Lime	0.0025	1	0.0025	0.011	0.921102
Error	0.8815	4	0.2204		
Time	8.6144	2	4.3072	15.984	0.001605
Time*Lime	0.0981	2	0.0491	0.182	0.836942
Error	2.1558	8	0.2695		

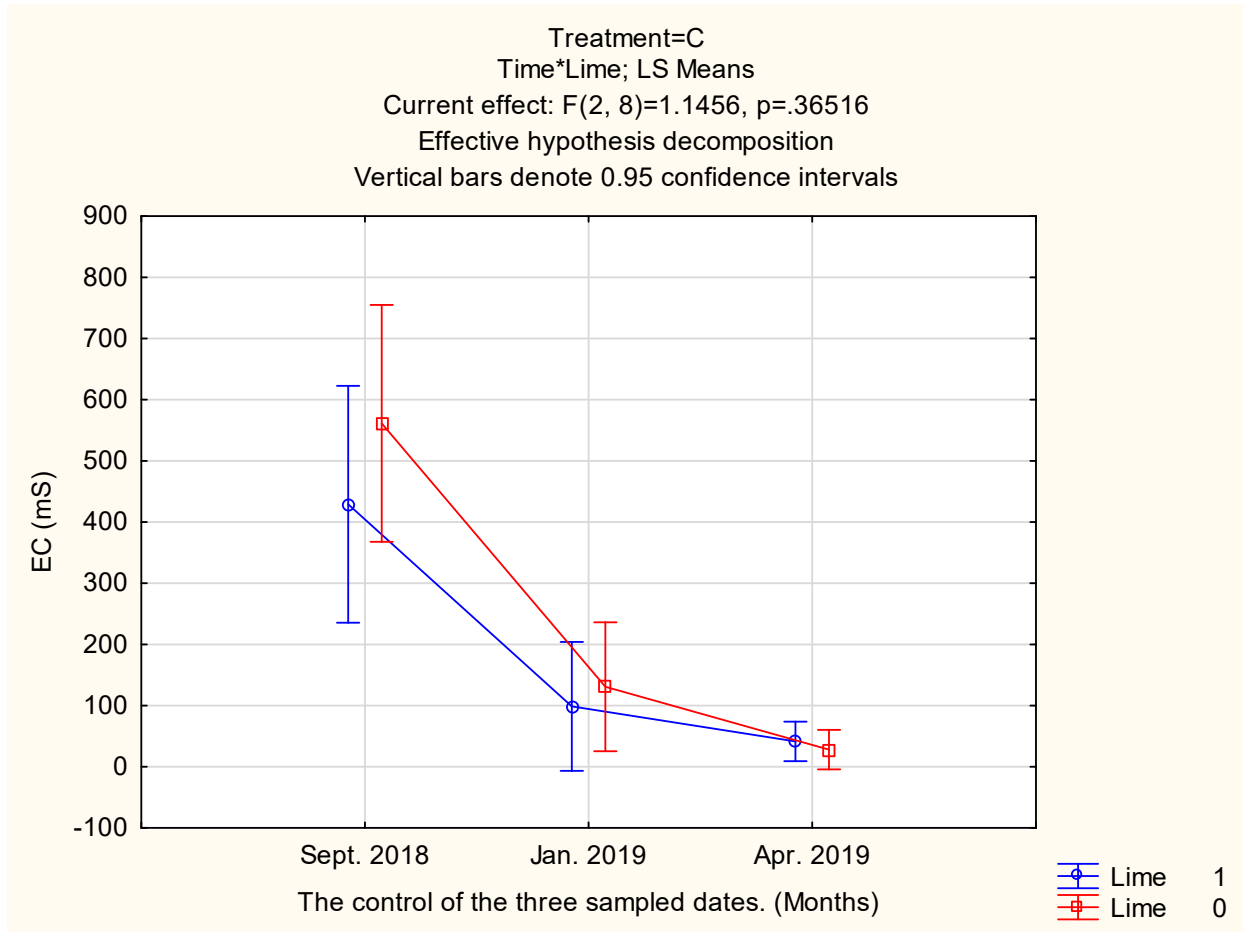
Annexures



Effect	Treatment=A3 Repeated Measures Analysis of Variance (pH) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	740.6118	1	740.6118	11035.61	0.000000
Lime	0.0098	1	0.0098	0.15	0.721797
Error	0.2684	4	0.0671		
Time	0.0974	2	0.0487	0.81	0.478932
Time*Lime	0.0485	2	0.0243	0.40	0.681241
Error	0.4819	8	0.0602		

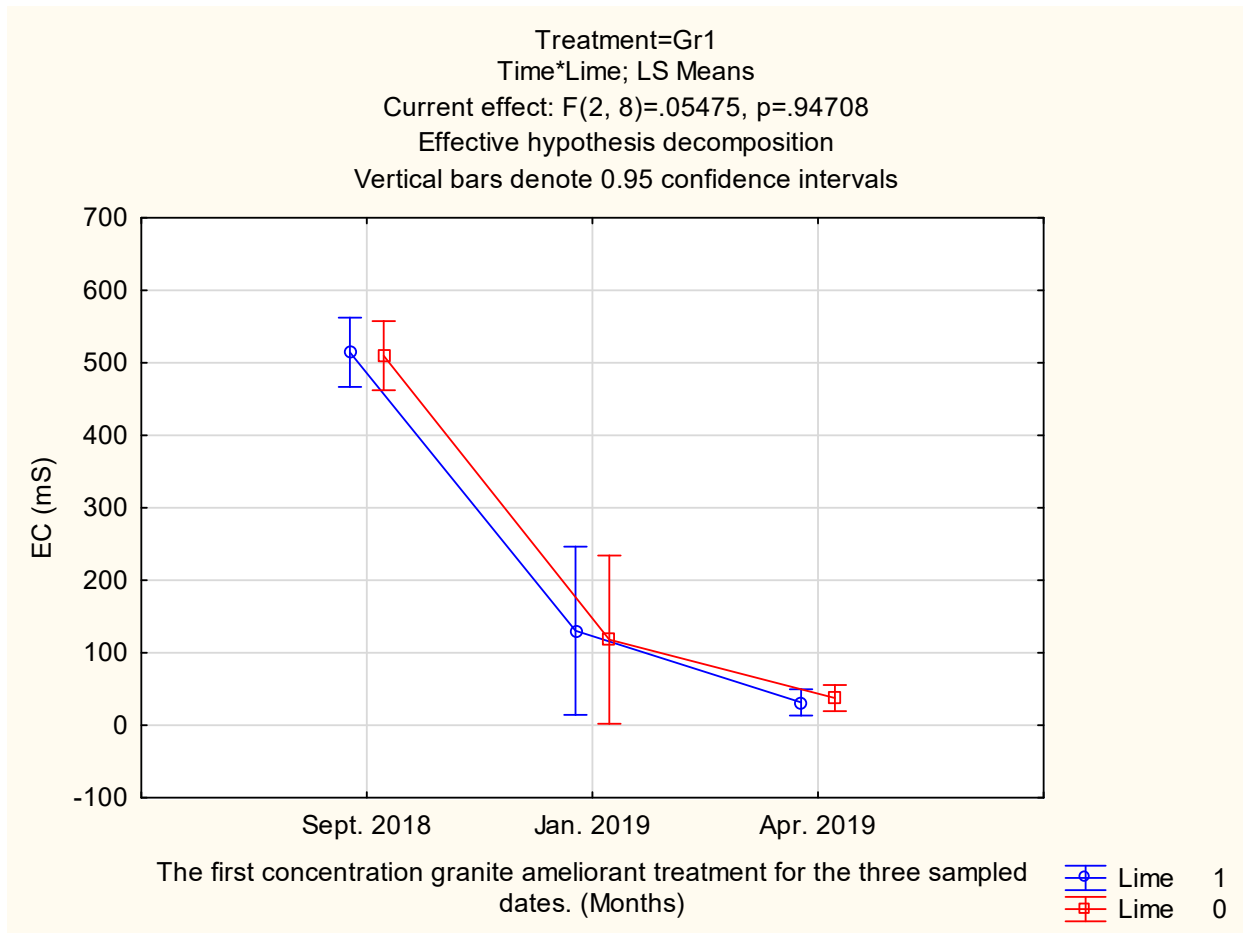
Annexures

Annexure 4: The statistical repeated measure ANOVA of the EC results for Sept 2018, Jan 2019 and Apr 2019.



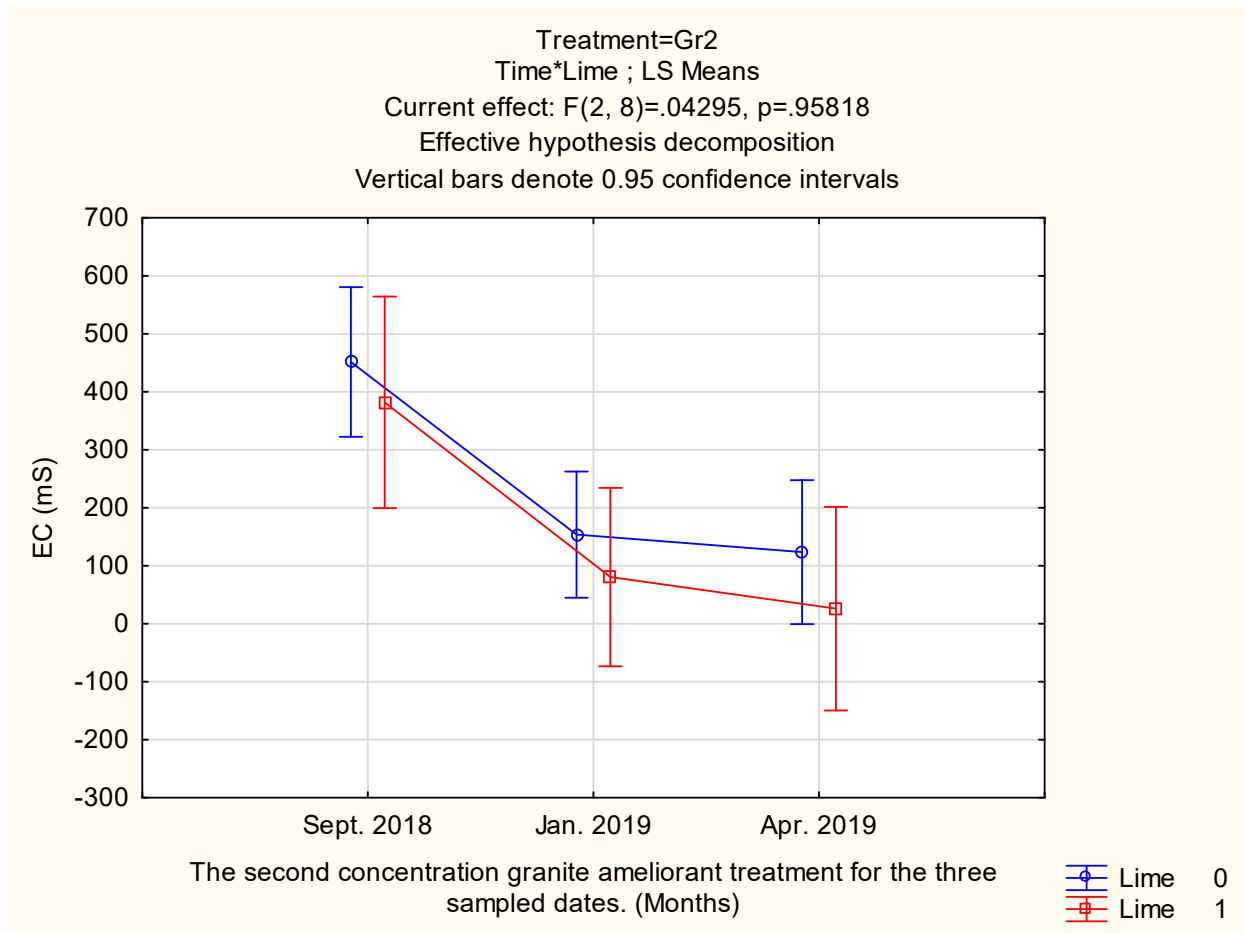
Effect	Treatment=C Repeated Measures Analysis of Variance (EC) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	831151.5	1	831151.5	174.7211	0.000189
Lime	11370.8	1	11370.8	2.3903	0.196986
Error	19028.1	4	4757.0		
Time	726132.6	2	363066.3	49.9101	0.000030
Time*Lime	16667.4	2	8333.7	1.1456	0.365165
Error	58195.2	8	7274.4		

Annexures



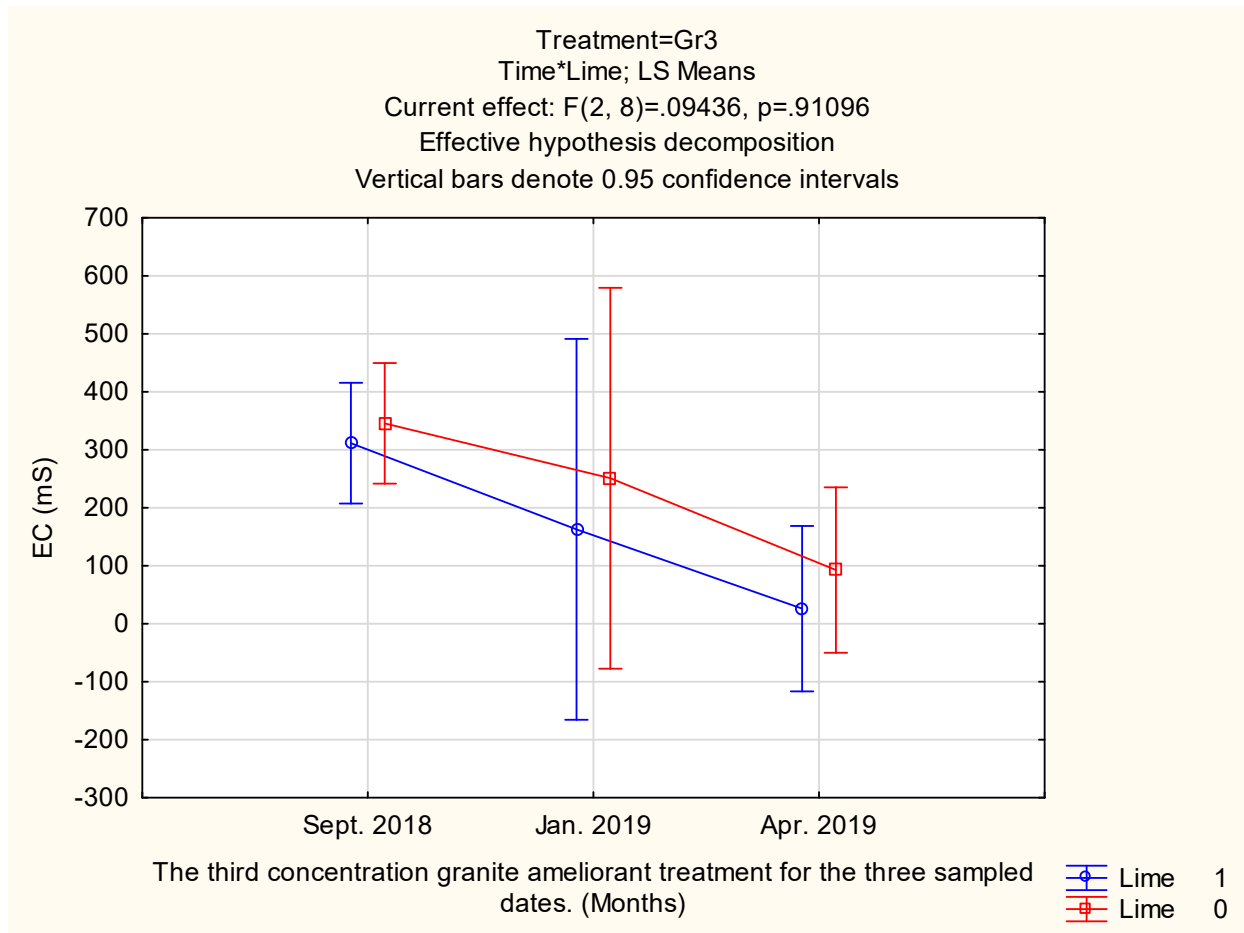
Effect	Treatment=Gr1 Repeated Measures Analysis of Variance (EC) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	899931.9	1	899931.9	555.6291	0.000019
Lime	60.1	1	60.1	0.0371	0.856636
Error	6478.7	4	1619.7		
Time	773389.7	2	386694.8	166.8169	0.000000
Time*Lime	253.8	2	126.9	0.0547	0.947075
Error	18544.6	8	2318.1		

Annexures



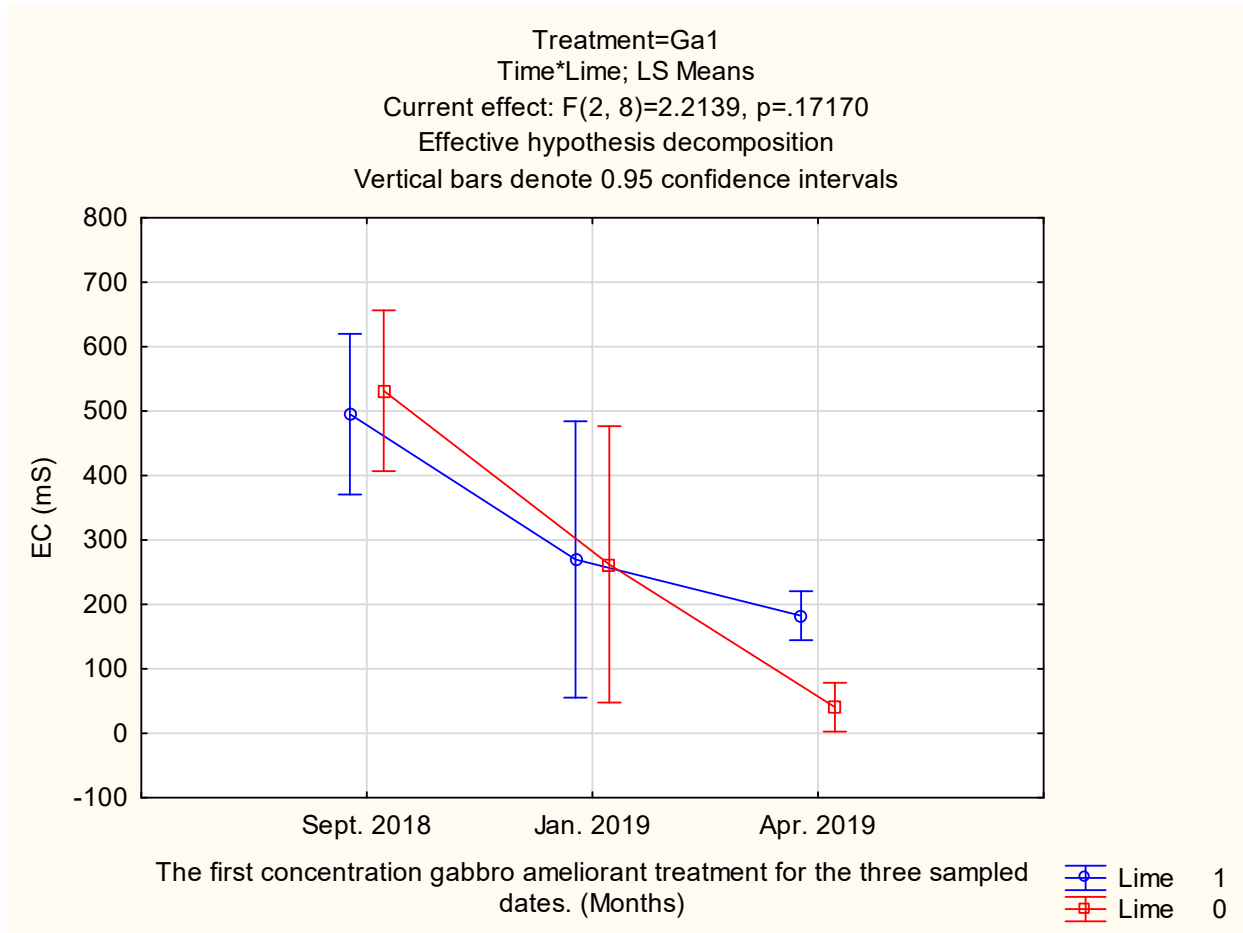
Effect	Treatment=Gr2 Repeated Measures Analysis of Variance (EC) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	658123.9	1	658123.9	76.23007	0.000948
Lime	25662.4	1	25662.4	2.97246	0.159785
Error	34533.6	4	8633.4		
Time	370172.2	2	185086.1	26.17969	0.000309
Time*Lime	607.3	2	303.7	0.04295	0.958179
Error	56558.7	8	7069.8		

Annexures



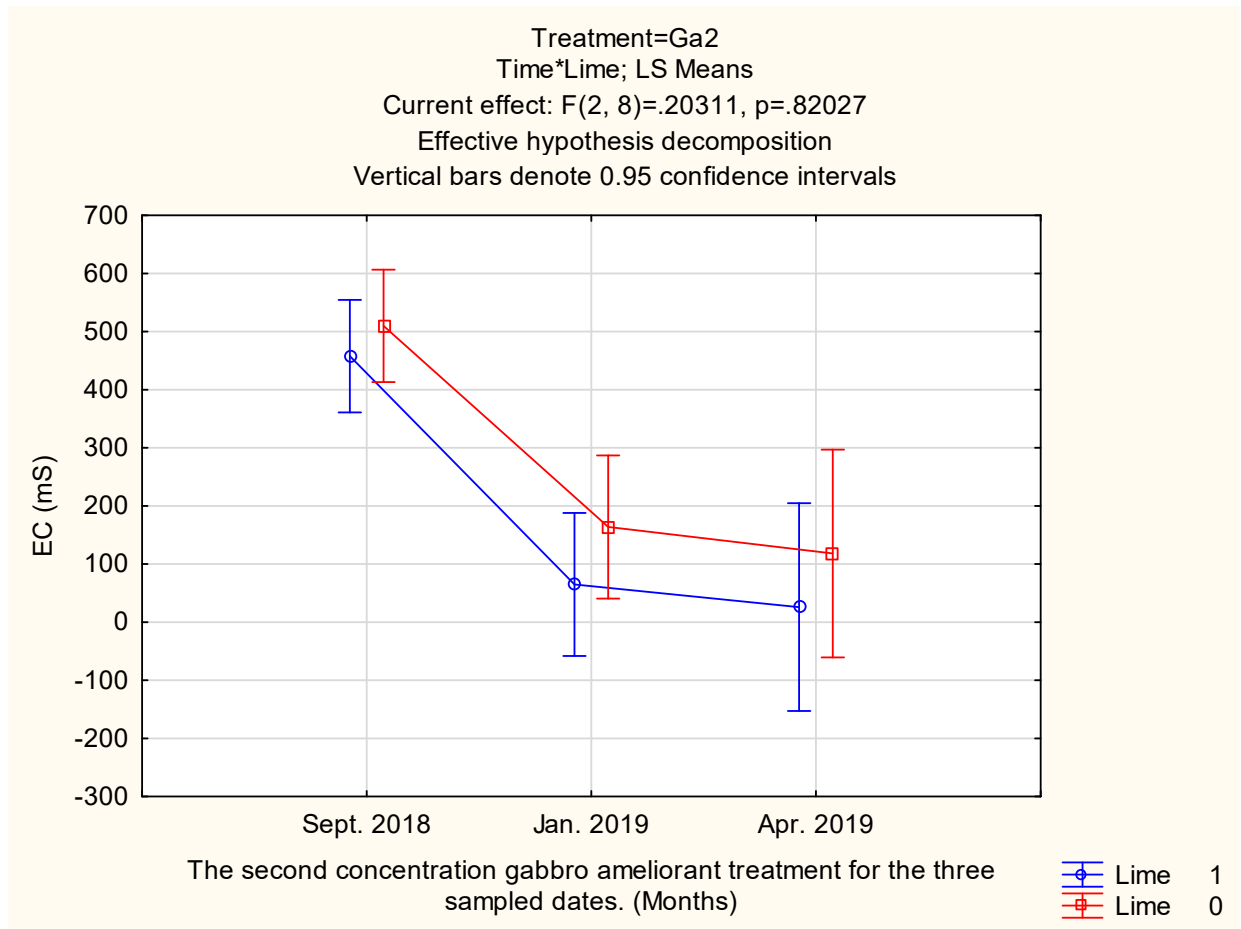
Effect	Treatment=Gr3 Repeated Measures Analysis of Variance (EC) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	707252.9	1	707252.9	23.02424	0.008659
Lime	17857.4	1	17857.4	0.58134	0.488271
Error	122871.0	4	30717.7		
Time	217975.8	2	108987.9	9.31898	0.008135
Time*Lime	2207.0	2	1103.5	0.09436	0.910957
Error	93562.1	8	11695.3		

Annexures



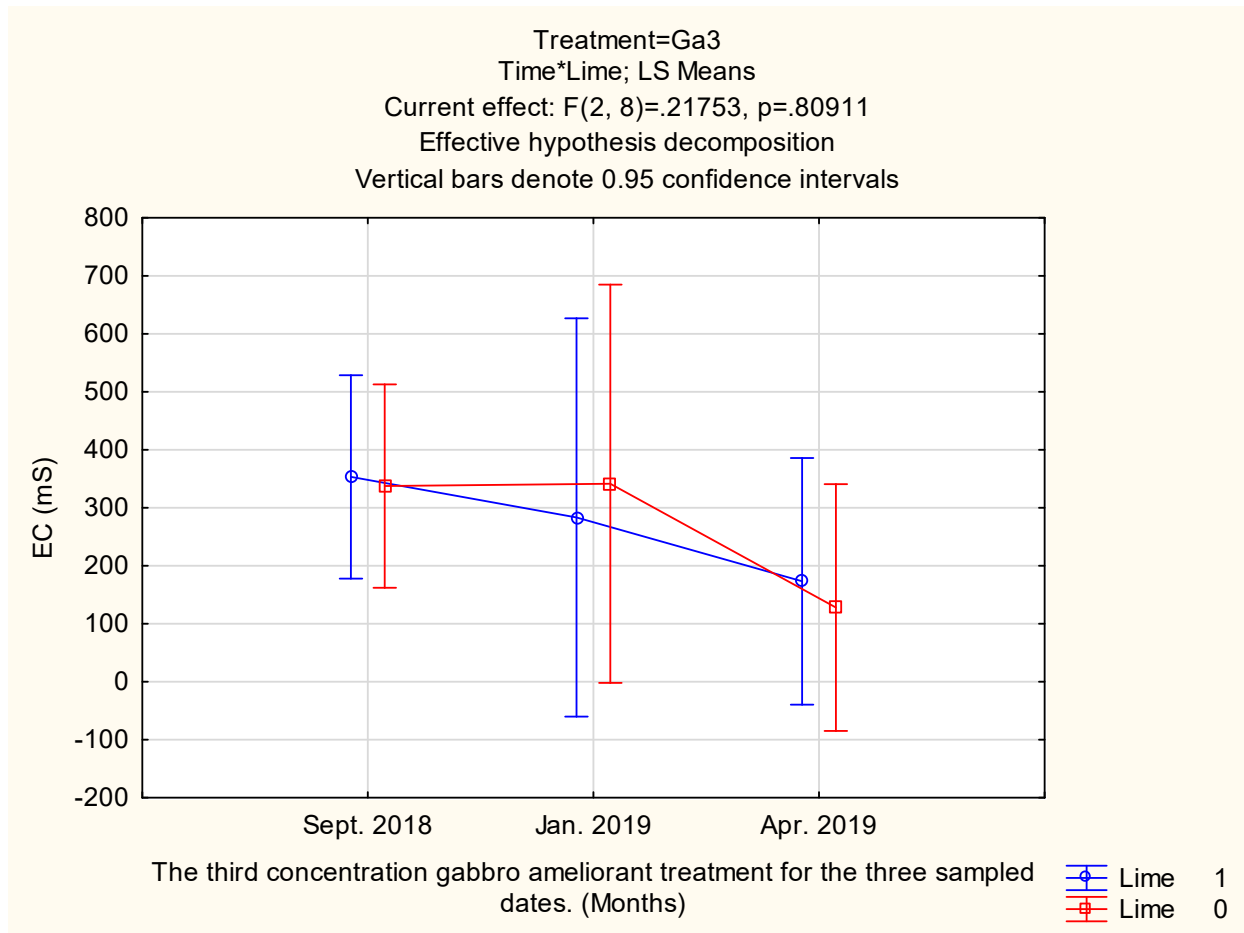
Effect	Treatment=Ga1 Repeated Measures Analysis of Variance (EC) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	1587423	1	1587423	123.7861	0.000371
Lime	6411	1	6411	0.4999	0.518540
Error	51296	4	12824		
Time	493287	2	246643	42.2224	0.00056
Time*Lime	25865	2	12933	2.2139	0.171702
Error	46732	8	5842		

Annexures



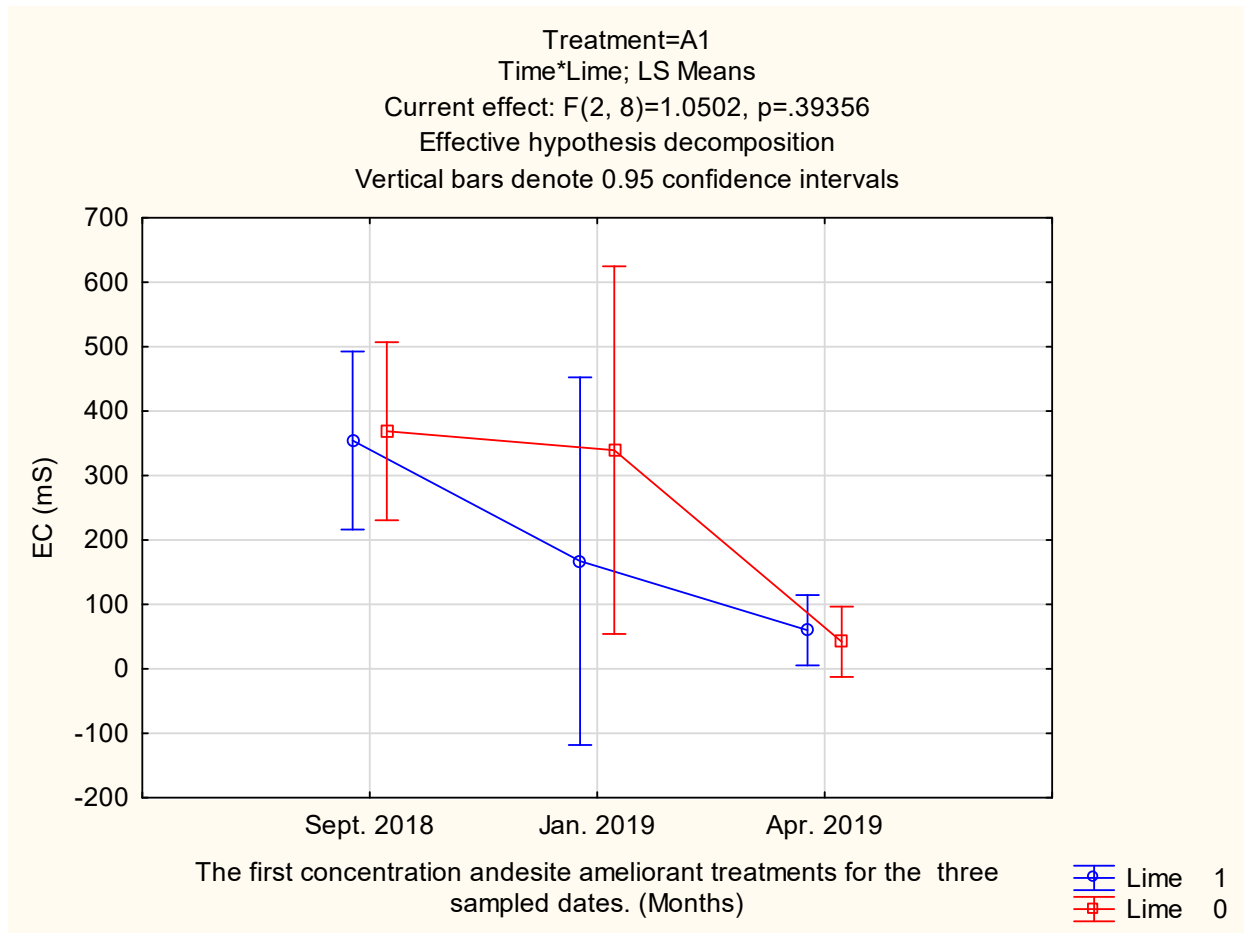
Effect	Treatment=Ga2 Repeated Measures Analysis of Variance (EC) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	898595.2	1	898595.2	71.96000	0.001059
Lime	29569.9	1	29569.9	2.36797	0.198679
Error	49949.7	4	12487.4		
Time	615509.1	2	307754.5	64.89909	0.000011
Time*Lime	1926.3	2	963.2	0.20311	0.820268
Error	37936.4	8	4742.0		

Annexures



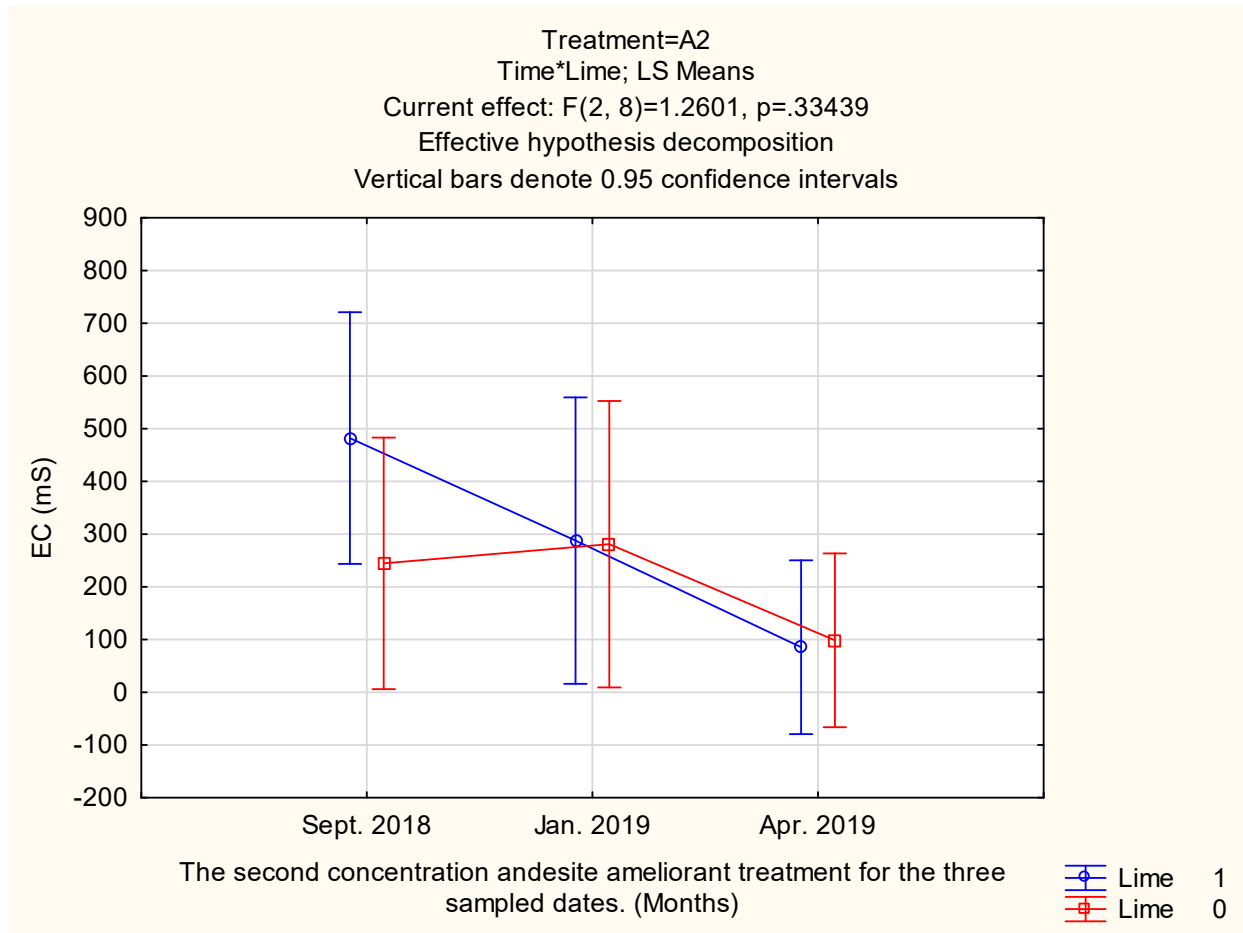
Effect	Treatment=Ga3 Repeated Measures Analysis of Variance (EC) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	1306439	1	1306439	35.83319	0.003916
Lime	4	1	4	0.00012	0.991909
Error	145836	4	36459		
Time	130368	2	65184	3.34119	0.088140
Time*Lime	8488	2	4244	0.21753	0.809108
Error	156074	8	19509		

Annexures



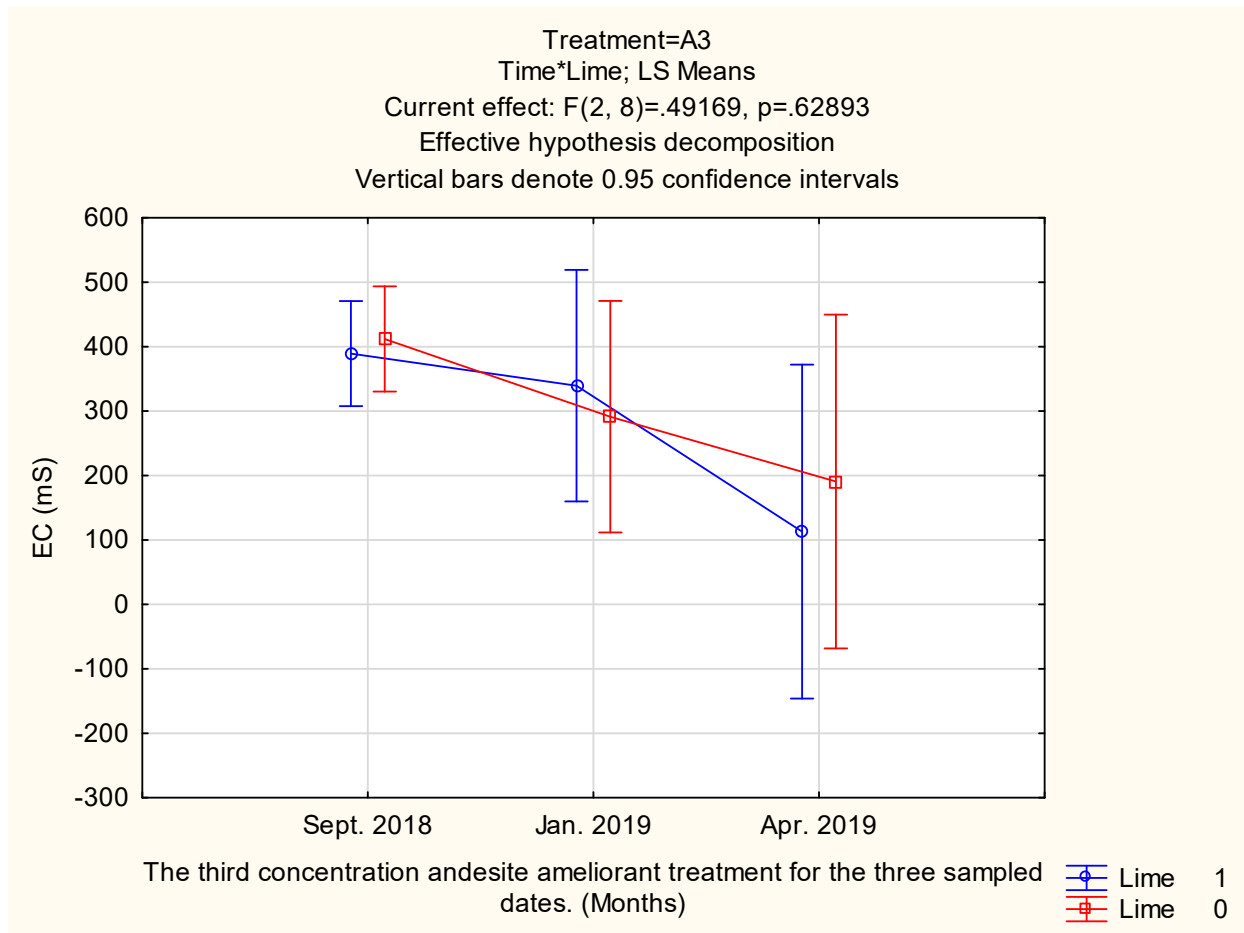
Effect	Treatment=A1 Repeated Measures Analysis of Variance (EC) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	886610.4	1	886610.4	82.82633	0.000808
Lime	14263.0	1	14263.0	1.33244	0.312641
Error	42817.8	4	10704.5		
Time	298208.3	2	149104.2	10.08993	0.006495
Time*Lime	31038.6	2	15519.3	1.05020	0.393557
Error	118220.1	8	14777.5		

Annexures



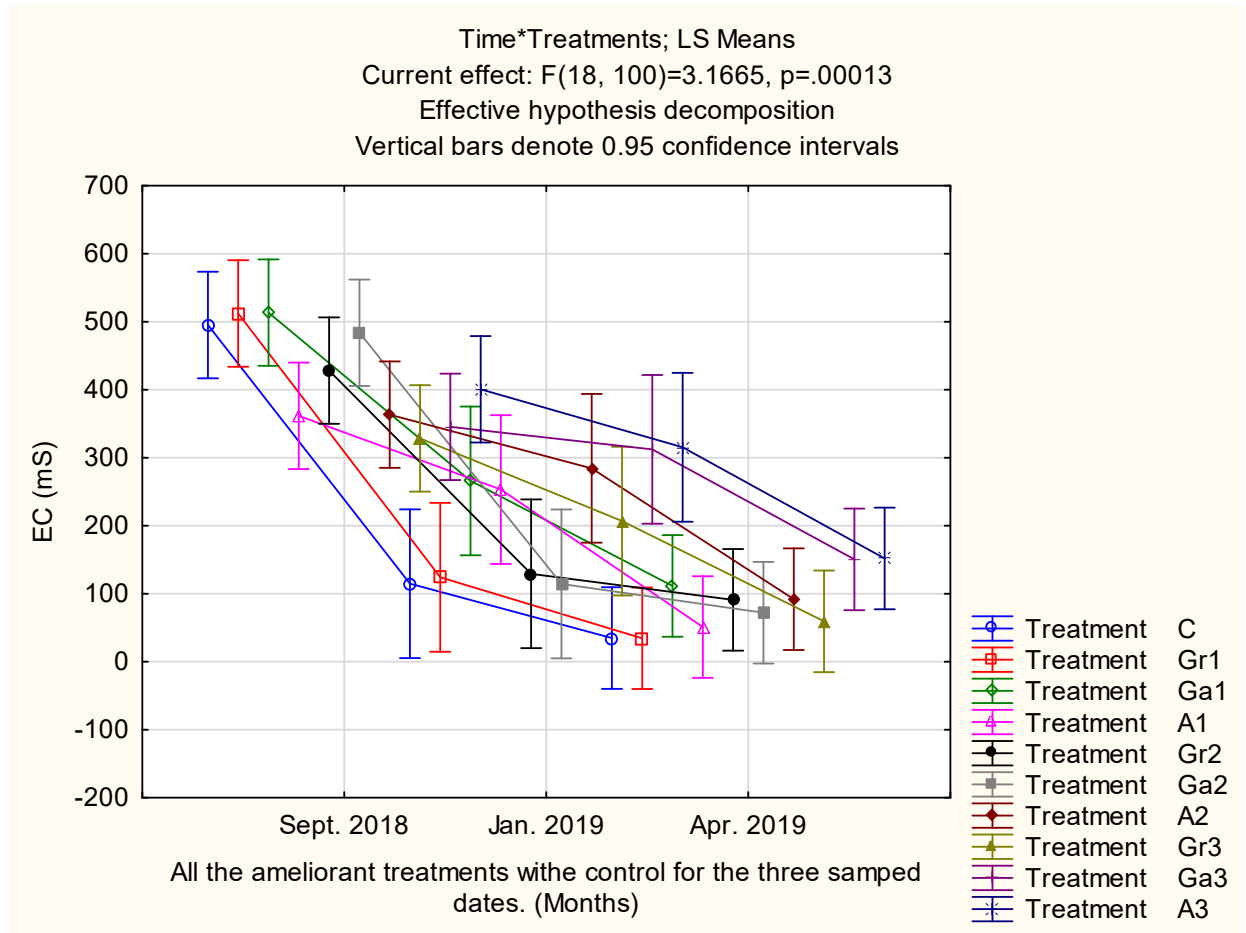
Effect	Treatment=A2 Repeated Measures Analysis of Variance (EC) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	1094593	1	1094593	72.37657	0.001047
Lime	26751	1	26751	1.76880	0.254298
Error	60494	4	15124		
Time	233706	2	116853	5.04570	0.038236
Time*Lime	58366	2	29183	1.26011	0.334394
Error	185272	8	23159		

Annexures



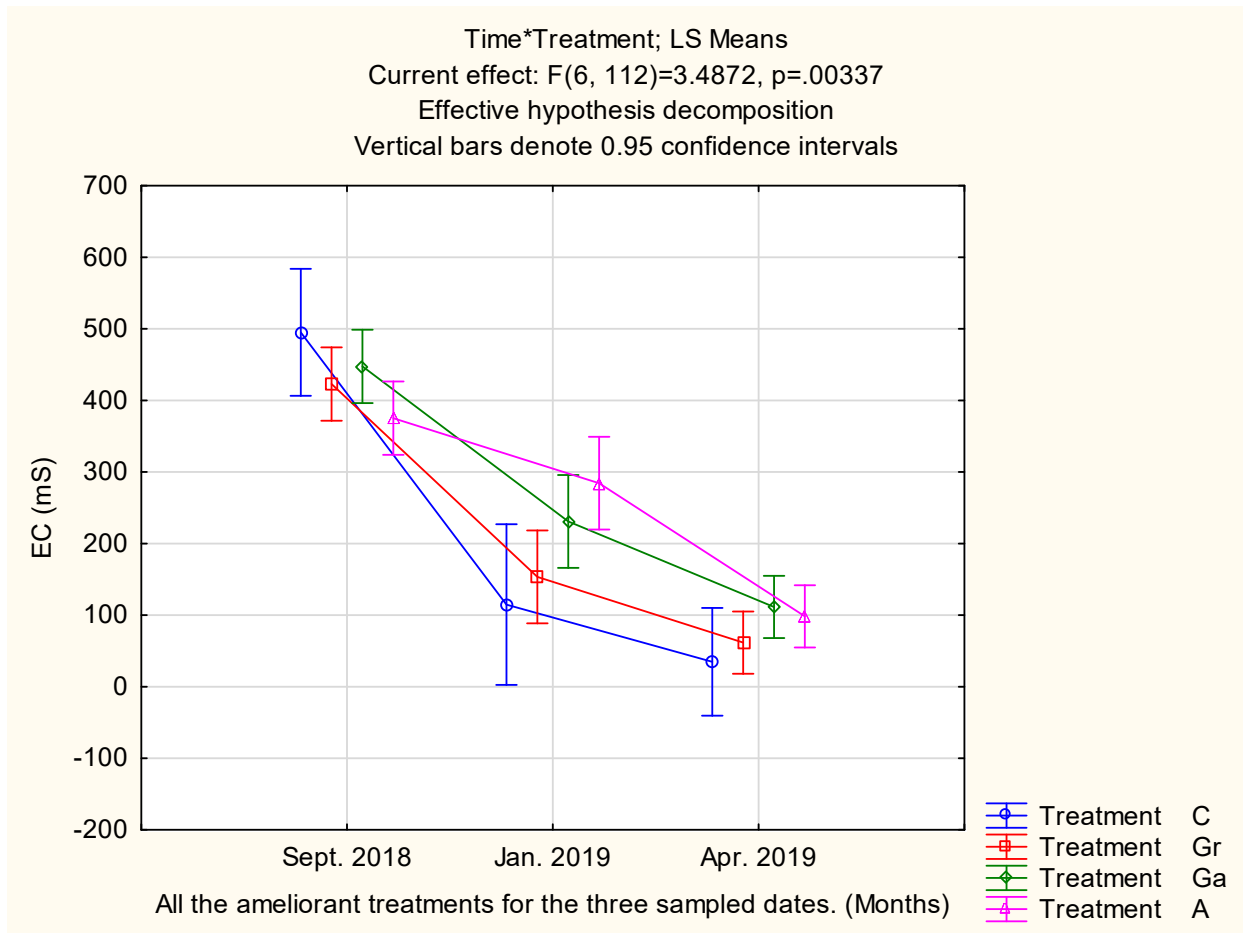
Effect	Treatment=A3 Repeated Measures Analysis of Variance (EC) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	1506385	1	1506385	88.90983	0.000705
Lime	1367	1	1367	0.08068	0.790475
Error	67771	4	16943		
Time	191743	2	95872	7.88007	0.012852
Time*Lime	11964	2	5982	0.49169	0.628926
Error	97331	8	12166		

Annexures



Effect	Repeated Measures Analysis of Variance (EC) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	10372296	1	10372296	706.1820	0.000000
Treatment	187152	9	20795	1.4158	0.206835
Error	734393	50	14688		
Time	3504466	2	1752233	170.8147	0.000000
Time*Treatment	584677	18	32482	3.1665	0.000126
Error	1025809	100	10258		

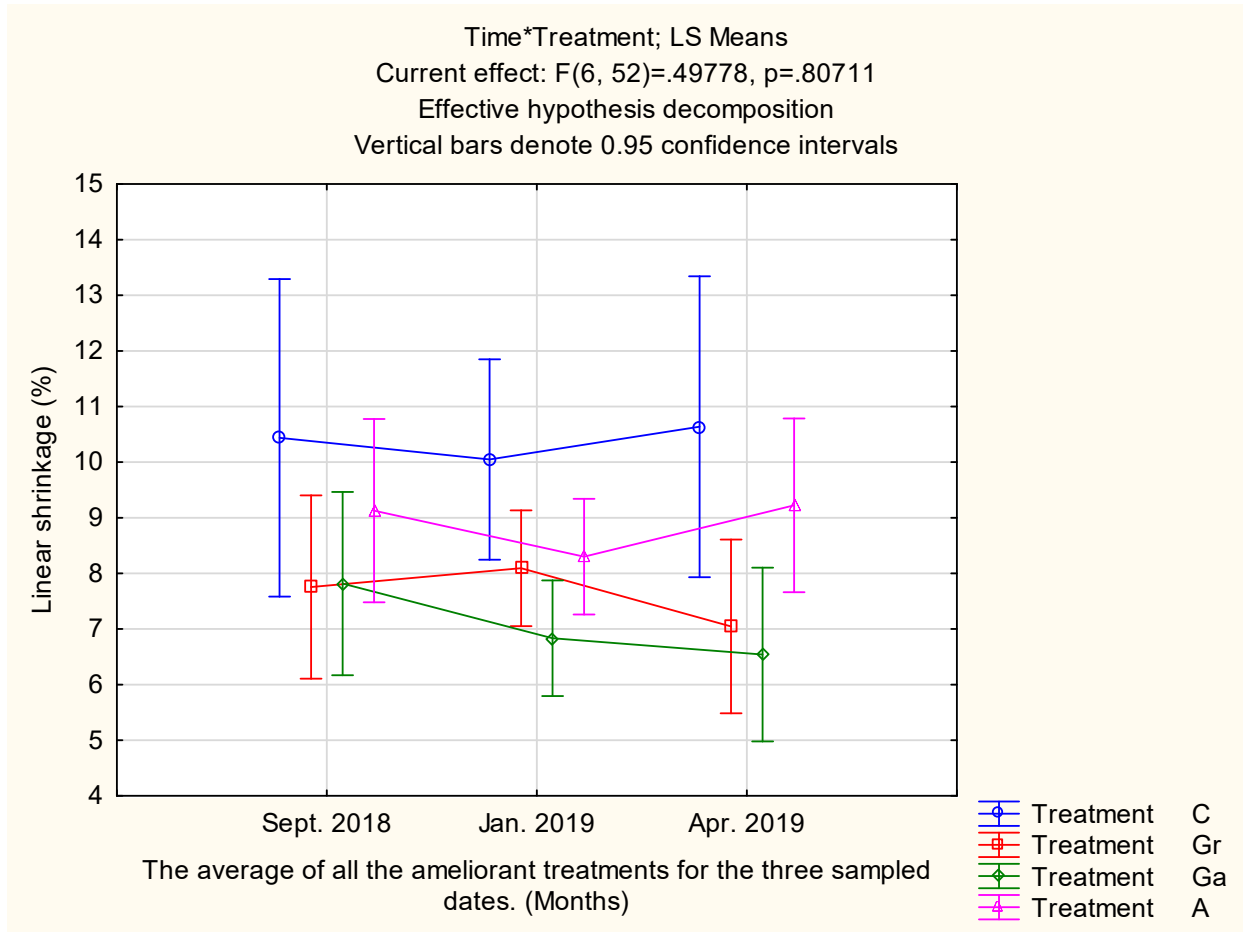
Annexures



Effect	Repeated Measures Analysis of Variance (EC) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	8010400	1	8010400	539.1578	0.000000
Treatment	89539	3	29846	2.0089	0.123131
Error	832006	56	14857		
Time	3202740	2	1601370	132.1710	0.000000
Time*Treatment	253507	6	42251	3.4872	0.003372
Error	1356980	112	12116		

Annexures

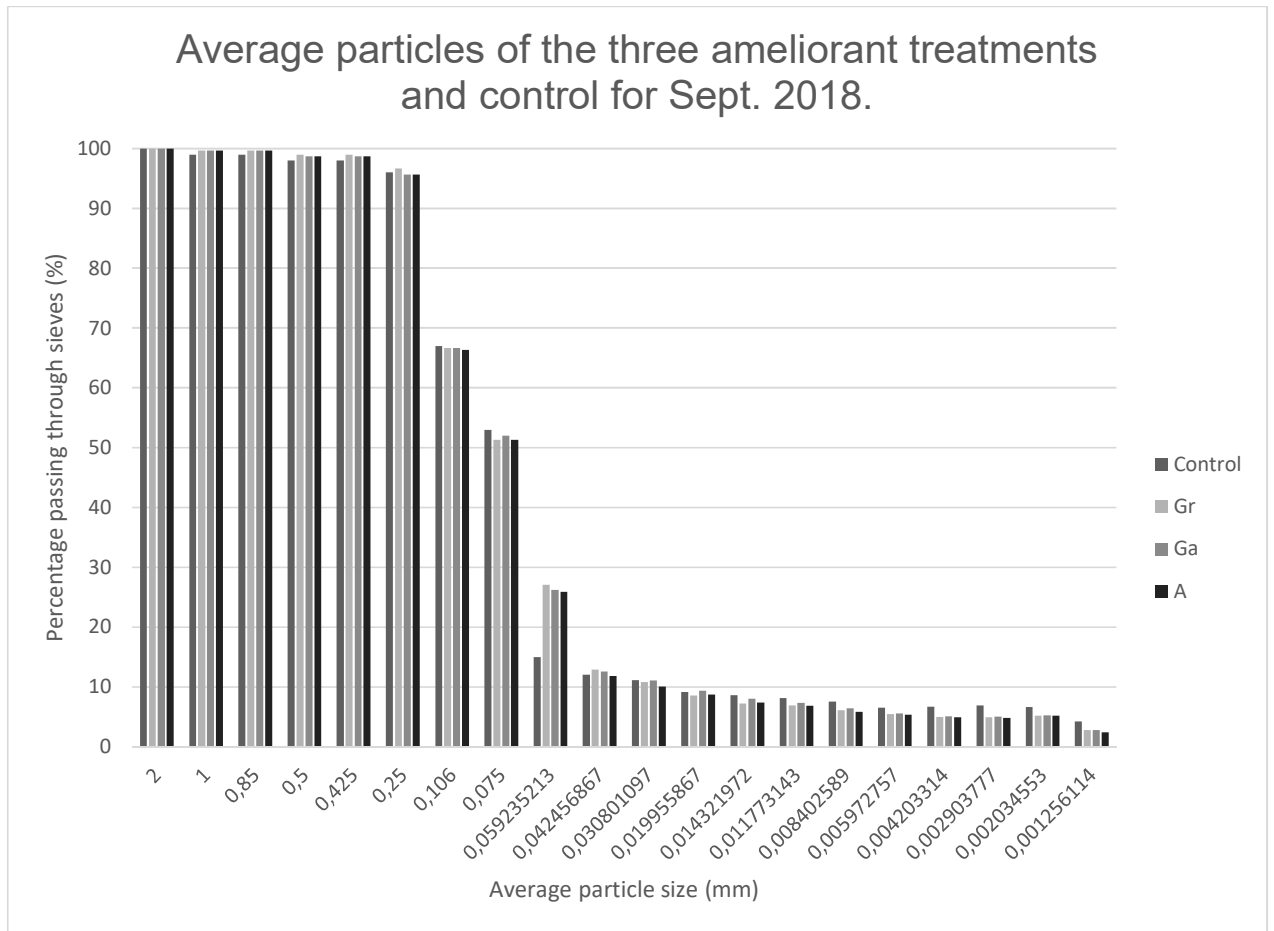
Annexure 5: The statistical results of linear shrinkage for Sept 2018, Jan 2019 and Apr 2019.



Effect	Repeated Measures Analysis of Variance (Linear shrinkage) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	5187.399	1	5187.399	1130.355	0.000000
Treatment	98.089	3	32.696	7.125	0.001200
Error	119.319	26	4.589		
Time	3.176	2	1.588	0.365	0.695813
Time*Treatment	12.988	6	2.165	0.498	0.807108
Error	226.131	52	4.349		

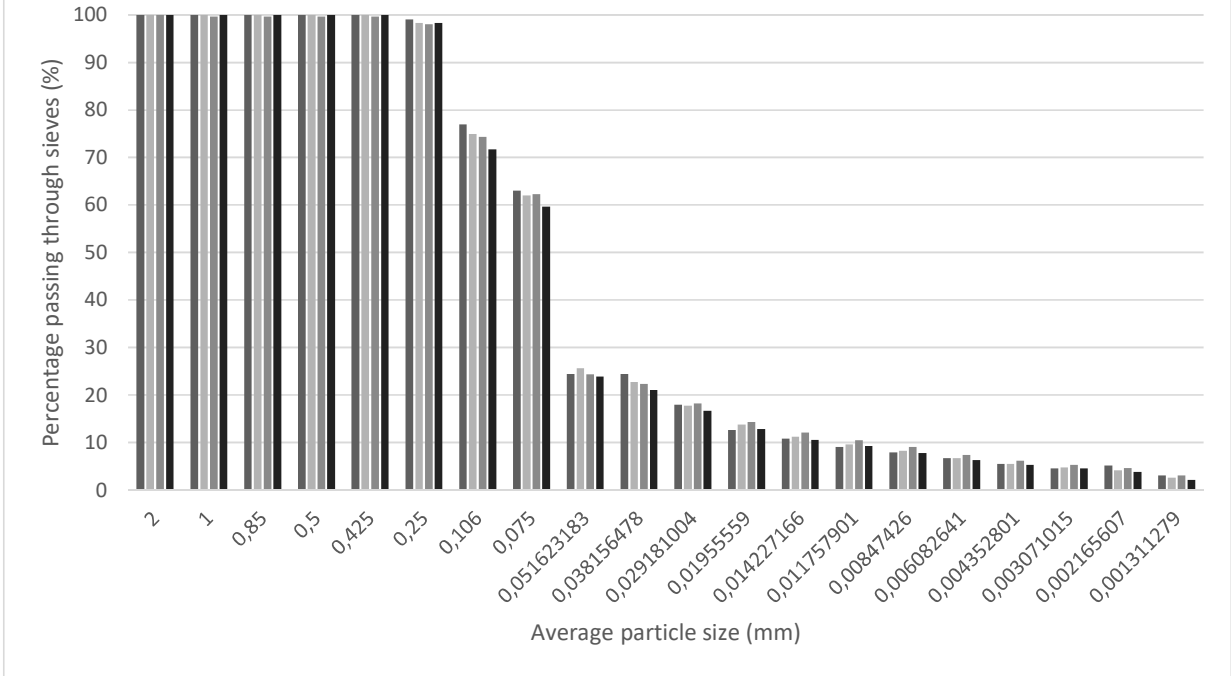
Annexures

Annexure 6: The full particle size distribution of the growth medium for Sept 2018, Jan 2019 and Apr 2019 for all the ameliorant treatments (control, Gr - Granite, Ga - Gabbro and A - andesite).

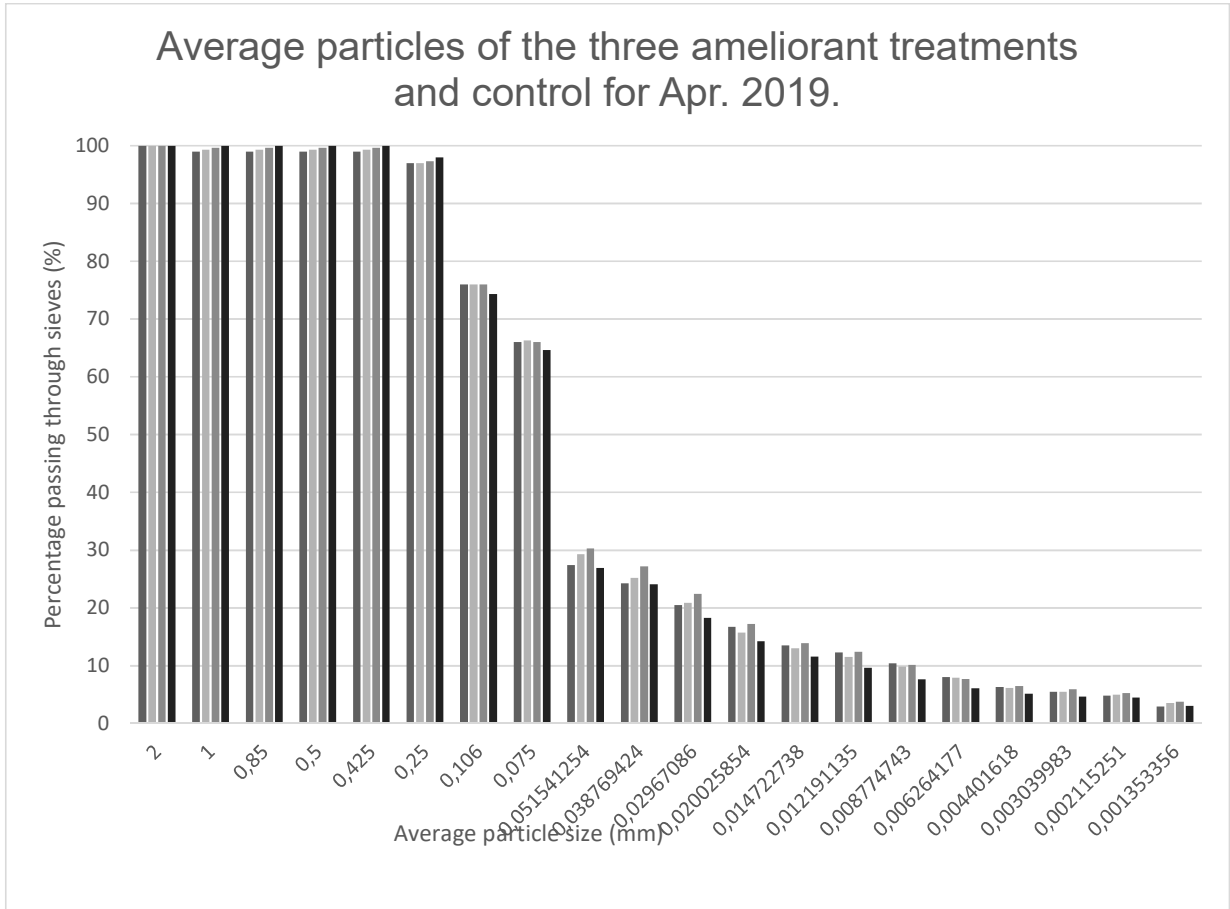


Annexures

Average particles of the three ameliorant treatments and control for Jan. 2019.

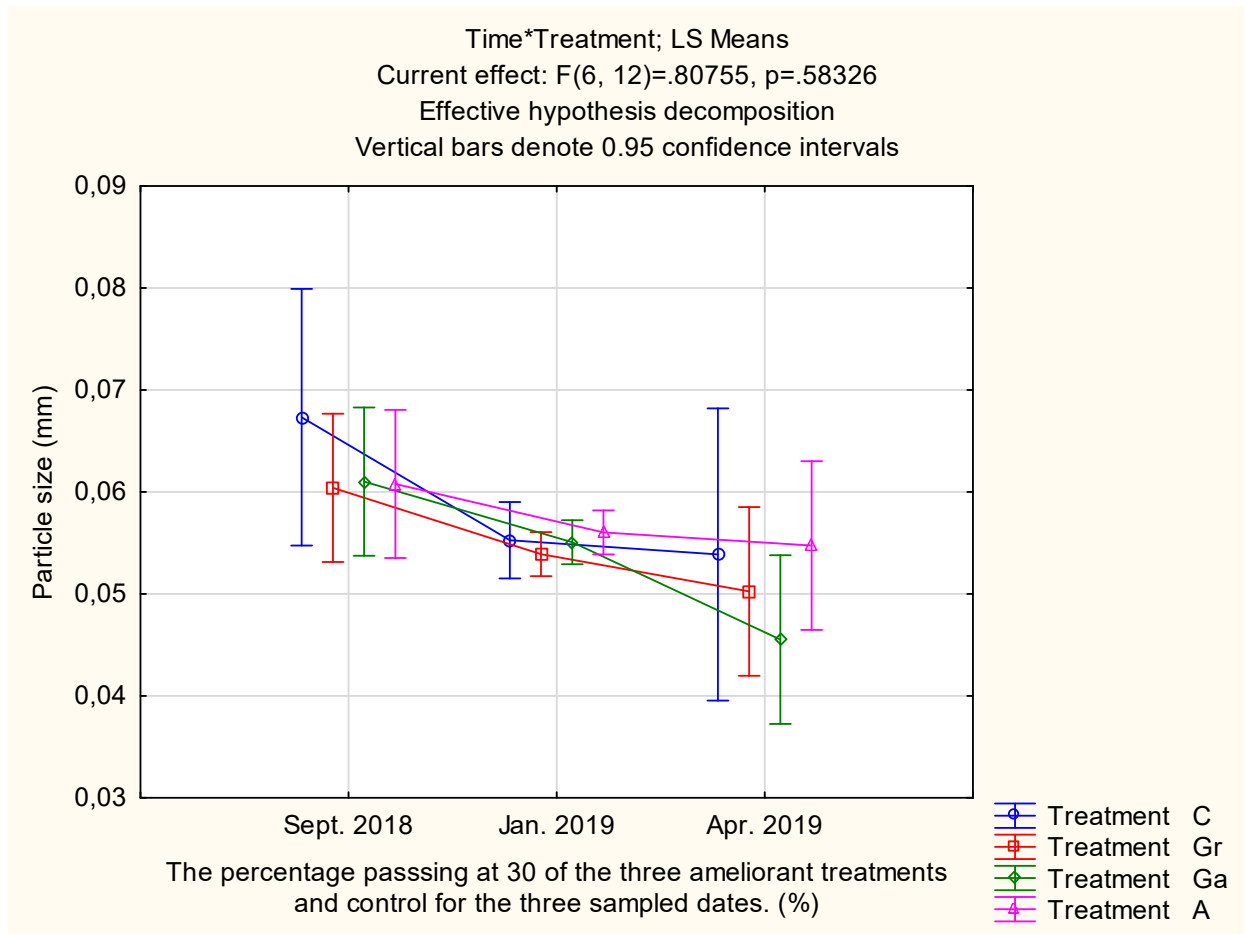


Annexures



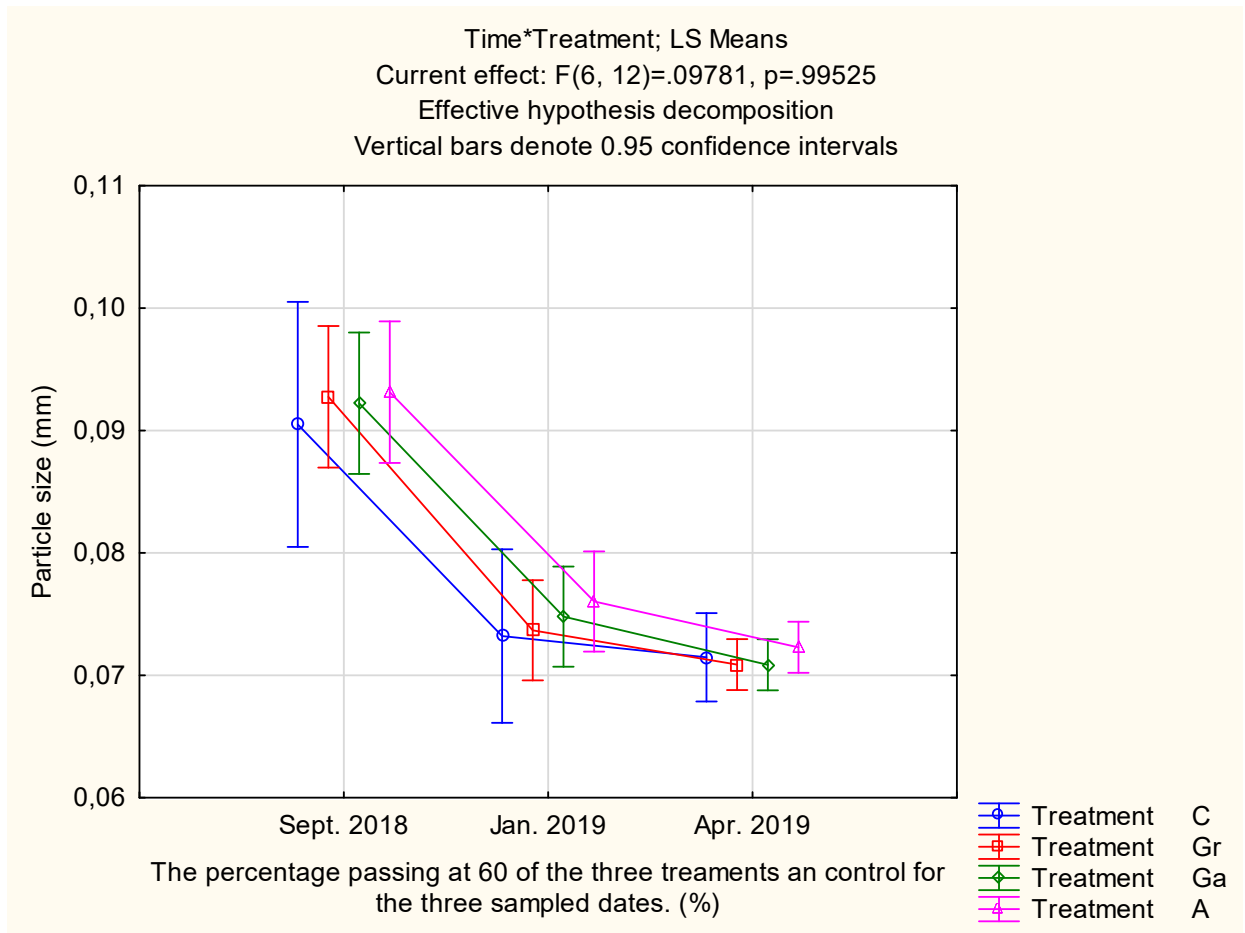
Annexures

Annexure 7: The repeated measures ANOVA results for the texture results for Sept 2018, Jan 2019 and Apr 2019.



Effect	Repeated Measures Analysis of Variance (Texture) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	0.075750	1	0.075750	3526.996	0.000000
Treatment	0.000086	3	0.000029	1.329	0.349639
Error	0.000129	6	0.000021		
Time	0.000525	2	0.000262	12.613	0.001122
Time*Treatment	0.000101	6	0.000017	0.808	0.583262
Error	0.000250	12	0.000021		

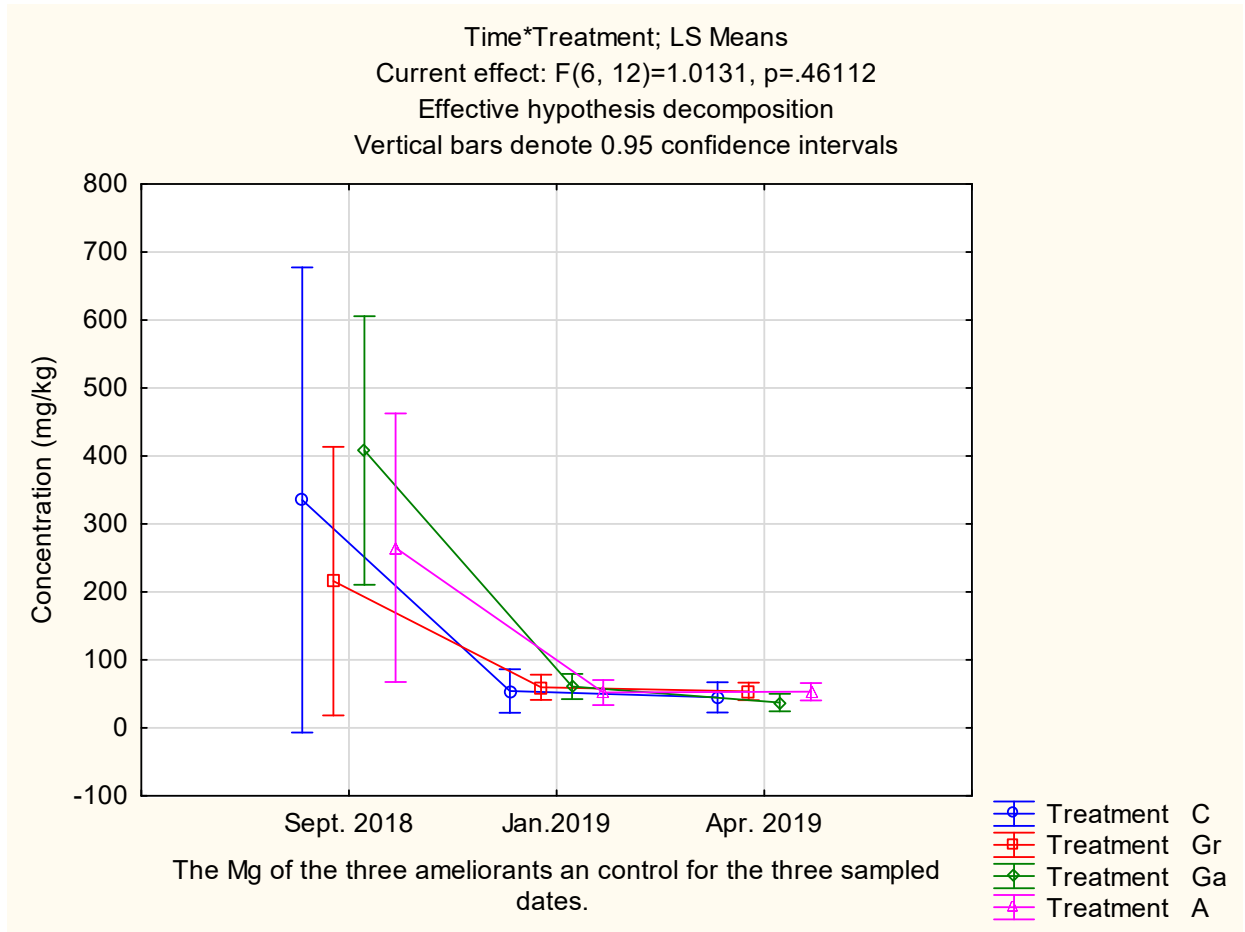
Annexures



Effect	Repeated Measures Analysis of Variance (Texture) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	0.150997	1	0.150997	24448.96	0.000000
Treatment	0.000014	3	0.000005	0.77	0.552895
Error	0.000037	6	0.000006		
Time	0.002014	2	0.001007	95.31	0.000000
Time*Treatment	0.000006	6	0.000001	0.10	0.995246
Error	0.000127	12	0.000011		

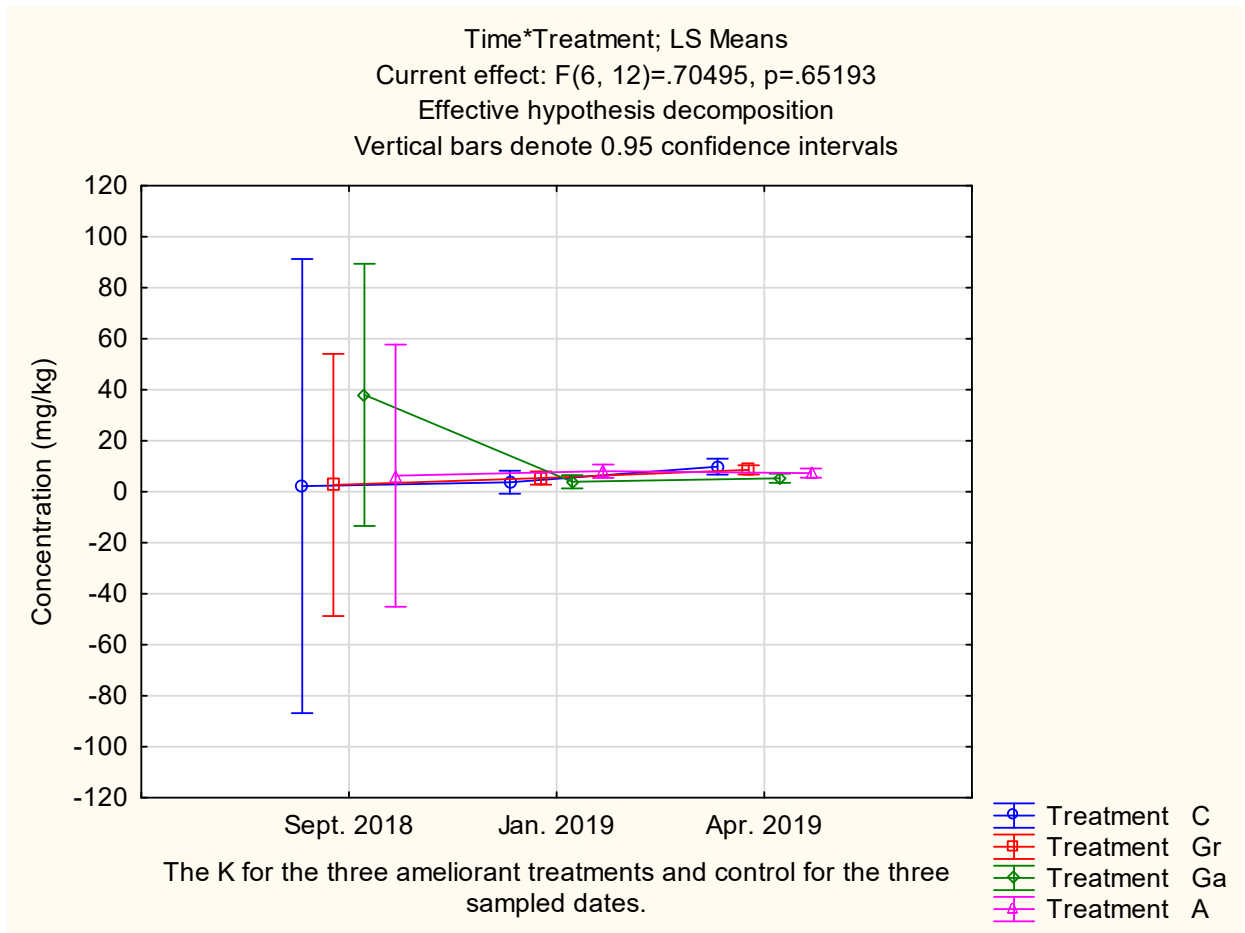
Annexures

Annexure 8: The statistical results of the soil analysis of each concentration ameliorant treatments.



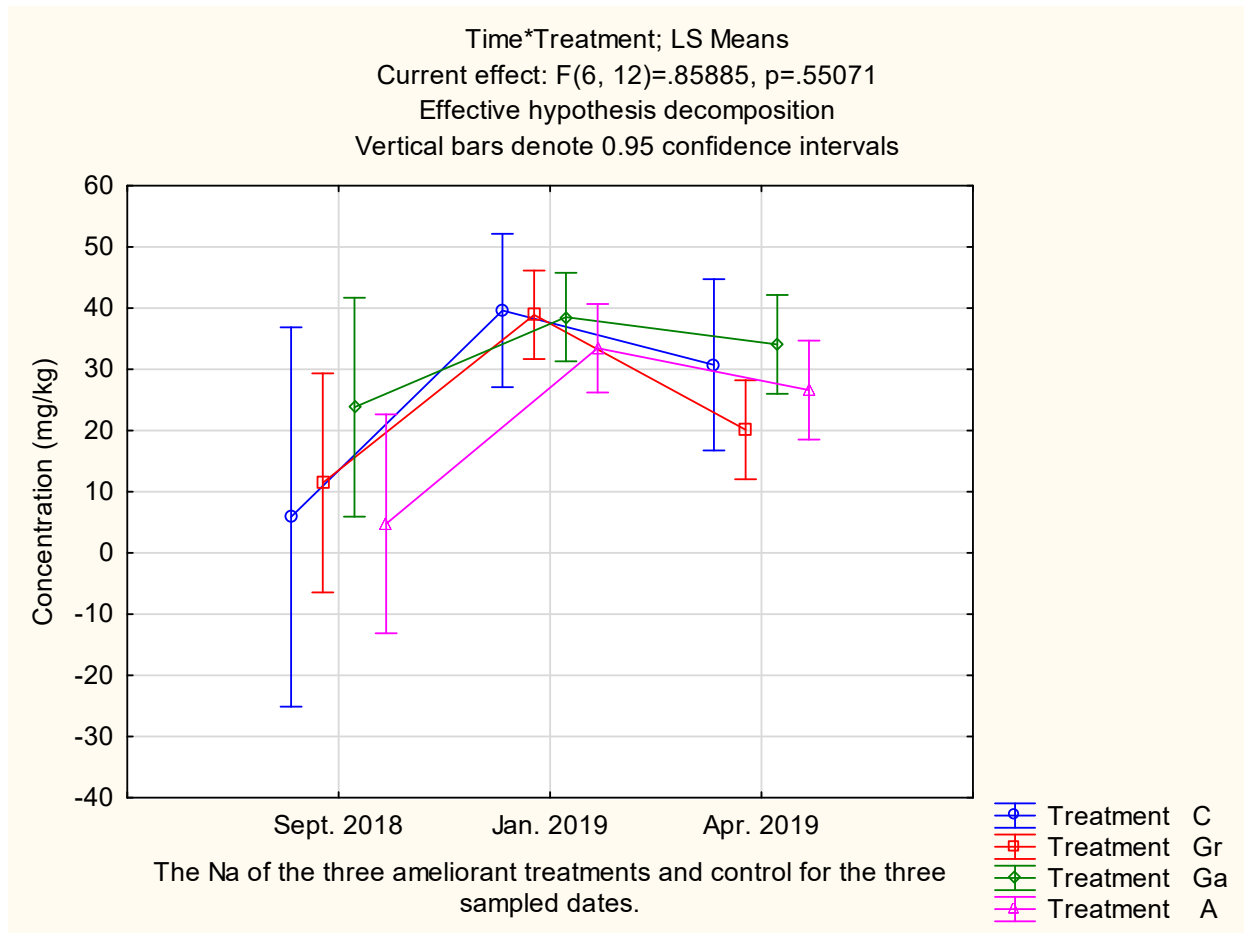
Effect	Repeated Measures Analysis of Variance (Nutrient status) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	448286.7	1	448286.7	86.16274	0.000088
Treatment	17469.2	3	5823.1	1.11922	0.412666
Error	31216.7	6	5202.8		
Time	344652.7	2	172326.4	23.60688	0.000069
Time*Treatment	44372.4	6	7395.4	1.01309	0.461117
Error	87598.0	12	7299.8		

Annexures



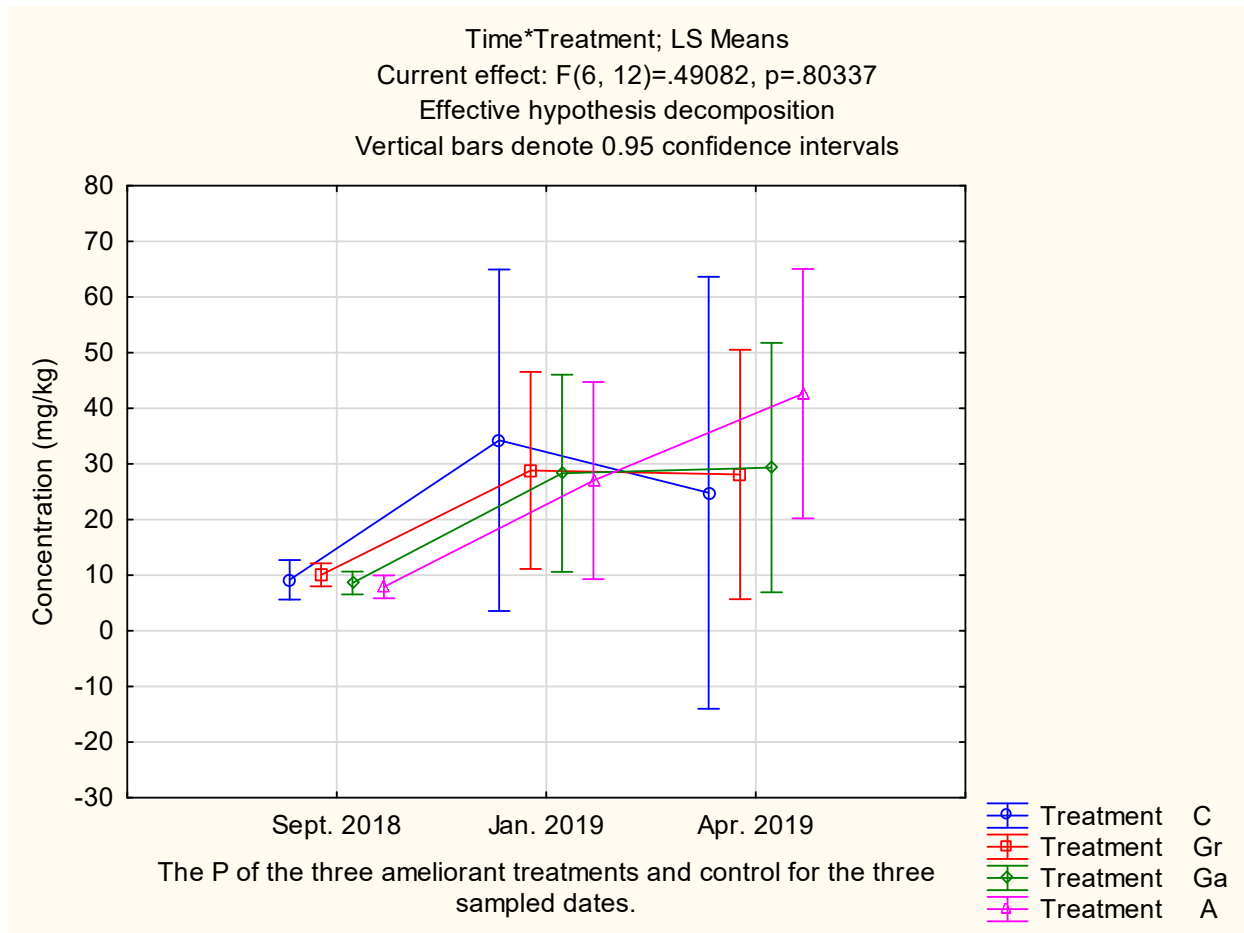
Effect	Repeated Measures Analysis of Variance (Nutrient status) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	1703.816	1	1703.816	3.936782	0.094481
Treatment	585.411	3	195.137	0.450877	0.725991
Error	2596.764	6	432.794		
Time	203.237	2	101.618	0.226678	0.800515
Time*Treatment	1896.155	6	316.026	0.704951	0.651926
Error	5379.541	12	448.295		

Annexures



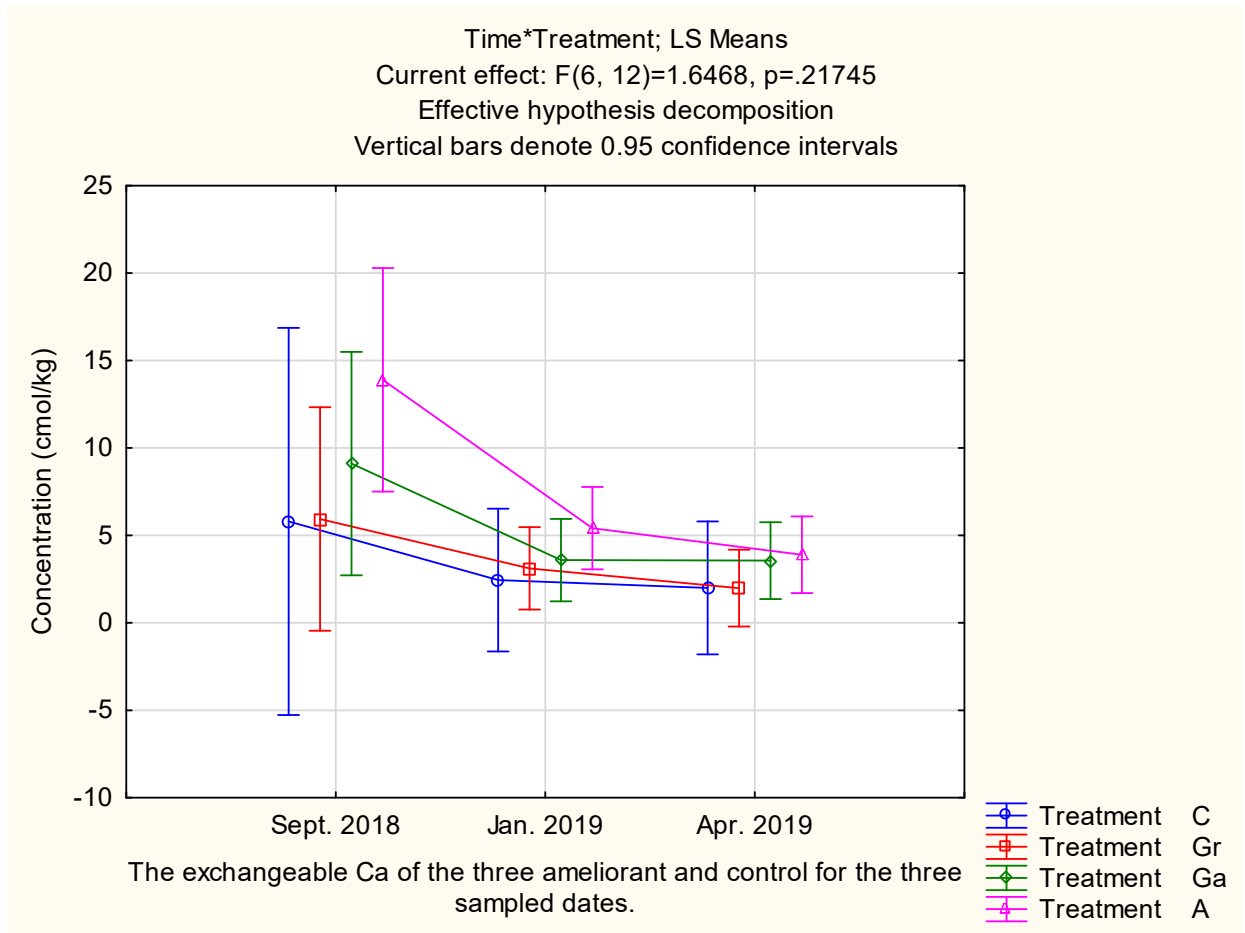
Effect	Repeated Measures Analysis of Variance (Nutrient status) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	15801.09	1	15801.09	262.1792	0.000004
Treatment	567.73	3	189.24	3.1400	0.108298
Error	361.61	6	60.27		
Time	2795.58	2	1397.79	17.5849	0.000271
Time*Treatment	409.61	6	68.27	0.8588	0.550712
Error	953.86	12	79.49		

Annexures



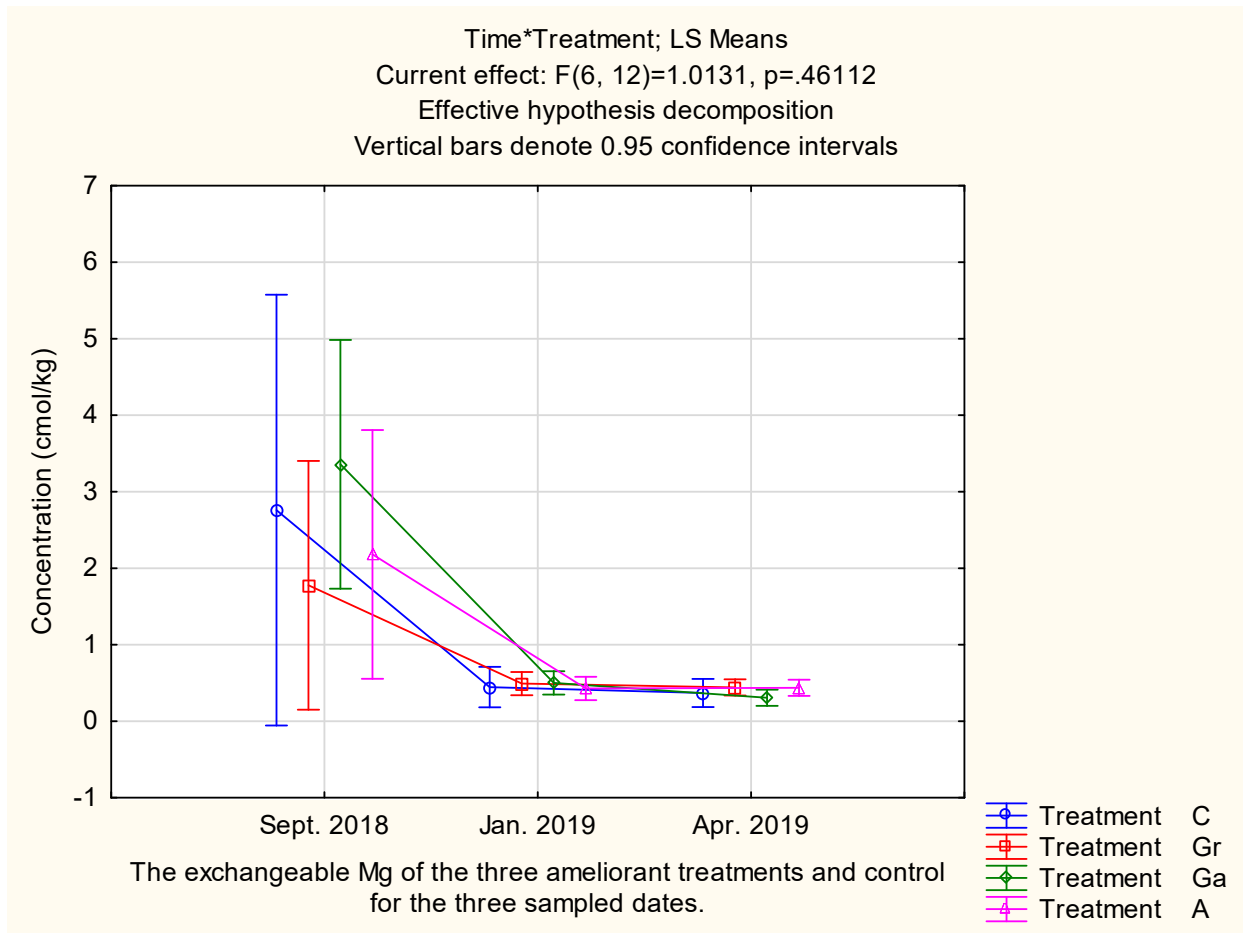
Effect	Repeated Measures Analysis of Variance (Nutrient status) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	12971.95	1	12971.95	103.4799	0.000053
Treatment	80.82	3	26.94	0.2149	0.882636
Error	752.14	6	125.36		
Time	2469.80	2	1234.90	8.6448	0.004729
Time*Treatment	420.68	6	70.11	0.4908	0.803373
Error	1714.19	12	142.85		

Annexures



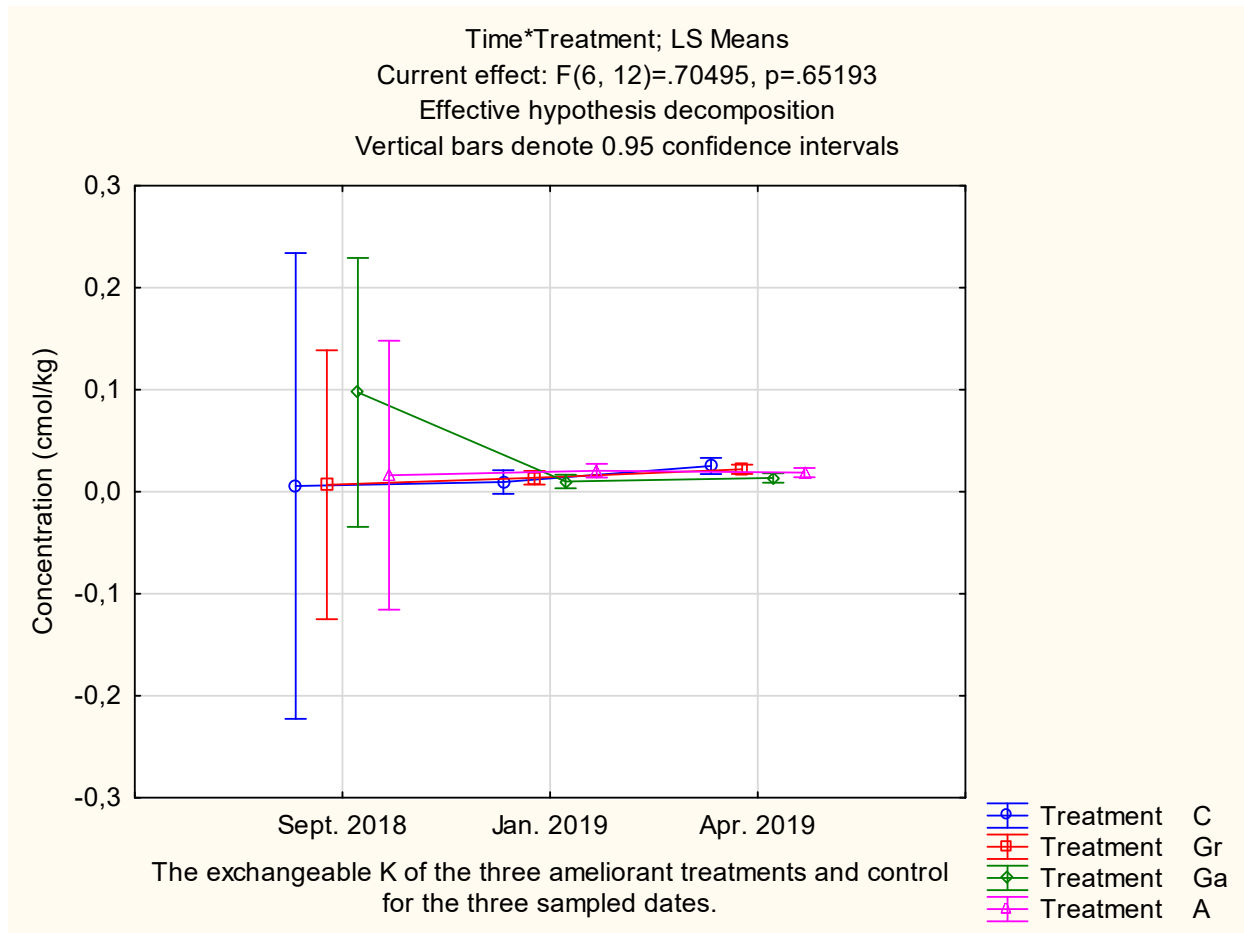
Effect	Repeated Measures Analysis of Variance (Exchangeable cations) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	615.4195	1	615.4195	35.30630	0.001015
Treatment	87.5398	3	29.1799	1.67404	0.270416
Error	104.5852	6	17.4309		
Time	160.0560	2	80.0280	19.44400	0.000172
Time*Treatment	40.6668	6	6.7778	1.64677	0.217453
Error	49.3898	12	4.1158		

Annexures



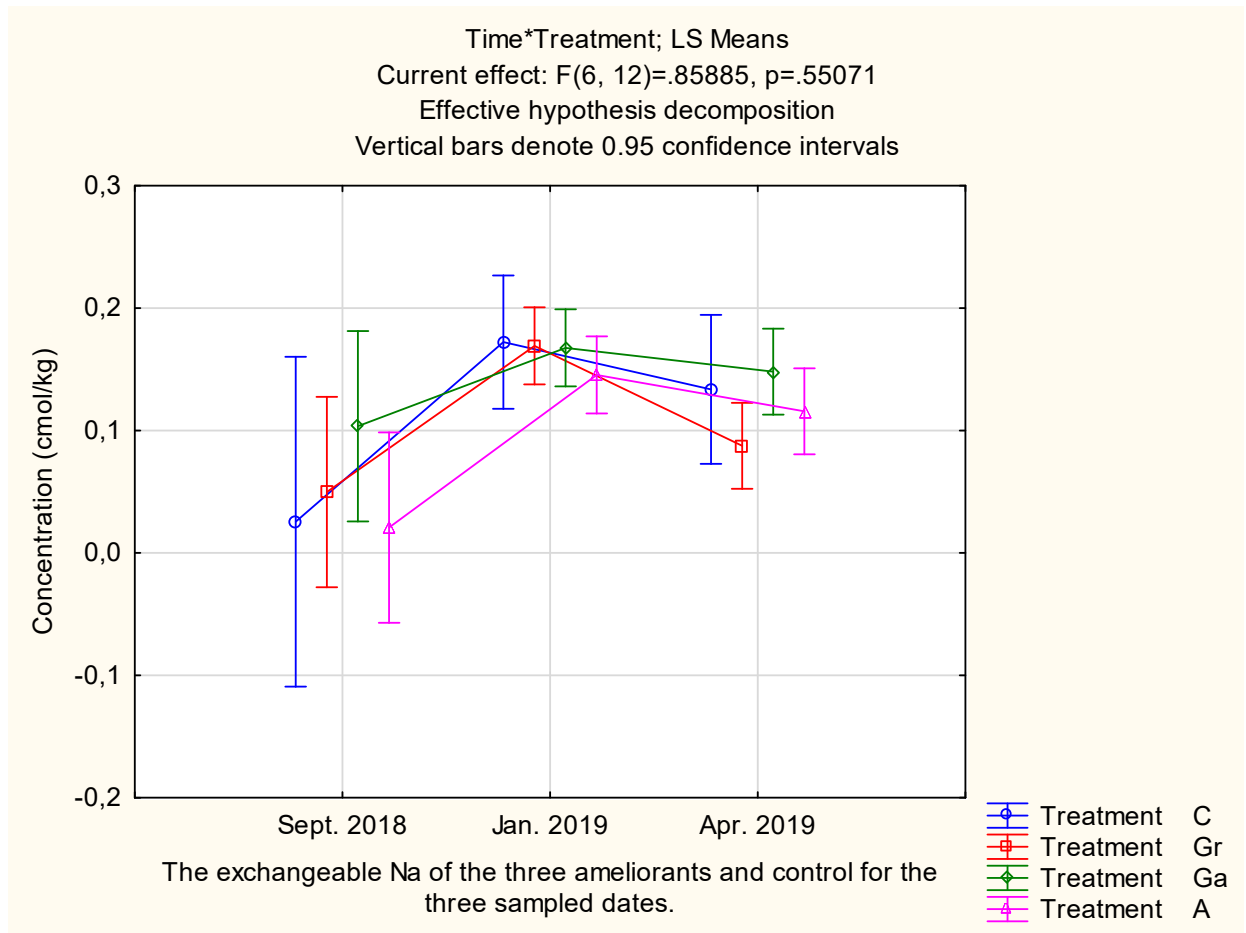
Effect	Repeated Measures Analysis of Variance (Exchangeable cations) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	30.36710	1	30.36710	86.16274	0.000088
Treatment	1.18337	3	0.39446	1.11922	0.412666
Error	2.11463	6	0.35244		
Time	23.34690	2	11.67345	23.60688	0.000069
Time*Treatment	3.00580	6	0.50097	1.01309	0.461117
Error	5.93392	12	0.49449		

Annexures



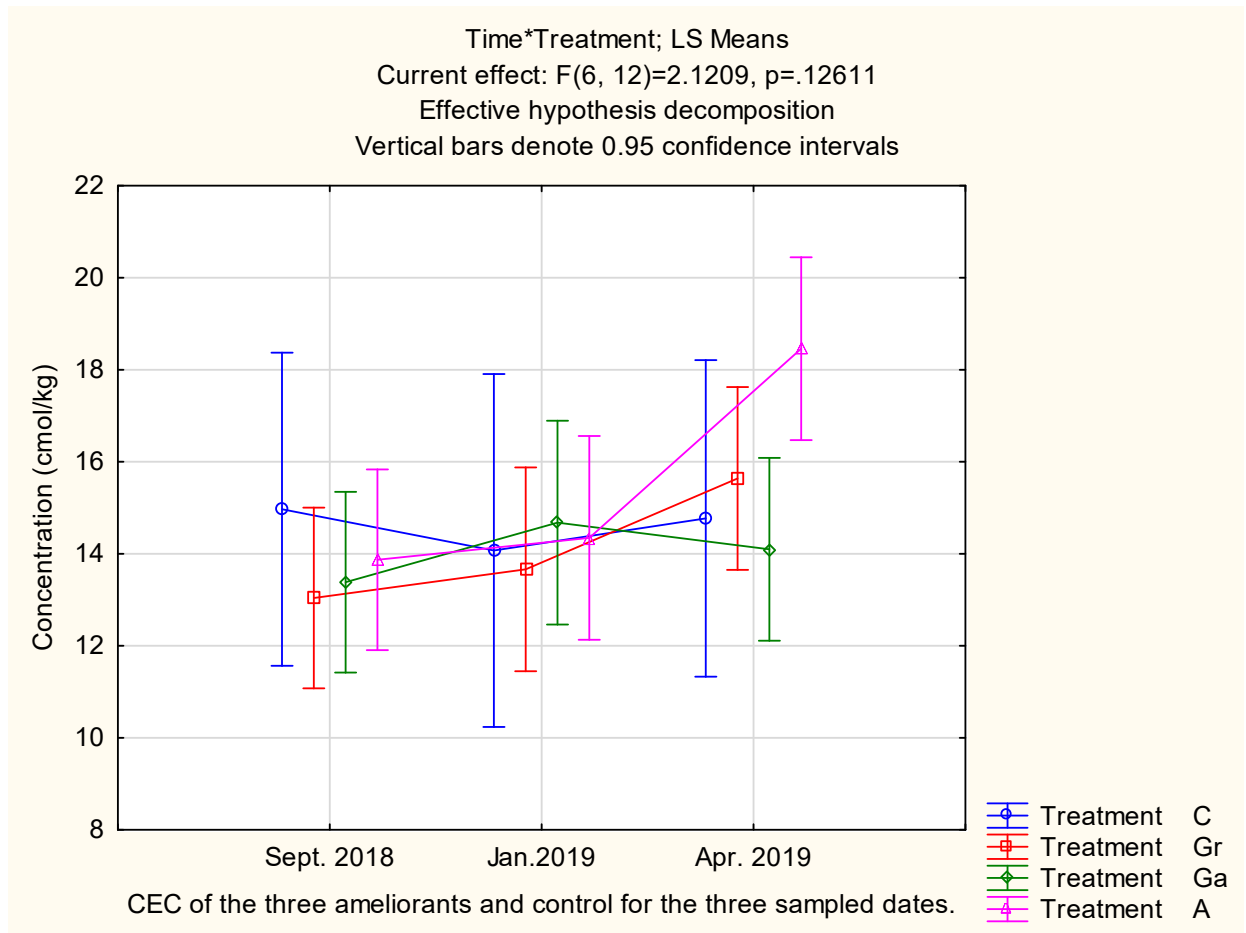
Effect	Repeated Measures Analysis of Variance (Exchangeable cations) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	0.011202	1	0.011202	3.936782	0.094481
Treatment	0.003849	3	0.001283	0.450877	0.725991
Error	0.017073	6	0.002845		
Time	0.001336	2	0.000668	0.226678	0.800515
Time*Treatment	0.012467	6	0.002078	0.704951	0.651926
Error	0.035368	12	0.002947		

Annexures



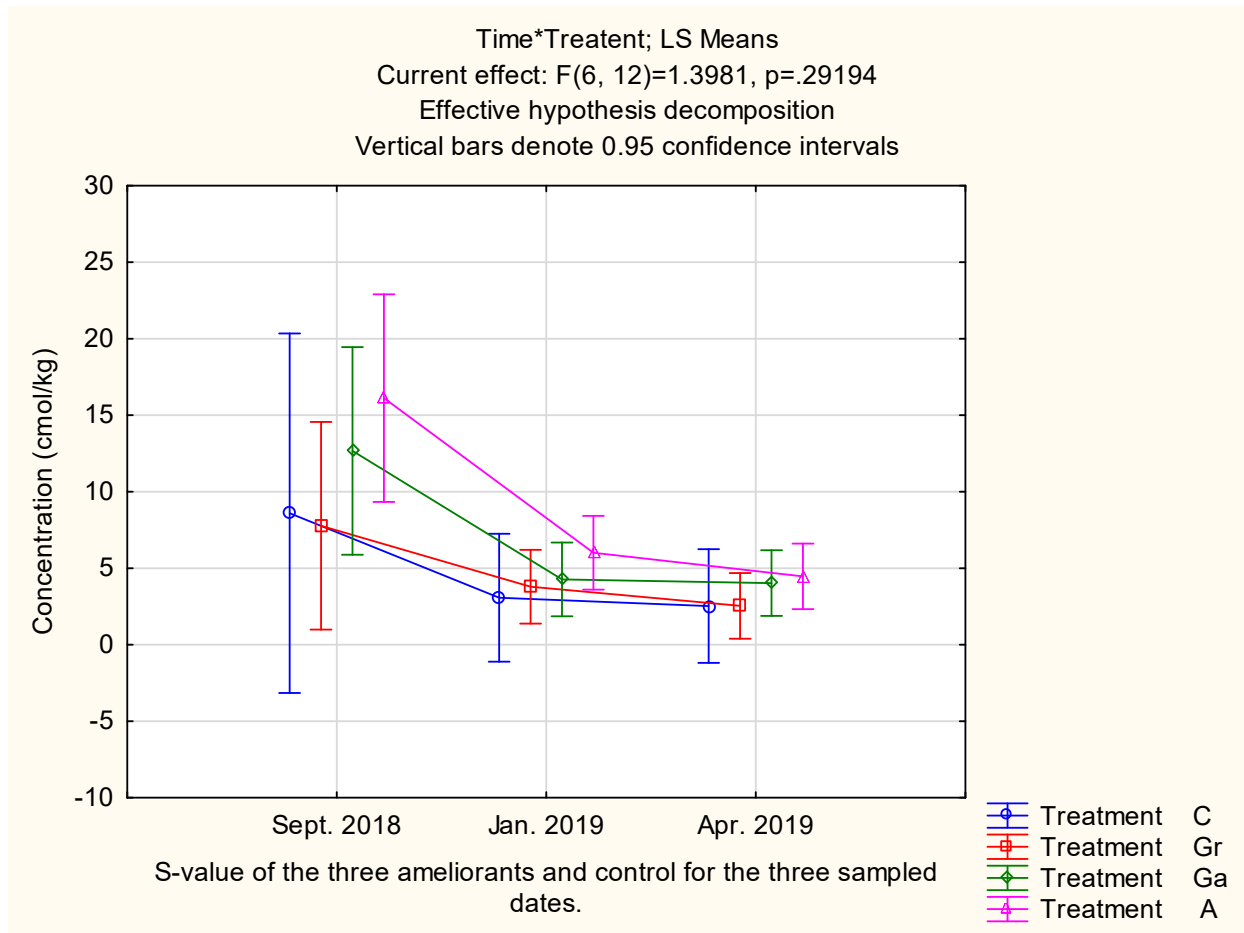
Effect	Repeated Measures Analysis of Variance (Exchangeable cations)				
	Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	0.298697	1	0.298697	262.1792	0.000004
Treatment	0.010732	3	0.003577	3.1400	0.108298
Error	0.006836	6	0.001139		
Time	0.052847	2	0.026423	17.5849	0.000271
Time*Treatment	0.007743	6	0.001291	0.8588	0.550712
Error	0.018031	12	0.001503		

Annexures



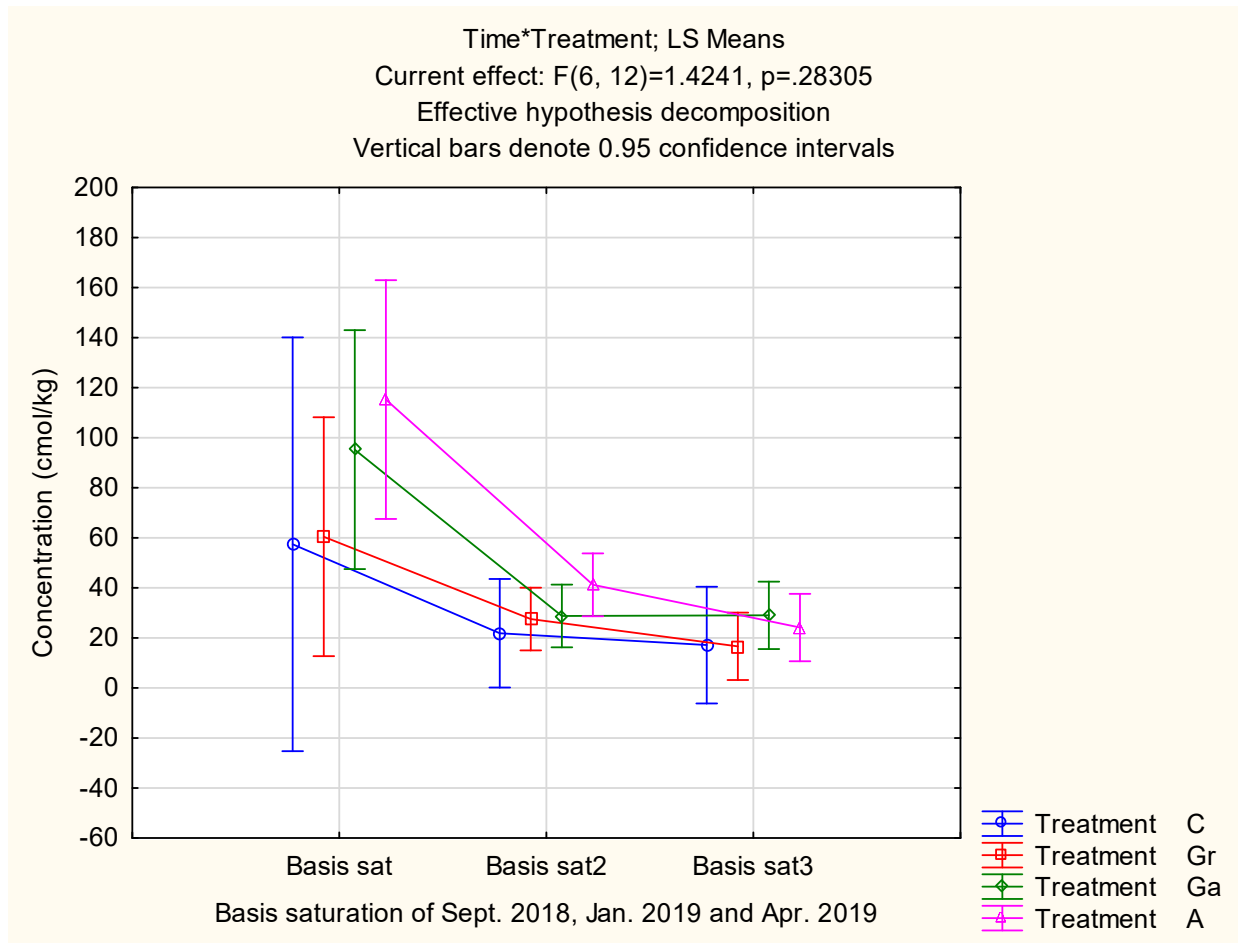
Effect	Repeated Measures Analysis of Variance (Exchangeable cations) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	5102.740	1	5102.740	1811.825	0.000000
Treatment	13.071	3	4.357	1.547	0.296646
Error	16.898	6	2.816		
Time	16.678	2	8.339	4.697	0.031141
Time*Treatment	22.593	6	3.766	2.121	0.126113
Error	21.305	12	1.775		

Annexures



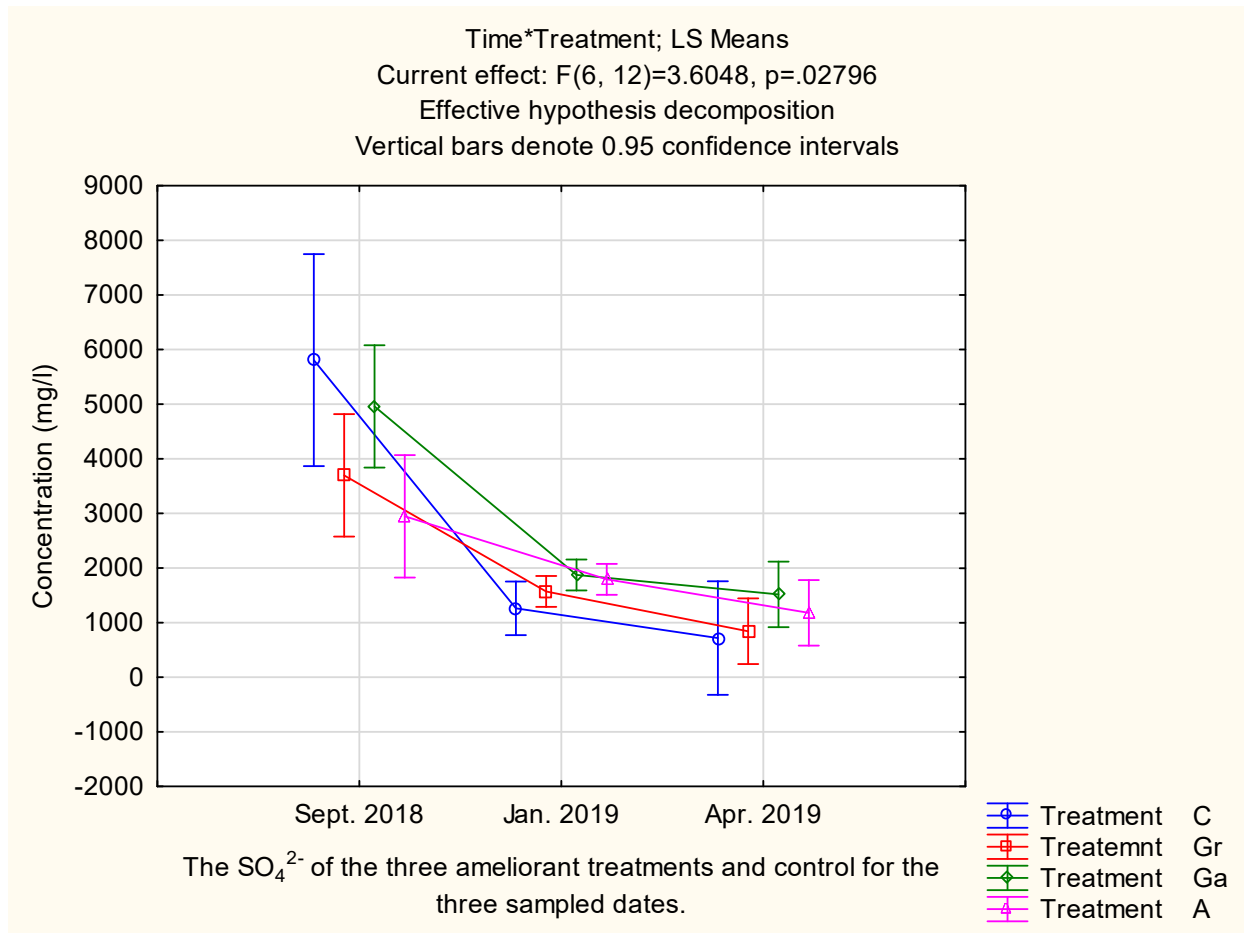
Effect	Repeated Measures Analysis of Variance (Exchangeable cations) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	959.1816	1	959.1816	54.30910	0.000320
Treatment	90.4022	3	30.1341	1.70620	0.264253
Error	105.9692	6	17.6615		
Time	299.1948	2	149.5974	28.17137	0.000029
Time*Treatment	44.5468	6	7.4245	1.39813	0.291943
Error	63.7232	12	5.3103		

Annexures



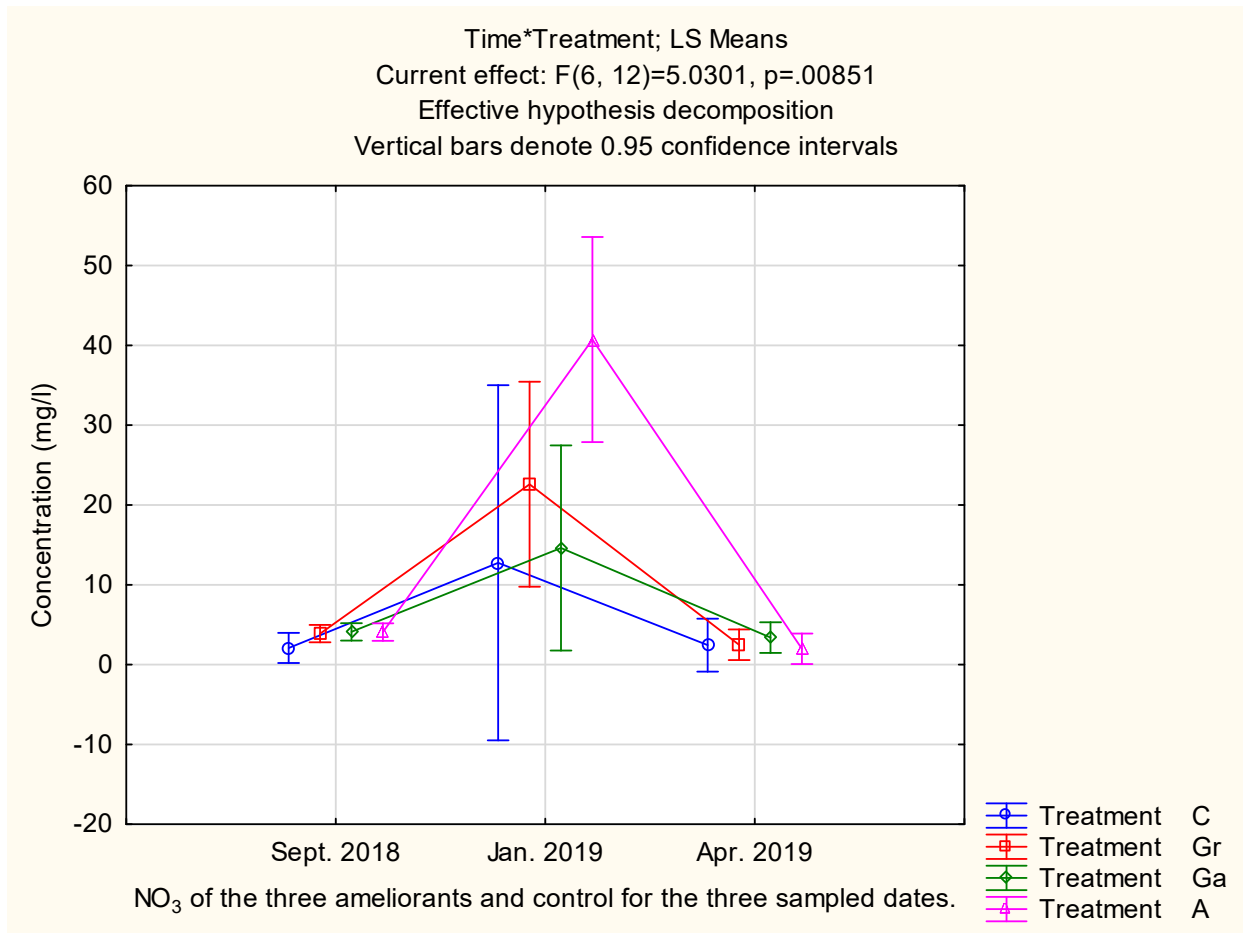
Effect	Repeated Measures Analysis of Variance (Exchangeable cations) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	47631.93	1	47631.93	67.83528	0.000173
Treatment	3702.80	3	1234.27	1.75779	0.254740
Error	4213.02	6	702.17		
Time	17169.75	2	8584.87	28.18718	0.000029
Time*Treatment	2602.38	6	433.73	1.42409	0.283055
Error	3654.80	12	304.57		

Annexures



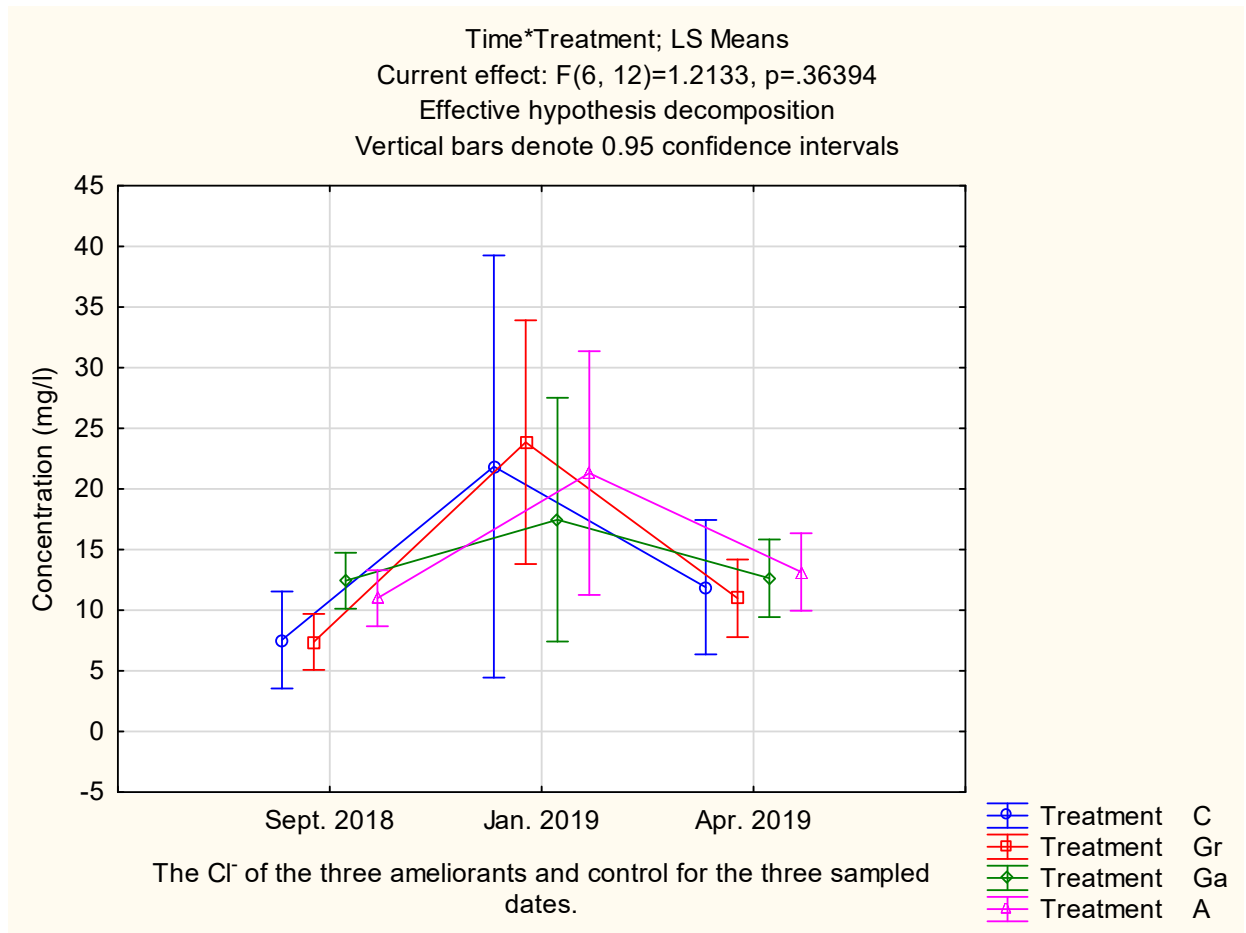
Effect	Repeated Measures Analysis of Variance (SO_4^{2-}) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	132158603	1	132158603	615.6359	0.000000
Treatment	3949811	3	1316604	6.1332	0.029364
Error	1288020	6	214670		
Time	49527263	2	24763631	77.9312	0.000000
Time*Treatment	6872920	6	1145487	3.6048	0.027964
Error	3813154	12	317763		

Annexures



Effect	Repeated Measures Analysis of Variance (NO ₃) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	2210.304	1	2210.304	75.63532	0.000128
Treatment	395.105	3	131.702	4.50675	0.055683
Error	175.339	6	29.223		
Time	2056.762	2	1028.381	36.81387	0.000008
Time*Treatment	843.086	6	140.514	5.03012	0.008506
Error	335.215	12	27.935		

Annexures



Effect	Repeated Measures Analysis of Variance (Saturated paste) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	4902.042	1	4902.042	174.2495	0.000012
Treatment	7.632	3	2.544	0.0904	0.962650
Error	168.794	6	28.132		
Time	586.020	2	293.010	19.3780	0.000175
Time*Treatment	110.073	6	18.346	1.2133	0.363939
Error	181.449	12	15.121		

Annexures

Annexure 9: The statistical t-tests results of the lime effects on the germination rate of the three different treatments and control (control, granite, gabbro and andesite).

Variable	Treatment=C T-tests; Grouping: Lime (Germination rate) Group 1: 1 Group 2: 0								
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1	Std.Dev. 0
Total	4.000000	0.00	1.000000	4	0.373901	3	3	6.92820 3	0.00

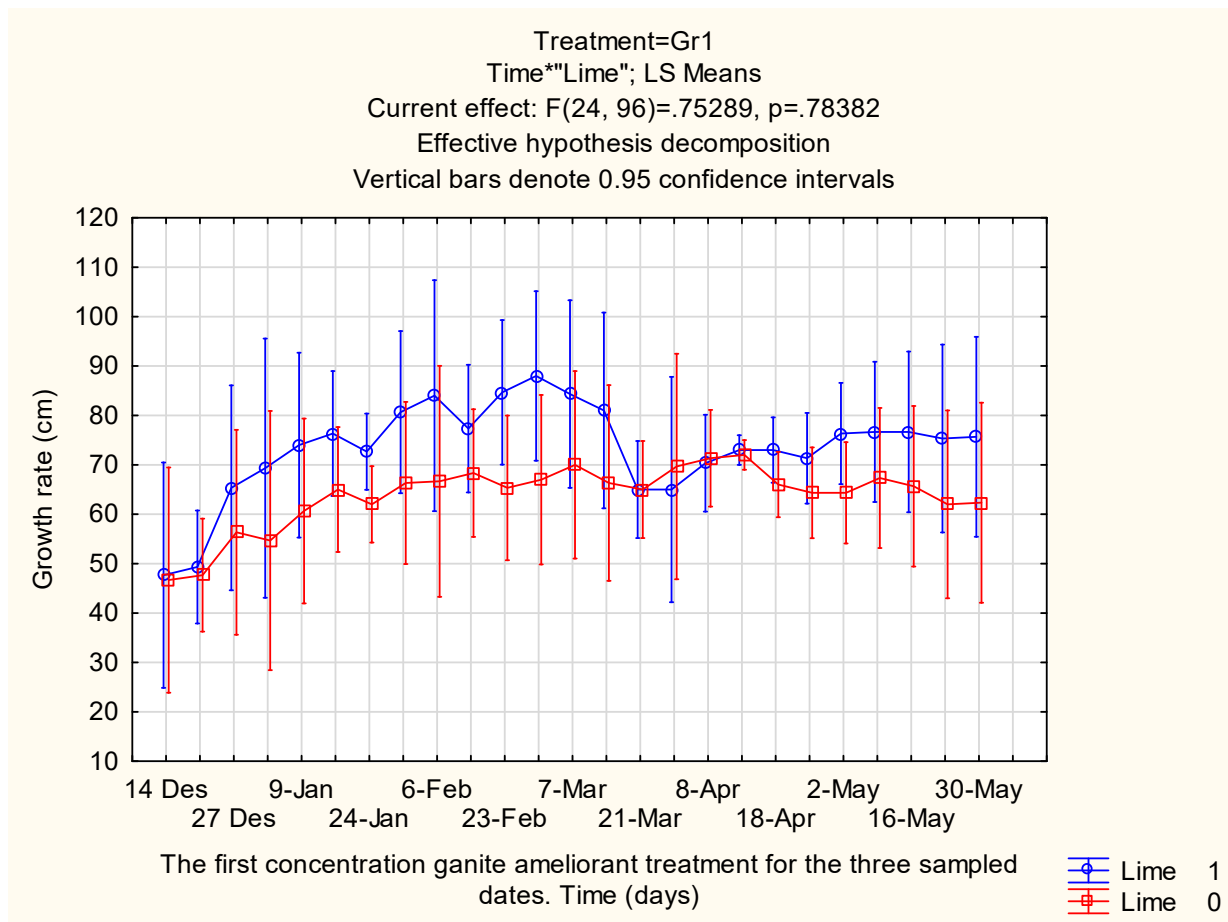
Variable	Treatment=Gr T-tests; Grouping: Lime (Germination rate) Group 1: 1 Group 2: 0								
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1	Std.Dev. 0
Total	0.125000	0.400000	-0.593350	16	0.561242	8	10	0.353553	

Variable	Treatment=Ga T-tests; Grouping: Lime (Germination rate) Group 1: 1 Group 2: 0								
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1	Std.Dev. 0
Total	6.000000	4.666667	0.242202	16	0.811701	9	9	11.13553	

Variable	Treatment=A T-tests; Grouping: Lime (Germination rate) Group 1: 1 Group 2: 0								
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1	Std.Dev. 0
Total	9.777778	8.222222	0.267921	16	0.792183	9	9	13.60862	

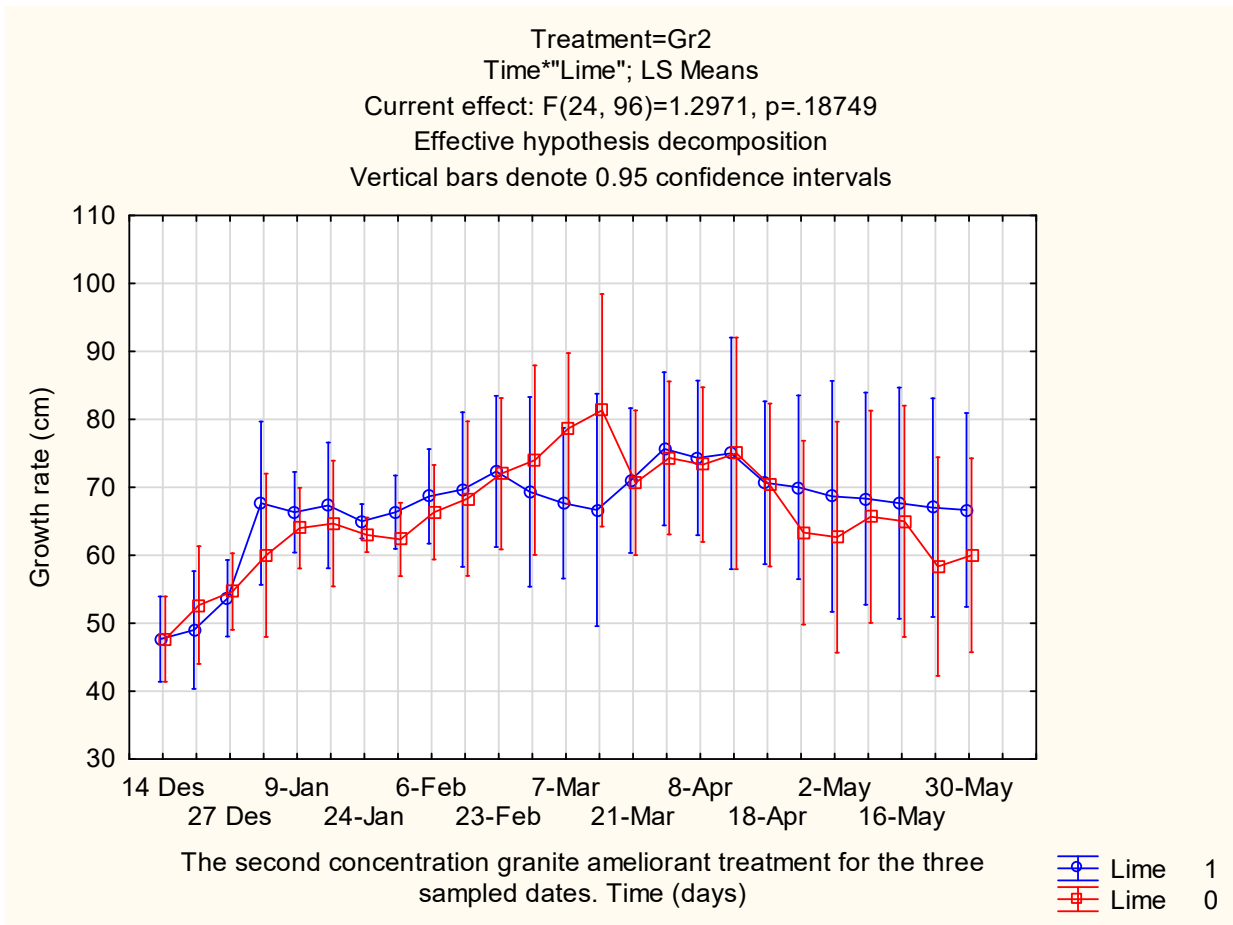
Annexures

Annexure 10: The statistical results of growth rate results for all the treatments (control, granite, gabbro and andesite).



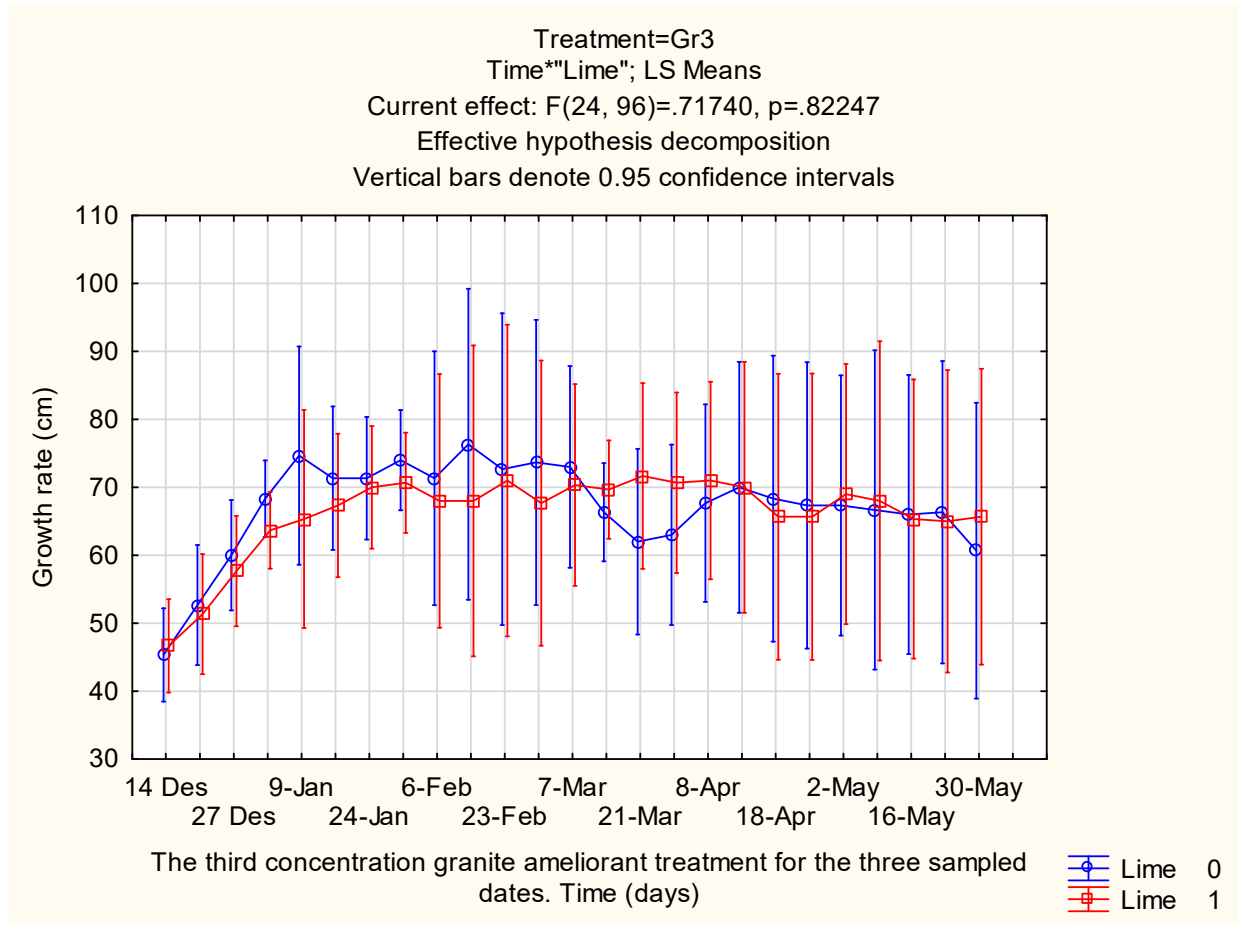
Effect	Treatment=Gr1 Repeated Measures Analysis of Variance (Growth rate) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	704248.6	1	704248.6	1384.245	0.000003
Lime	3456.0	1	3456.0	6.793	0.059649
Error	2035.0	4	508.8		
Time	8031.4	24	334.6	3.776	0.000002
Time**Lime"	1601.3	24	66.7	0.753	0.783824
Error	8507.6	96	88.6		

Annexures



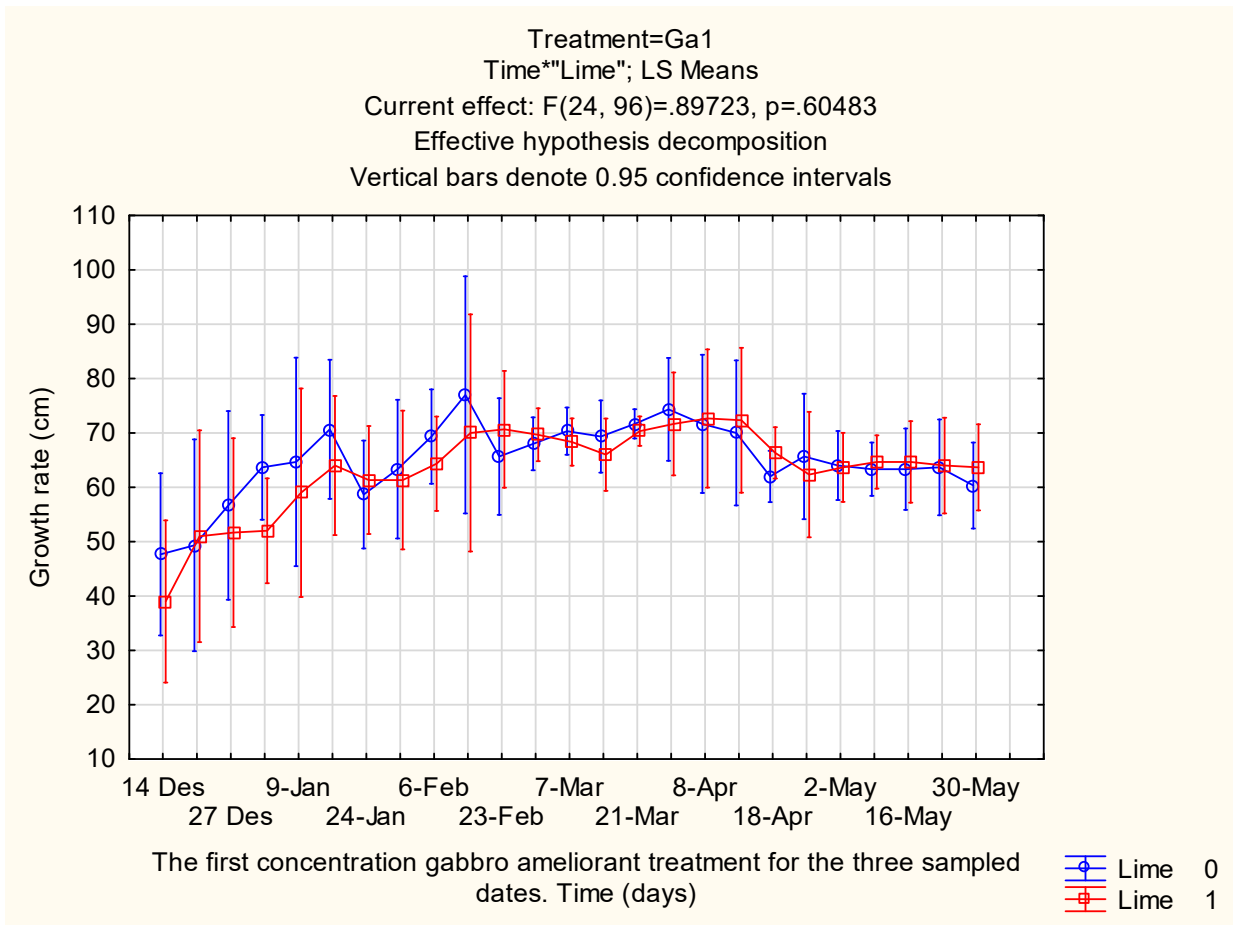
Effect	Treatment=Gr2 Repeated Measures Analysis of Variance (Growth rate) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	661609.6	1	661609.6	1029.305	0.000006
Lime	34.6	1	34.6	0.054	0.828013
Error	2571.1	4	642.8		
Time	7186.0	24	299.4	9.342	0.000000
Time*"Lime"	997.8	24	41.6	1.297	0.187490
Error	3076.9	96	32.1		

Annexures



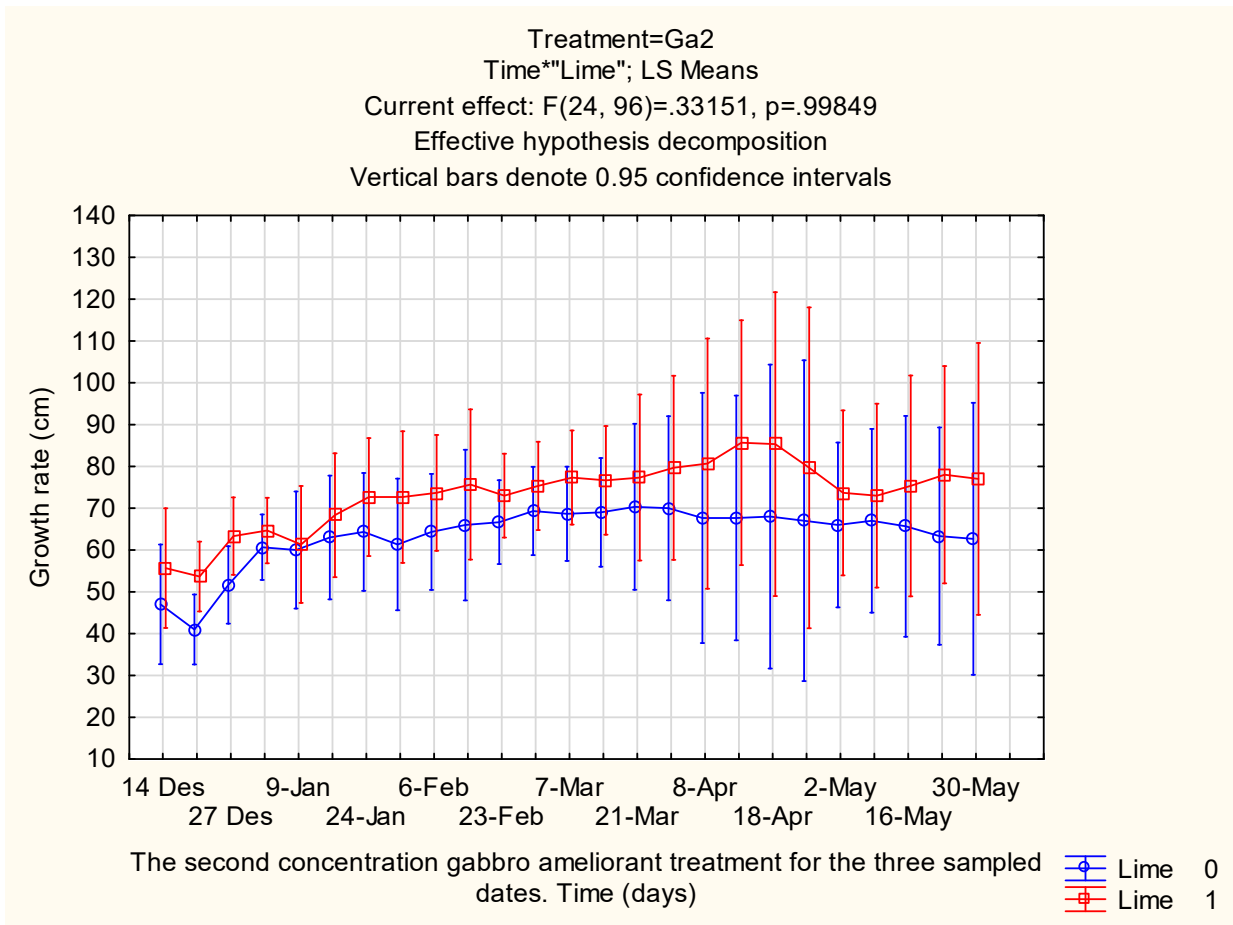
Effect	Treatment=Gr3 Repeated Measures Analysis of Variance (Growth rate) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	665866.9	1	665866.9	387.3376	0.000039
Lime	27.3	1	27.3	0.0159	0.905787
Error	6876.3	4	1719.1		
Time	5486.4	24	228.6	5.5695	0.000000
Time*"Lime"	706.7	24	29.4	0.7174	0.822468
Error	3940.3	96	41.0		

Annexures



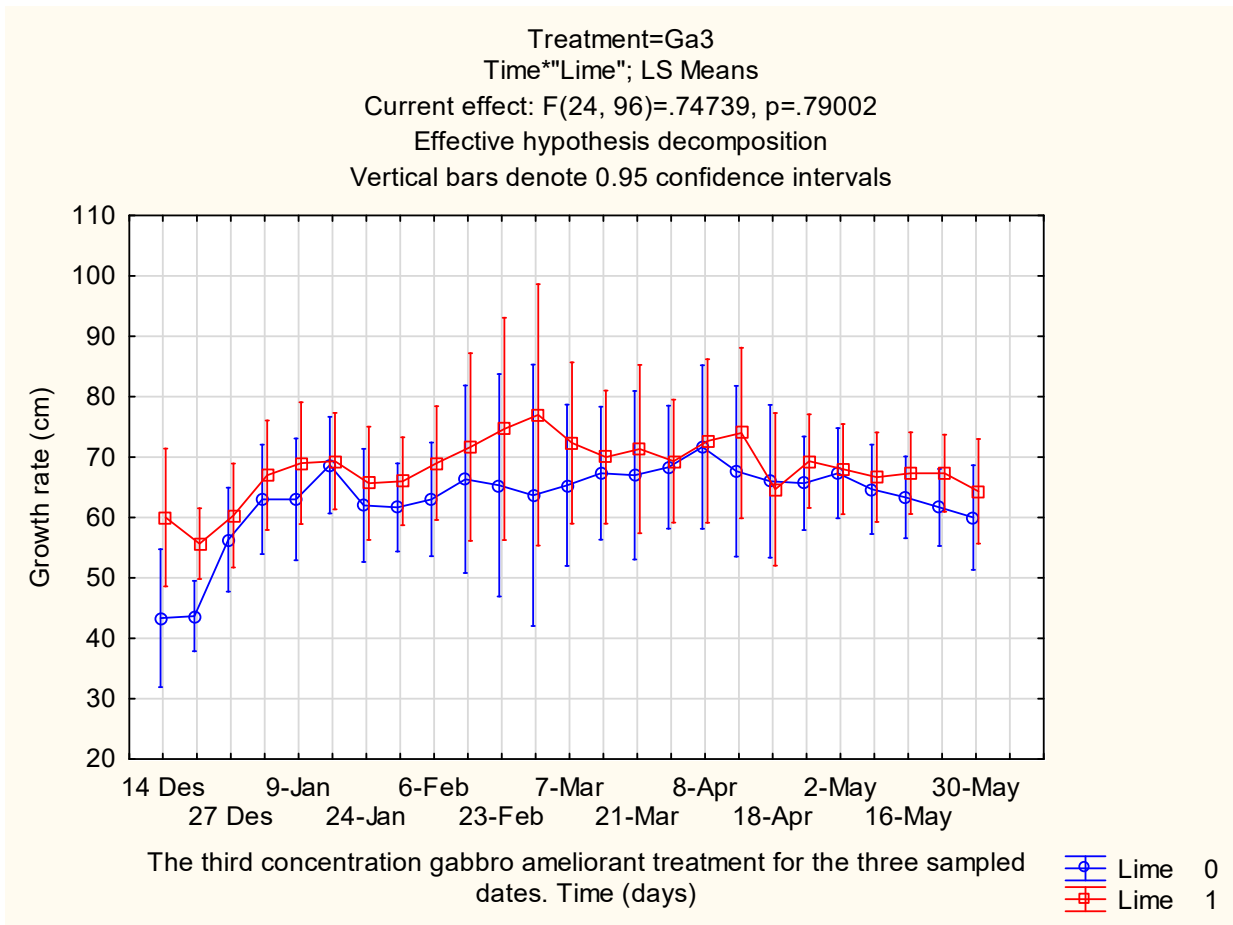
Effect	Treatment=Ga1 Repeated Measures Analysis of Variance (Growth rate) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	617860.9	1	617860.9	1058.247	0.000005
Lime	94.4	1	94.4	0.162	0.708160
Error	2335.4	4	583.9		
Time	7320.0	24	305.0	9.935	0.000000
Time*"Lime"	661.1	24	27.5	0.897	0.604826
Error	2947.3	96	30.7		

Annexures



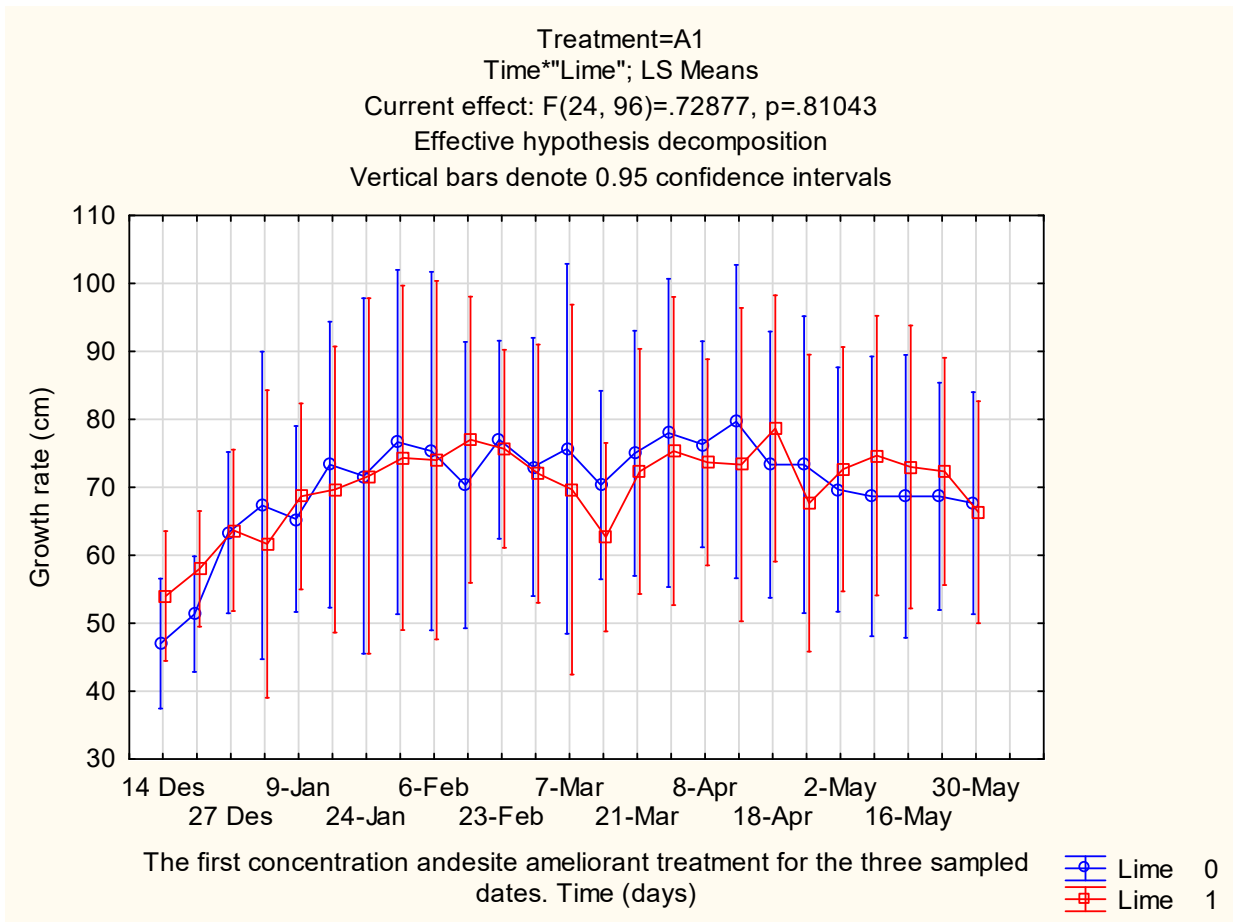
Effect	Treatment=Ga2 Repeated Measures Analysis of Variance (Growth rate) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	700826.7	1	700826.7	276.4806	0.000077
Lime	3484.9	1	3484.9	1.3748	0.306053
Error	10139.3	4	2534.8		
Time	7811.8	24	325.5	4.4473	0.000000
Time*"Lime"	582.3	24	24.3	0.3315	0.998492
Error	7026.1	96	73.2		

Annexures



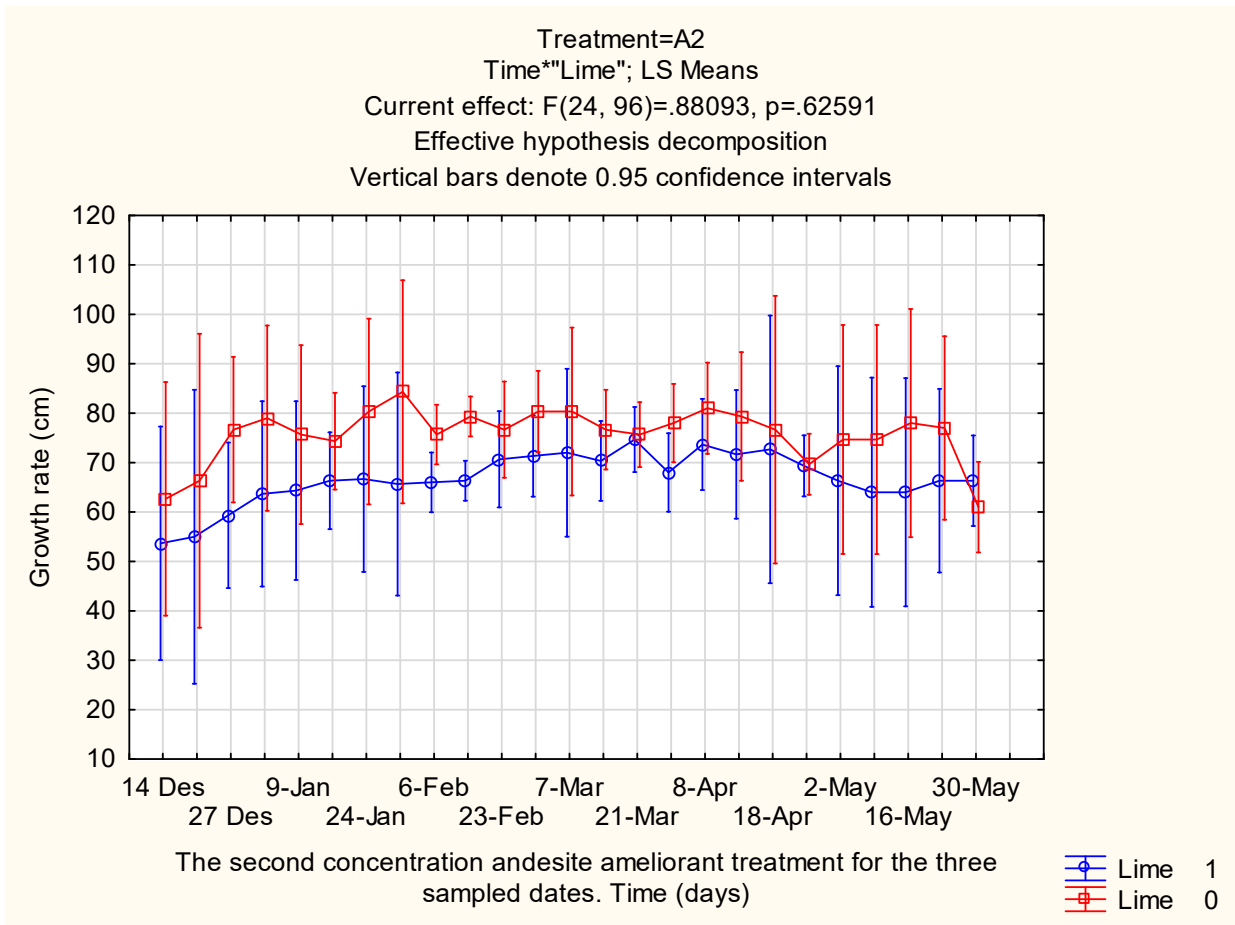
Effect	Treatment=Ga3 Repeated Measures Analysis of Variance (Growth rate) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	644979.3	1	644979.3	1502.864	0.000003
Lime	962.7	1	962.7	2.243	0.208566
Error	1716.7	4	429.2		
Time	4243.0	24	176.8	5.112	0.000000
Time*"Lime"	620.3	24	25.8	0.747	0.790017
Error	3320.0	96	34.6		

Annexures



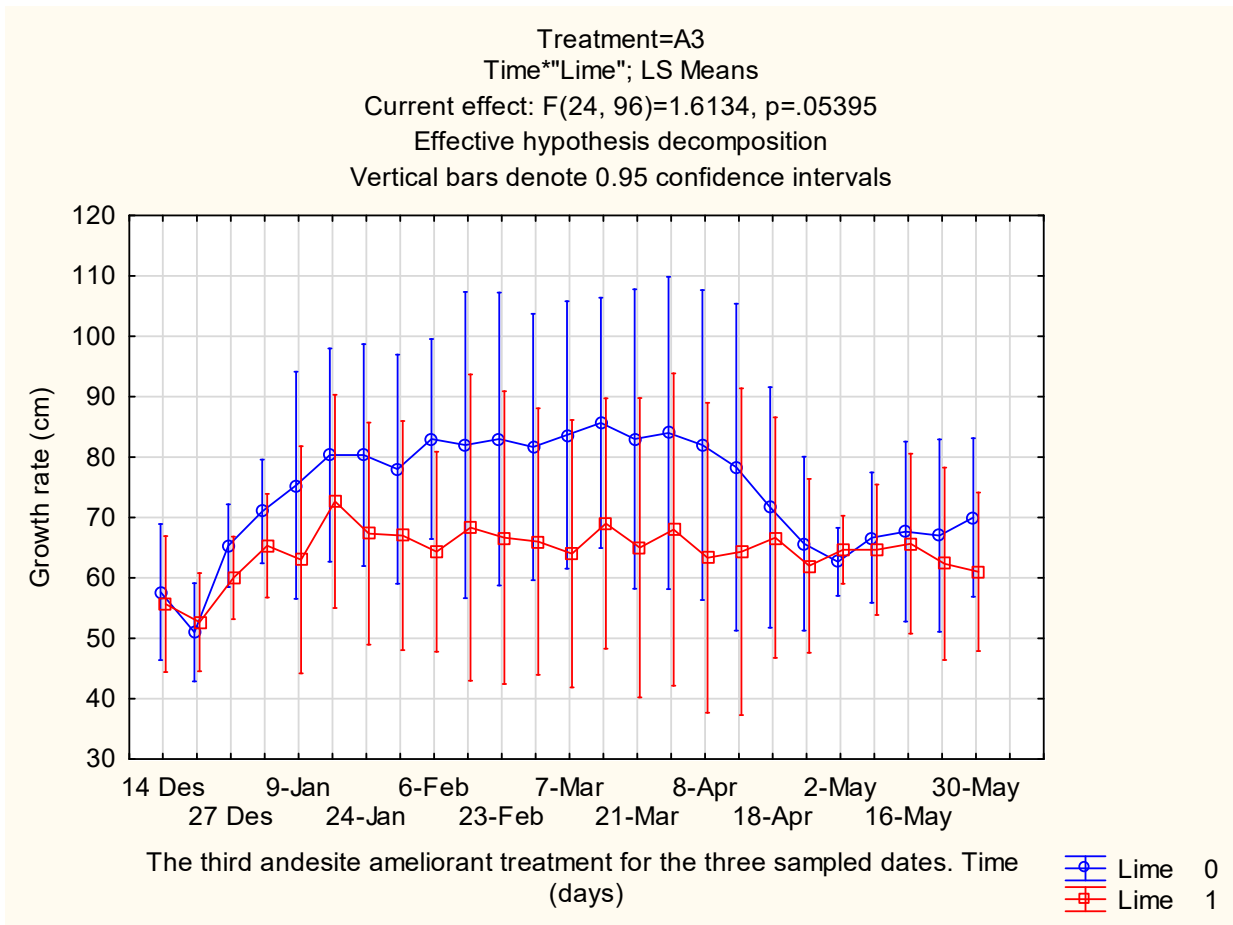
Effect	Treatment=A1 Repeated Measures Analysis of Variance (Growth rate) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	738925.2	1	738925.2	272.6386	0.000079
Lime	1.0	1	1.0	0.0004	0.985886
Error	10841.1	4	2710.3		
Time	6046.1	24	251.9	5.8773	0.000000
Time*"Lime"	749.7	24	31.2	0.7288	0.810431
Error	4114.9	96	42.9		

Annexures



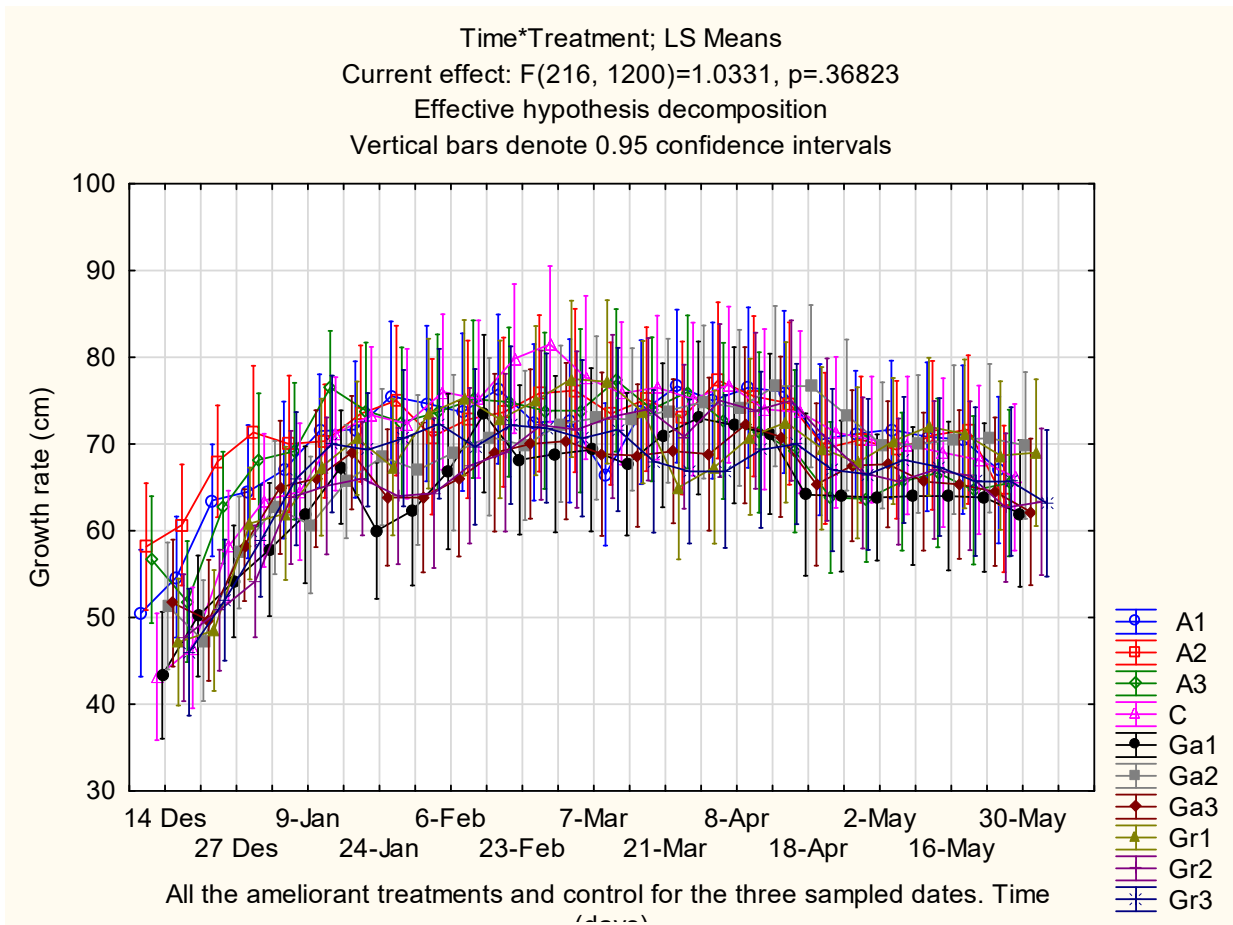
Effect	Treatment=A2 Repeated Measures Analysis of Variance (Growth rate) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	761413.1	1	761413.1	480.0274	0.000026
Lime	3055.5	1	3055.5	1.9263	0.237466
Error	6344.7	4	1586.2		
Time	3145.4	24	131.1	2.7336	0.000280
Time*"Lime"	1013.6	24	42.2	0.8809	0.625912
Error	4602.6	96	47.9		

Annexures



Effect	Treatment=A3 Repeated Measures Analysis of Variance (Growth rate) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	720928.0	1	720928.0	309.3669	0.000061
Lime	3660.5	1	3660.5	1.5708	0.278348
Error	9321.3	4	2330.3		
Time	5894.8	24	245.6	5.6736	0.000000
Time*"Lime"	1676.3	24	69.8	1.6134	0.053952
Error	4156.0	96	43.3		

Annexures



Effect	Repeated Measures Analysis of Variance (Growth rate) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	6944571	1	6944571	4782.393	0.000000
Treatment	6948	9	772	0.532	0.844540
Error	72606	50	1452		
Time	57088	24	2379	51.052	0.000000
Time*Treatment	10397	216	48	1.033	0.368232
Error	55912	1200	47		

Annexures

Annexure 11: The statistical results of the lime effects on the biomass production of the three different treatments and control (control, granite, gabbro and andesite).

Effect	All Groups Univariate Tests of Significance (Biomass) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	49462.18	1	49462.18	445.3189	0.000000
Lime	275.34	3	91.78	0.8263	0.484938
Error	6220.00	56	111.07		

Effect	Treatment=C Univariate Tests of Significance (Biomass) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	4637.633	1	4637.633	50.22708	0.019334
Lime	78.833	3	26.278	0.28460	0.836358
Error	184.667	2	92.333		

Effect	Treatment=Gr Univariate Tests of Significance (Biomass) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	10015.47	1	10015.47	152.6140	0.000000
Lime	39.73	3	13.24	0.2018	0.893402
Error	918.77	14	65.63		

Effect	Treatment=Ga Univariate Tests of Significance (Biomass) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	18748.90	1	18748.90	100.9039	0.000000
Lime	45.17	3	15.06	0.0810	0.969256
Error	2601.33	14	185.81		

Annexures

Effect	Treatment=A Univariate Tests of Significance (Biomass) Sigma-restricted parameterisation Effective hypothesis decomposition				
	SS	Degree of Freedom	MS	F	p
Intercept	16782.68	1	16782.68	235.5332	0.000000
Lime	620.06	3	206.69	2.9007	0.072132
Error	997.56	14	71.25		

Variable	All Groups T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Biomass only	31.89655	34.67742	-1.02638	58	0.308976	29	31	8.636901

Variable	Treatment=C T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Biomass only	30.66667	32.33333	-0.253510	4	0.812371	3	3	6.110101

Variable	Treatment=Gr T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Biomass only	28.37500	26.80000	0.431485	16	0.671874	8	10	10.04188

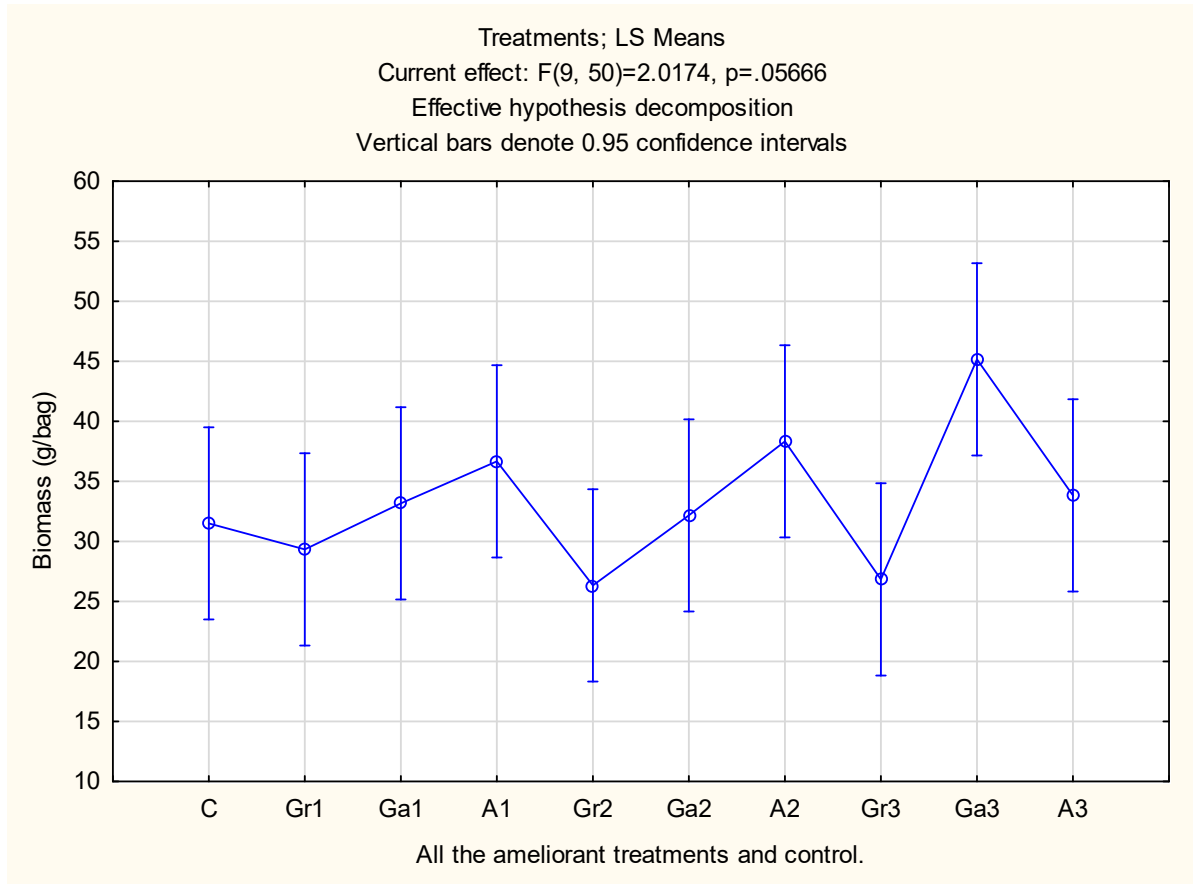
Variable	Treatment=Ga T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Biomass only	35.33333	38.33333	-0.498655	16	0.624808	9	9	8.139410

Annexures

Variable	Treatment=A T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Biomass only	32.00000	40.55556	-2.02264	16	0.060154	9	9	8.426150

Annexures

Annexure 12: The statistical results of biomass production of each concentration ameliorant treatments.



Variable	Treatment=C T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
	Biomass only	30.66667	32.33333	-0.253510	4	0.812371	3	3

Variable	Treatment=Gr1 T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
	Biomass only	33.66667	25.00000	1.096744	4	0.334347	3	3

Annexures

Variable	Treatment=Ga1 T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Biomass only	28.66667	37.66667	-0.745982	4	0.497132	3	3	7.371115

Variable	Treatment=A1 T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Biomass only	28.00000	45.33333	-2.14262	4	0.098796	3	3	9.165151

Variable	Treatment=Gr2 T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Biomass only	23.50000	27.75000	-0.956703	4	0.392894	2	4	4.949747

Variable	Treatment=Ga2 T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Biomass only	36.00000	28.33333	1.345973	4	0.249535	3	3	2.645751

Variable	Treatment=A2 T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Biomass only	32.66667	44.00000	-1.40453	4	0.232851	3	3	12.58306

Variable	Treatment=Gr3 T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Biomass only	26.33333	27.33333	-0.139272	4	0.895966	3	3	11.15049

Annexures

Variable	Treatment=Ga3 T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Biomass only	41.33333	49.00000	-0.735083	4	0.503060	3	3	9.073772

Variable	Treatment=A3 T-tests; Grouping: Lime (Biomass) Group 1: 1 Group 2: 0							
	Mean 1	Mean 0	t-value	df	p	Valid N 1	Valid N 0	Std.Dev. 1
Biomass only	35.33333	32.33333	0.684257	4	0.531399	3	3	0.577350